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# LASER MICROMACHINING OF TITANIUM ALUMINUM VANADIUM ALLOY RODS

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## ABSTRACT

**Introduction:** Osteoblastic cell adhesion to the titanium alloy (Ti-6Al-4V) was found to improve as non-random repetitive surface roughness was provided, the aim of the current work was to produce 10 $\mu$m laser micro-grooves on titanium close to the size of osteoblastic cell body, and the results were verified by profilometry, and linear measurements of the scanning electron microscope images.

**Materials and methods:** Plain titanium rods, 30 mm in length and 1.5 mm in diameter, were laser grooved using the coherent AVIA laser machine with different laser energies, and the resulting surface topographies were examined by profilometry, and the linear distance measurement tool of the scanning electron microscope for determination of the laser energy that produced an average of 10 $\mu$m groove width and depth.

**Results:** Different surface topographies were obtained, ranging from surface melt down to specific micro-grooves of about 10 $\mu$m depth and width, which were produced with laser energy of 10 $\mu$J.

**Conclusion:** The current work produced 10 $\mu$m micro-grooves on the Ti-6Al-4V alloy using 10 $\mu$J energy of ultraviolet laser.

**KEY WORDS**: dental implants, Laser, micro-grooving

## INTRODUCTION

Laser micromachining, or micro-grooving, of titanium-aluminum-vanadium (Ti-6Al-4V) alloy represented a unique method to modify surface topography, which was found to increase human osteoblastic cell adhesion and growth.[1,2] Such modification of the cellular responses was found to improve on uniform features more than on random surface roughnesses.[3] Also, the uniform laser surface engravements were proved as recent advancement in biomaterials for biomedical applications. [4,5]

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The unique spatial oreintation of the surface micro-grooves, together with the mediation of adsorbed proteins, resulted in uniform alignment and profileration of osteoblasts, in a process called contact guidance.[6] The contact guidance phenomenon was found to enhance tissue integration at the bone-implant interface.[7-11] Ultraviolet laser surface micro-texturing of Ti–6Al–4V was used in the development of the Laser-Lok surface implants,[12] that were successfully used in clinical restorations of single teeth, up to full mouth prostheses.[13,14]

The laser micro-grooved Ti-6Al-4V surfaces were found to be biocompatible.[15] And their effect on osteoblastic attachment, differentiation, and bone deposition was found to enhance osseointegration.[16-18] These findings were the motive to conduct the current study, to determine the laser frequency and energy, that produces such surface features, in a size close to osteoblast cell size.

## MATERIALS AND EQUIPMENT:

Plain titanium rods (McMaster Carr, INC., USA), 30 mm in length and 1.5 mm in diameter, were laser grooved using the laser machine (coherent AVIA 355-4500, Coherent Henry Dr. Santa Clara, Ca 95054). The AVIA was a pulsed laser. This is in contrast to a CW (continuous wave) laser in that the output only occurs in bursts every time the laser is triggered. The AVIA was set up to output 40 ns pulses. It outputs at 355 nm, which is in the ultraviolet spectrum.

The laser was triggered internally or through an external triggering source (DG 535 pulse generator, Stanford Research Systems, Inc.). The Internal mode was used, for the startup, and calibration of the laser. When the laser is in External mode, the laser was triggered from an external device. It was also possible to have the Automation 3200 system (Aerotech XY stage controller, ALS36220-10-LT20-NC, AEROTECH, 101 Zeta Drive, Pittsburgh, PA 15238) output this signal directly to the AVIA laser controller.

After setting the AVIA laser machine to work on external mode, with the laser beam pulsed with every 20 $\mu$m movement of the Aerotech stage, the titanium rods were laser micro-grooved (Fig.1), using different energies (Table 1), with a 1 mm separation between each micro-grooving process (Fig. 2). The titanium rods were laser micro-grooved in 17 zones, using different energies, to detect which could produce 10 $\mu$m grooves. Certain girths (rotation speed) and hops (translation distance) were used. After this process, the resulting surface topographies were examined by the linear distance measurement tool of the SEM (PHILIPS, XL30 FEG, XL Series), for determination of the laser energy that produced an average of 10 $\mu$m groove width and depth, and were further confirmed by profilometry measurements of laser grooved zones. The measurements of the resulting grooves were collected and statistically compared using the one-way analysis of variance (ANOVA).

TABLE (1) Different energy, girth, and hop used to engrave titanium rods surfaces.

| Rod # | Energy | Girth | Hop |
|---|---|---|---|
| Pin #1, zone 1 | 35 | 5 | 5 |
| Pin #1, zone 2 | 30 | 5 | 5 |
| Pin #1, zone 3 | 25 | 5 | 5 |
| Pin #1, zone 4 | 20 | 5 | 5 |
| Pin #2, zone 5 | 15 | 5 | 5 |
| Pin #2, zone 6 | 35 | 10 | 10 |
| Pin #2, zone 7 | 30 | 10 | 10 |
| Pin #2, zone 8 | 25 | 10 | 10 |
| Pin #2, zone 9 | 20 | 10 | 10 |
| Pin #2, zone 10 | 15 | 10 | 10 |
| Pin #2, zone 11 | 15 | 10 | 10 |
| Pin #2, zone 12 | 14 | 10 | 10 |
| Pin #3, zone 13 | 13 | 10 | 10 |
| Pin #3, zone 14 | 12 | 10 | 10 |
| Pin #3, zone 15 | 11 | 10 | 10 |
| Pin #3, zone16 | 10 | 10 | 10 |
| Pin #3, zone 17 | 9 | 10 | 10 |

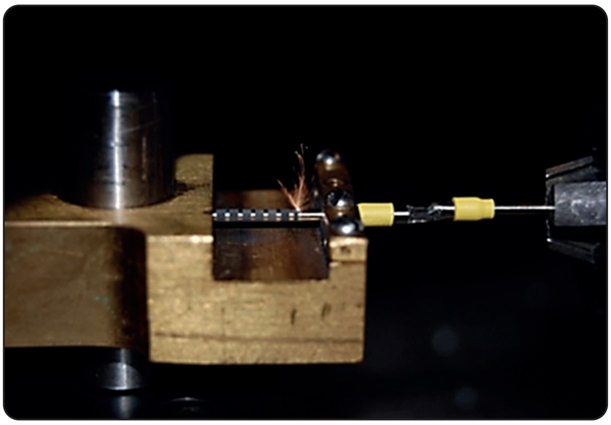


Fig. (1) Titanium rod laser micro-grooving set-up

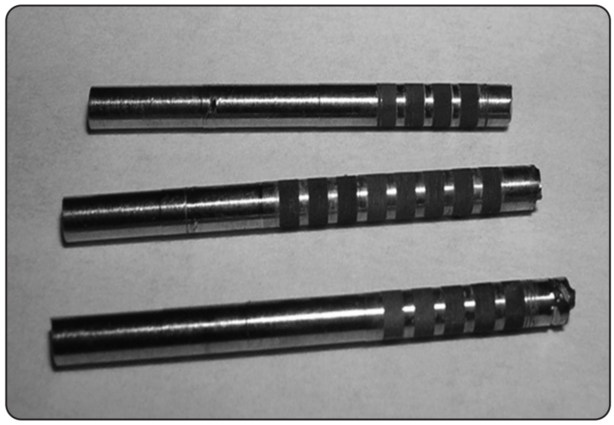


Fig. (2) The titanium alloy laser engraved rods.

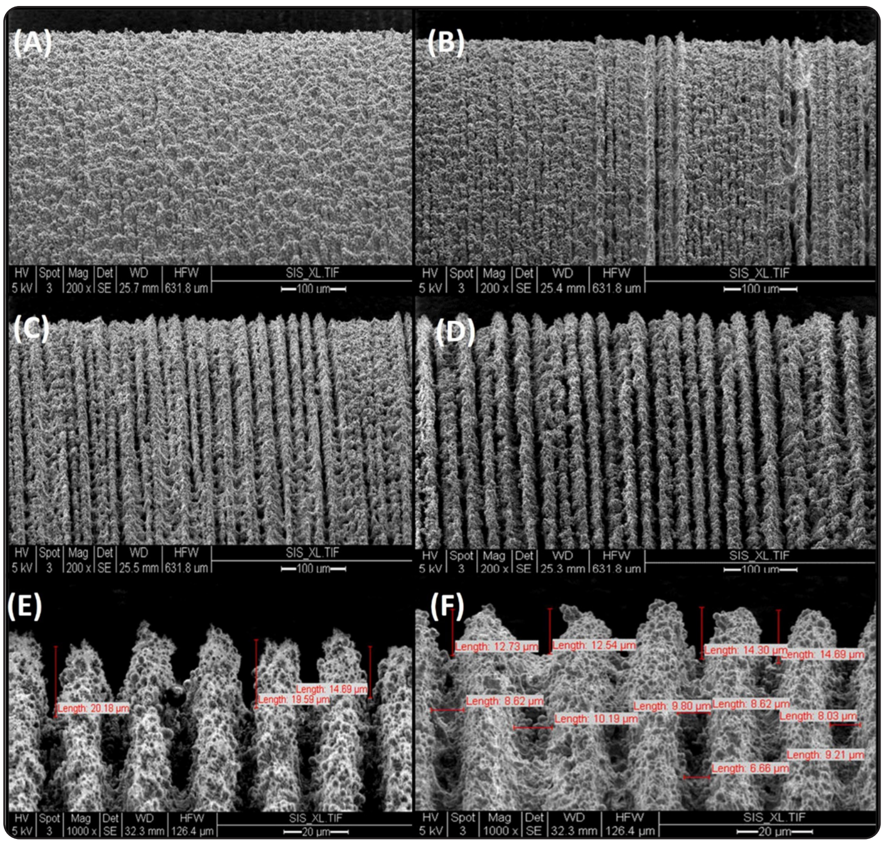



Fig. (3) SEM images with linear measurements recorded. A: Rod #1 zone 1. B: Rod #2, zone 5. C: Rod #2, zone 6. D: Rod #2, zone 11. E: Rod #2, zone 12. F: Rod #3, zone 14.

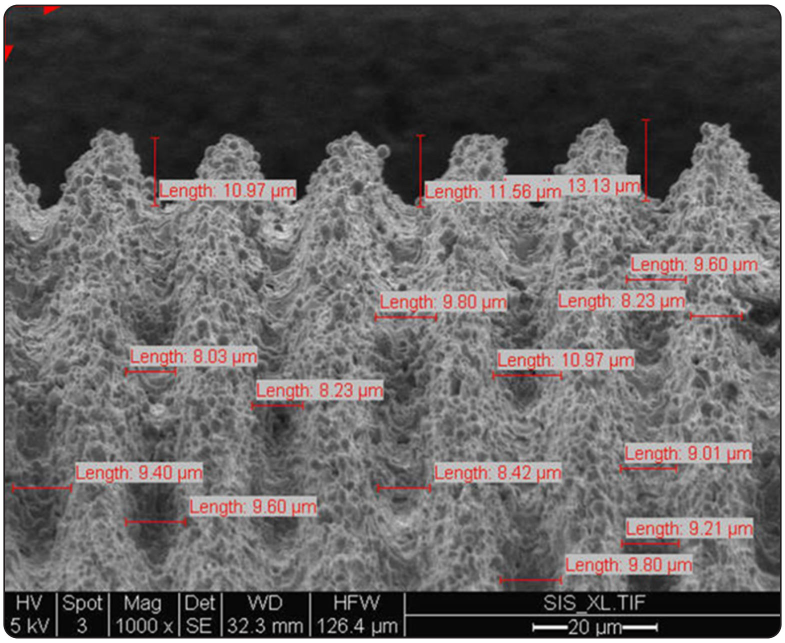



Fig. (4): Linear measurements of Rod #3, zone16, note that locations of the measurements were manually placed at almost the middle of each groove sloping wall.

## RESULTS

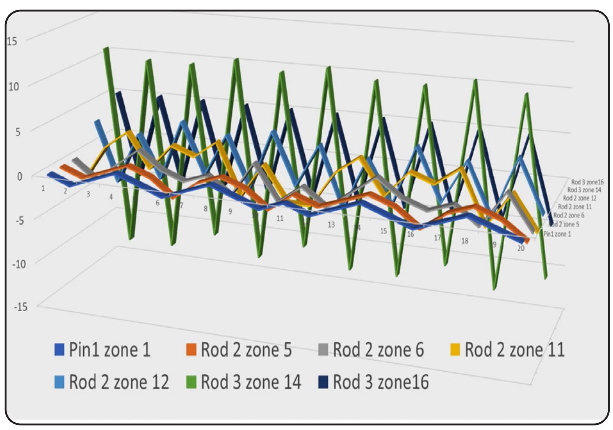
The micro-machining process, using different energies, girths, and hops, resulted in a series of topographies. The resulting engravements ranged from a complete surface melt, as seen with Rod #1 zone 1 in Figure 3A. And when a girth and a hop of 5, and a 35 $\mu$J energy were used, non-distinctive adjacent ridges resulted on Rod #2, zone 5, in Figure 3B.

As an energy of 15 $\mu$J was used, definite ridges were obtained, but were jammed, on Rod #2, zone 6, as seen in Figure 3C, with the use of 35 $\mu$J. However, with 15 $\mu$J, distinctive adjacent surface micro-grooves were produced on Rod #2, zone 11, as seen in Figure 3D. Up to this moment, all the produced surface topographies had no distinct measurement valid for statistical analysis.

On the other hand, with the use of 12, and 14 $\mu$J energies, statistically significant differences started to appear, as the grooves assumed an average depth of 14 $\mu$m as seen on Rod #2, zone 12 in Figure 3E, and on Rod #3, zone 14 in Figure 3F. However, these grooves were too narrow as compared to an osteoblastic cell body of 10 $\mu$m.

Eventually, on Rod #3, zone16 seen in Figure 4, the desired 10 $\mu$m grooves were produced, with an energy of 10 $\mu$J.

The previous results were confirmed by profilometry measurements of each zone topography depressions and elevations as seen in Figure 5.




Fig, (5): Surface topography profilometry of titanium rods different laser micro-grooving zones

## DISCUSSION

The importance of the titanium surface microgrooves was emphasized by the work of Anselme et al,[1] who observed that human osteoblasts demonstrated better orientation and proliferation on surfaces with a micro-roughness in the order of their body size. Bigerelle et al[2] concluded that these cells preferred the isotropic smooth surface features, that formed many 'bowl-like nests' of the surface laser micro-grooves. Zhu et al[3] further added that when osteoblasts met a flat surface, they tended to retract their filopodia back to their cell bodies, in contrast to the situation of the micro-grooves, where the cells assume their spatial 3-dimensional body configuration. Hsiao et al[11] also used low energy pulsed ultraviolet (UV) laser on the Ti–6Al–4V surfaces, to produce surface micro-grooves, and concluded that such topographies sustained osteogenic cells growth, normal cell function, better adhesion, and proliferation.

Compared to other random surface roughness, Veiko et al[13] found that the laser micro-grooves, with their continuous open groove geometry, together with their subcellular to cellular sized surface roughness, were more beneficial for cellular activity as compared to the non-repetitive random surface topographies with individual slots. Another advantage of the controlled uniform surface roughness, over random roughness, was also reported by Zheng et al[15] who detected better osteoblastic proliferation and differentiation. These findings were believed to be due to the reduced liquid-solid contact angles created by the titanium micro-grooves. This reduction in contact angle improved cells growth along the microgrooves explaining the contact guidance process. In conclusion, the laser micro-grooving process was found by Mastrangelo et al[16] to positively affect the bone deposition process, and improve osseointegration in its early phases, which could represent a promising improvement for maxillofacial and dental implants.

A disadvantage of the laser micro-grooving process was the use of laser energy heat, which could affect the titanium mechanical properties, as a heat affected zone was found to form in between the grooves, as reported by Eghbali et al,[18] with a possibility of delamination. However, such delamination requires tense surface tension, which is a rare occurrence process. The laser micro-grooving might be preferred to other random surface treatments, which could release microparticles in the surrounding tissues.

Despite the success of the current study to produce uniform micro-grooves, limitations are still encountered. Such as, using X-ray diffraction to detect the surface content of alloying elements, or Atomic Force Microscopy (AFM), and Field Emission Scanning Electron Microscopy (FE-SEM), to identify the quality and regularity of the micro-grooves patterns.

## CONCLUSION

The use of 10 $\mu$J UV laser energy together, with a girth of 10 rounds and hop of 10 $\mu$m jumps, was able to engrave the desired 10 $\mu$m width and depth grooves, as verified by the linear measurements made on the scanning electron microscope images, and the profilometry measurements.

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