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Influence of Fiber Laser 1064 Nm Processing parameters on surface Topography of Titanium discs

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ABSTRACT

Objectives: This work was performed for enhancement of titanium abutment retention to crown by surface modification using fiber laser 1064 nm considering (hatch distance, scanning speed, frequency and average power).

Materials and methods: Titanium specimens of 6 mm diameter and 3 mm thickness (disk form) were prepared. Q-switched nanosecond fiber laser of 1064 nm wavelength ,81 ns pulse duration, 6.6 mm beam diameter, 0.01 mm spot size was used for surface modification of titanium specimens. Titanium specimens were categorized into four groups according to the variation in laser parameters (1) hatch distance group, (2) scanning speed group, (3) frequency group and (4) average power group. Characterization of the specimens was performed by optical microscope, scanning electron microscope (SEM), and surface roughness tester. Phase analysis was performed by X-ray diffractometer (XRD).

Results: The results of this work showed that the surface roughness was increased with the increasing in the hatch distance up to 0.1 mm then decreased when the hatch distance was 0.15 mm .The surface roughness was indirectly proportionate with the increased scanning speed. Furthermore, surface roughness was increased with the increasing in the average power up to 10 W but this relation was inversely proportionated when the average power was increased up to 50 W. A clear relationship between average surface roughness and frequency was not observed.

Conclusion: Using of fiber laser can be effectively modify the surface of titanium abutment considering (the standoff distance, hatch distance, scanning speed, average power and frequency).

Key words: Fiber laser 1064 nm, Titanium, Surface roughness, Hatchdistance, Scanning speed, Frequency, Average power

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INTRODUCTION

At present, titanium is widely utilized in dentistry due to its good biological compatibility and tolerance, low cost, and superior mechanical properties. It is a low-density material with high resistance especially to corrosion, good thermal conductivity, acceptable strength to weight ratio and have low modulus of elasticity as compared with other metals.

Because of these properties, titanium has been widely used in the fields of implantology and prosthodontics.

One of its utilization is in the construction of implant supported prosthesis [1]. The connection between implant fixture and their superior prosthesis either by cement or screw. The major advantages of screw-retained prosthesis are ease of retrievability and good marginal integrity ,while cement-retained prosthesis provide good esthetic, ease of cleaning, reduction in technique sensitivity and recompensing ability of minor prosthesis misfitting, thus the cement retained type are preferred to use more than screw retained type prosthesis retention in cement-retained type is affected by many factors such as surface area and height of abutment, abutment taper, type of luting cement and surface finish or roughness. The retention of the restoration increased by surface roughness because of formation of micro retentive grooves and ridges as well as it increases the surface area and in turn the retention increased [2].

Since Maiman's invention of the ruby laser in 1960, lasers have become widely used in dentistry and medicine.

Laser used to improve the bond strength of dental materials by altering their surface, through creating microstructures or nanostructures on the material surface.

Studies have shown that application of lasers such as Nd:YAG , CO_2, Er,Cr:YSGG, and Fiber laser for modification of titanium surface lead to alteration in material surface and create a larger area for bonding, therefore the bonding strength improved. The most recent products of modern laser technology are fiber lasers, these lasers have a place in dentistry as well because they are compatible with biomedical and industrial applications, and they deliver very high power in a short time period. Furthermore in terms of stability of oscillating mode, monolithic packaging capability, performance, and low-cost maintenance, fiber lasers deliver major advantages over other technologies. Fiber lasers have powerful and rapid effect on the surface of material, as compared to other lasers they cause less thermal and mechanical damage [3]. The aim of this study was to modify the surface of titanium being used as an implant abutment to enhance crown retention by using of fiber laser considering (standoff distance, hatch distance, scanning speed, frequency and average power) and their effects.

MATERIAL AND METHOD

Samples preparation

Titanium samples were cut from commercially pure titanium rod grade 2 (Baoji Jinsheng Metal Material/ China) by Wire cut Lathe machine into circular disks of 6mm in diameter and 3 mm in thickness. The grinding and polishing of samples was performed by using silicon carbide papers consecutively with 120, 180, 320, 500, 800, 1000, 1200, 2000 and 2400 grit size, the specimens were ultrasonically cleaned with ethanol then with distilled water for 15 min and 10 min respectively then the specimens were left to dry at room temperature. One specimen kept without any laser modification and considered as a control specimen.

Laser treatment

For this study, Q-switched nanosecond fiber laser of 1064 nm wavelength (Wuxi Raycus fiber laser Technologies Co., Ltd/RFL-P 100Q, China) was used. The pulse duration was 81 ns, the beam diameter was 6.6 mm focused into 0.01 mm spot size, and the pattern of titanium surface modification was in the form of lines. First, a pilot study was conducted to estimate the best standoff distance between the laser source and the surface of the titanium specimen. For this purpose the average power was 5 W, the frequency was 20 KHz, the scanning speed of 10000 mm/sec and the surface treatment of the samples was performed at distance of 116 mm, 117 mm, 118 mm and 119 mm. The most suitable standoff distance without evidence of charring was 119 mm as shown in (Figure 1), which was kept constant for all of the experimental groups.

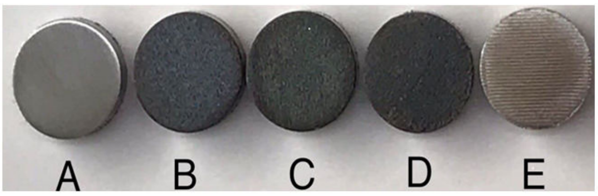

Figure1: (A) Control specimen without laser treatment and (B)-(E) specimens irradiated at a standoff distance of 116,117,118 and 119 mm respectively.

The titanium specimens were categorized into four groups according to the variation in laser parameters as following:

- Hatch distance group (H): Titanium surface modification with fiber laser was performed with laser parameters of 5 W average power, 20 KHz frequency and 10000 mm/sec scanning speed which were kept constant for all the group´s specimens and the variation of hatch distance for the specimens was H1= 0.001mm, H2=0.01 mm, H3= 0.05 mm, H4=0.1 and H5=0.15.The most suitable hatch distance according to optical microscope examination and surface roughness measurement was 0.1 mm, which was kept constant for the other groups.
- Scanning speed group (S): In this group the titanium specimens were irradiated at different scanning speed which include S1=10000 mm/sec, S2=15000 mm/sec, S3=20000 mm/sec, S4=25000 mm/sec, S5=30000 mm/sec and S6=35000 mm/sec. The other parameters were kept constant which include average power of 5 W, frequency of 20 KHz and hatch distance of 0.1 mm. The most suitable scanning speed according to surface roughness measurement was 10000 mm/sec.
- Frequency group (F): The surface of the specimens in this group were irradiated with different values of frequency include F1=20 KHz, F2=30 KHz, F3=40 KHz, F4=50 KHz, F5=60 KHz, F6=70 KHz and F7=80 KHz.The other parameters of laser were kept constant which include 5 W average power, 10000 mm/sec scanning speed and 0.1 mm hatch distance. According to the surface roughness measurement, the most suitable frequency was 30 KHz.
- Average power group (P): For this group, the average power values of P1=3 W ,P2=5 W,P3=7 W ,P4=10 W ,P5=15 W,P6=20 W,P7=25 W, P8=30 W ,P9=40 W and P10 =50 W were used for titanium irradiation.The other parameters were kept constant which include 30 KHz frequency, 10000 mm/sec scanning speed and hatch distance of 0.1 mm.

Sample characterization

- Selected specimens were inspected by means of an optical microscope (OLYMPUS/BX51, Korea) with a photographic system for recording and storing images. Furthermore, the surface topography of the selected specimens were inspected via scanning electron microscope (TESCAN/ VEGA 2, Czech Republic) at magnification of 500 X and 2000 X.
- Surface roughness measurement of all the specimens including the control one were performed by using surface roughness tester (SRT-6210, China) with diamond probe pin of 5 μm radius oriented perpendicular to the specimen surface and the cut-off level was 0.25mm.Three measurements were measured on each specimen's surface at distinct point then the average roughness value (Ra) in micrometer (μm) for each specimen was calculated.

- Analysis of titanium specimens' phase was carried out by using X-ray diffractometer (XRD-6000/SHIMADZU, Japan), operated at a voltage of 40 kV and current of 30 mA with scan range from 10 to 90 degree and 2 theta.

RESULTS

Optical microscope observation

The morphology of titanium specimens surface for hatch distance group (H) was displayed in (figure 2).The photograph of the untreated titanium specimen seems to be smoother than that treated with fiber laser and the texture of the titanium surface consist of micro retentive grooves with different degree of spacing between two adjacent laser scan paths and different roughness degrees.

Also overlapping between adjacent laser scan paths noted in H1, H2 and H3 specimens. No defects or micro cracks were observed in optical microscope images.

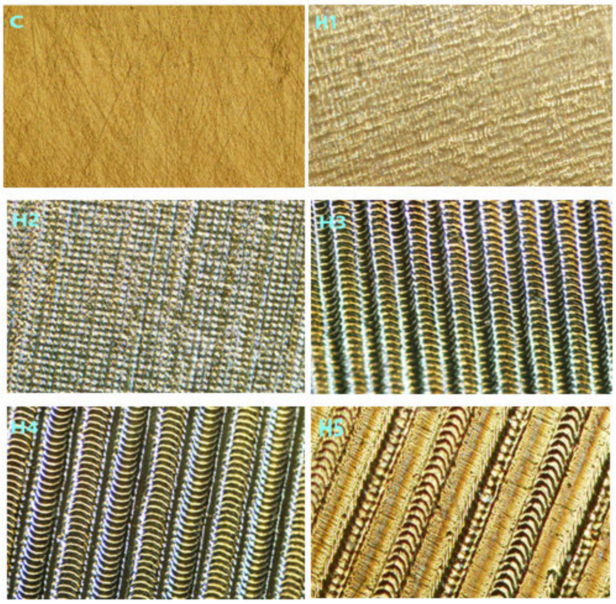

Figure2: Optical microscope pictures with (20 X) of (C) control, H1, H2, H3, H4 and H5 specimens.

Scanning electron microscope observation

Selected specimens from average power group (P) in addition to the the untreated specimen were inspected by SEM as shown in (figure 3) and (figure 4).

The SEM pictures of the laser-treated titanium specimens had a roughened form when compared with the untreated specimen. In addition, SEM pictures indicate uniform pattern of surface roughness,deep penetration areas by laser without cracks or defects.

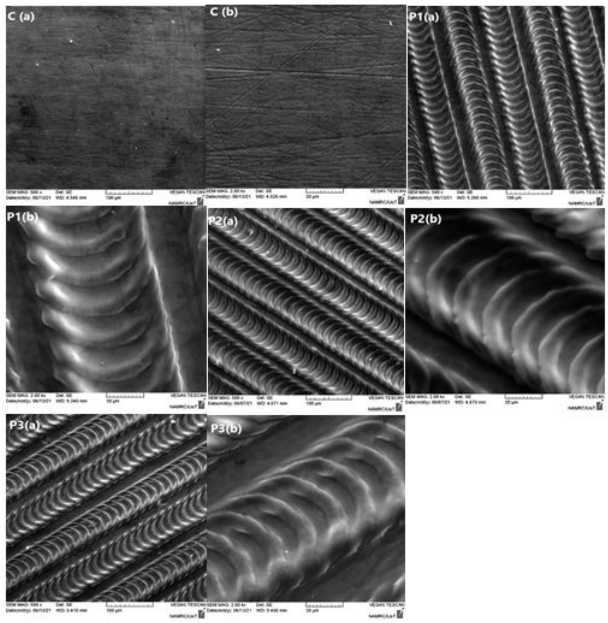

Figure3: SEM images of titanium specimens with magnification of ((a) 500 X and (b) 2000 X) of untreated (C) and (P1,P2 and P3) laser treated specimens.

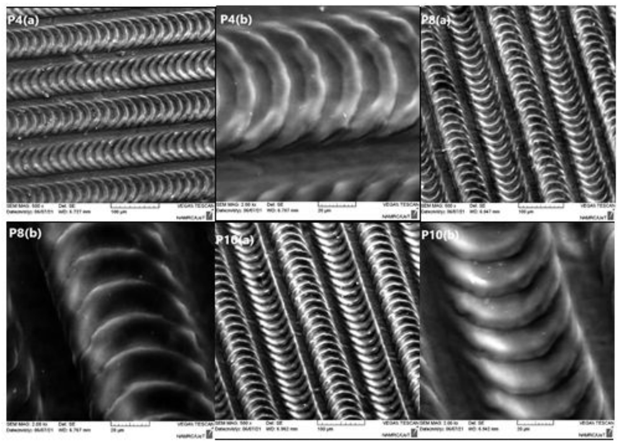

Figure4: SEM images of titanium specimens with magnification of ((a) 500 X and (b) 2000 X) of (P4, P8 and P10) laser treated specimens.

Surface roughness

Evaluation of surface roughness was performed by surface roughness tester. The control specimen had the lowest Ra value of 0.421 μm. Tables 1, 2, 3 and 4 display the average surface roughness (Ra) of the experimental groups. (Figure 5) display the surface roughness (Ra) of treated titanium specimens according to the variation in laser parameters. For the hatch distance group (H), the highest Ra value was observed at 0.1mm hatch distance and the lowest Ra value was obtained at 0.001 mm hatch distance.

Sample ID	H1	H2	H3	H4	H5
Hatch distance (mm)	0.001	0.01	0.05	0.1	0.15
Surface roughness Ra (μm)	0.653	1.467	1.708	1.951	1.245

Table1: Average surface roughness (Ra) of hatch distance group (H).

For scanning speed group (S), the average surface roughness at various scanning speeds were shown in figure 5 (B).It was indicated that there is a downtrend in surface roughness values with increasing in scanning speed.

Sample ID	S1	S2	S3	S4	S5	S6
Scanning speed (mm/ sec)	10000	15000	20000	25000	30000	35000
Surface roughness Ra (μm)	1.951	1.867	1.761	1.708	1.564	1.399

Table2: Average surface roughness (Ra) of scanning speed group (S).

For frequency group (F), the relation between average surface roughness (Ra) and the frequency were indicated in figure 5 (C).The highest average roughness value was obtained at frequency of 30 KHz.

Sample ID	F1	F2	F3	F4	F5	F6	F7
Frequency (KHz)	20	30	40	50	60	70	80
Surface roughness Ra (μm)	1.951	2.012	1.835	1.933	2.003	1.884	1.674

Table3: Average surface roughness (Ra) of frequency group (F).

In the average power group (P) the surface roughness value increased with increasing the average power until it reach to its maximum (2.359 μm) at 10 W then gradually start to decrease up to 50 W as shown in figure 5 (D).

Sample ID	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
Average power (W)	3	5	7	10	15	20	25	30	40	50
Surface roughness Ra (μm)	1.533	2.012	2.321	2.359	2.319	2.304	2.259	2.213	2.176	1.964

Table4: Average surface roughness (Ra) of average power group (P).

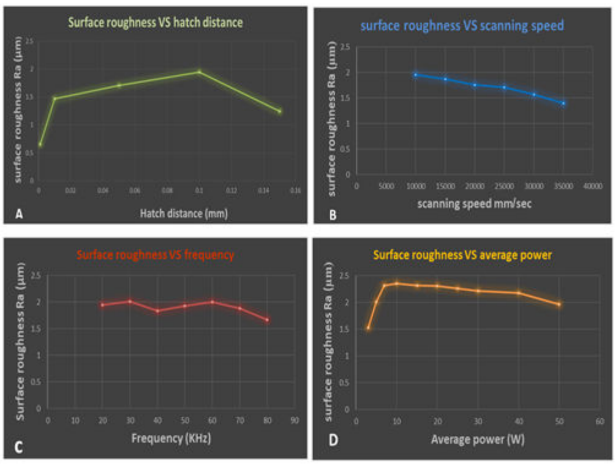

Figure5: Average surface roughness (Ra) of titanium specimens as a function of (A) hatch distance, (B) scanning speed, (C) frequency, and (D) average power.

Phase analysis

Phase analysis of selected titanium specimens from average power group (P) in addition to control specimen were performed by XRD.

The XRD patterns of untreated and irradiated titanium specimens were indexed to International Centre for Diffraction Data (ICDD).

No alteration in phase was occurred in titanium specimens after laser irradiation as shown in (figure 6) and (figure 7) which is an important condition during treating of Ti.

The diffraction peaks indexed to 100, 002, 101, 102, 110, 103, 200,112 and 201 are corresponding with those of hexagonal α-Ti. After laser irradiation, some new peaks of TiO_2 in addition to α-Ti peaks indexed to 004, and 301 were observed, which corresponded with those of tetragonal anatase Ti_2. There was no determination of TiO_2 (rutile), β-Ti or oxynitrides are obvious in any case.

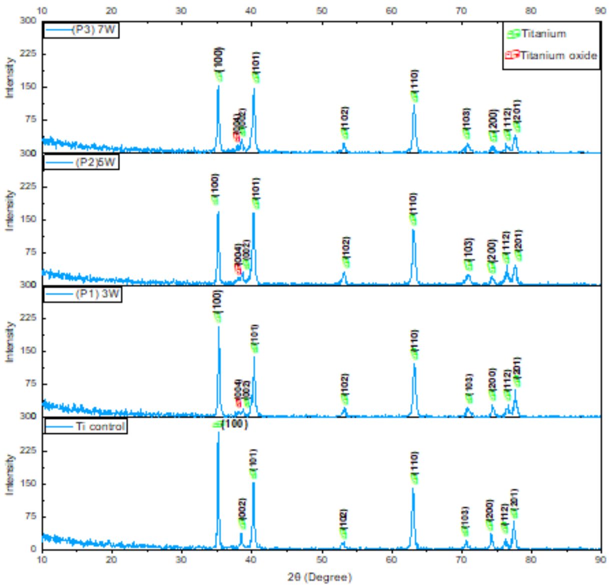

Figure 6: XRD pattern of untreated and (P1, P2, and P3) laser treated specimens.

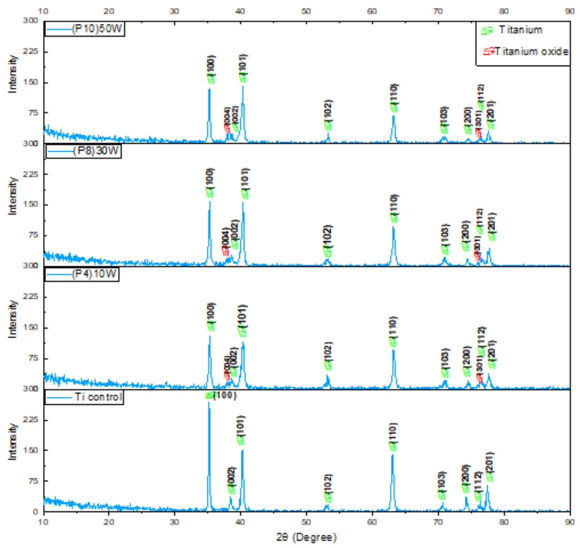

Figure 7: XRD pattern of untreated and (P4, P8, and P10) laser treated specimens.

DISCUSSION

This study investigated the variation effect of fiber laser parameters (hatch distance, scanning speed, frequency and average power) on average surface roughness of titanium.

The standoff distance between laser source and the surface of the specimen is also an important factor and must be considered. When the standoff distance variated, the surfaces of laser irradiated titanium discs had been changed obviously. This fact is in agreement with the study of Ercan et al which concluded that, the standoff distance is most important factor that should be considered during texturing of material surface because the standoff distance affect the spot area, power in addition to energy density [4].

All laser irradiated specimens had higher Ra value compared with the control specimen, this variation in surface morphology and roughness resulted from the interaction of laser beam with the material that lead to melting and vaporization.

The optimum roughness of titanium surface achieved when the hatch distance is 0.1 mm, the frequency is 30 KHz and the average power is 10 W followed by 7 W. The average surface roughness is directly proportionate with the hatch distance. The surface roughness increased with increasing the hatch distance but then decreased at hatch distance of 0.15 mm. The hatch distance is the space between two adjacent laser scan paths and hence it affect the width of the melted volume for the specimen. By varying the hatch distance between two adjacent paths, the overlapped portion between the paths edges change and consequently affect the roughness of the surface. Smaller hatch distance result in large overlapped area lead to receiving more energy, further raising the temperature forming larger heat affected zone and increased the melting of the surface resulting in lower surface roughness. The surface roughness increases gradually with increasing the hatch distance as the overlapped area decreased and the melting volume minimized, while at hatch distance of 0.15 the width of melted volume decreased due to increase the space between two adjacent laser scan paths, which lead to reduction in roughness value [5].

One of the important factors that affect the processing efficiency of material surface is scanning speed. In this study, there is reduction in surface roughness with increasing scanning speed. Increasing the scanning speed resulted in shorted laser-material interaction time and shorter heat impact, this in turn resulted in improper melting of the titanium surface and thus decrease the surface roughness. On the other hand when the frequency and the average power were constant, resulting in a constant pulse energy. During increasing the scanning speed, the pulses number that produced on the unit line of the material surface decreased, which in turn resulted in reduction of material removal rate as a result of decrease in pulse overlap.

There was no evidence of a direct association between the average surface roughness and the frequency values that applied. However, a logical relationship may be exist. The variation in frequency values affect other parameters, which are complicated and subsequently affecting the final surface roughness. At a constant power of the laser, the variation in frequency values can change the peak power, the pulse energy, the volume of melt for each pulse, the rate of solidification and morphology of the surface ,which directly affect the up and down fluctuation of the surface (the roughness) that resulted from the process of solidification. Actually, the logical relationship between the average roughness of the surface and the frequency not exist unless providing the complicated parameters above.

Laser frequency does not have a direct effect on the surface texturing of material in comparison with hatch distance, scanning speed, and average power. This finding agree with the other studies by Xi et al and Rafiee et al. They reported that the variation in laser frequency had no direct effect on surface roughness values.

There is a direct relationship between surface roughness and laser average power. With increasing in the average power, there is increasing in surface roughness, but after a specific value of average power the surface roughness decreased. This is because of the fact that, with increasing in power the energy per unit area increases and the surface temperature rises lead to the melting increases initially followed by solidification, which result in improving of surface roughness. Conversely, too much power raises the temperature of the specimen lead to increase melting and more melt accumulation on the surface, thus the roughness of the surface reduced to certain extent.

Phase analysis of titanium specimens demonstrated that, there was no alteration in phase occurred in titanium specimens after fiber laser irradiation. However, new peaks of TiO_2 (anatase) in addition to α-Ti peaks were detected due to the performance of the process under open environment.

Titanium absorbs and interact with some elements in the air for example O, C and N. The binding between Oxygen and titanium create amorphous ,thin oxide (TiO_2) layer. The surface of the titanium specimen was superficially melted by fiber laser beam during laser irradiation. As a result oxygen diffused into the molten material and subsequently lead to oxidation of Ti surface.

Morphological analysis of this study demonstrated that fiber laser treatment of titanium surface modify surface roughness which lead to increase in the surface area of the titanium without any micro cracks or defects even up to (50 W).This findings agree with the study by Korkmaz and Aycan, which reported that fiber laser treatment of titanium alloy lead to increase in surface roughness without any cracks or defects.

Fiber lasers are easily absorbed into the surface of metal and providing good surface treatment with no thermal effect because they have short pulse duration. Very high repetition rates of fiber laser reduce the energy of laser pulse needed for ablation process, make the cooling of ablation process possible and increase the removal process efficiency.Therefore, fiber lasers being more favored in laser material processing .

CONCLUSION

Fiber laser 1064 nm effective for surface modification of titanium surface without any cracks or defects.The standoff distance between the laser source and the surface of material should be considered as well during texturing the surface of materials.Average surface roughness (Ra) had a positive correlation with average power and hatch distance, and negative correlation with scanning speed. However, excessive power and hatch distance lead to reduction in surface roughness. A clear correlation between the average surface roughness and laser frequency was not observed.

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