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To cite this article: N Kumar et al 2016 IOP Conf. Ser.: Mater. Sci. Eng. 149 012056

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Studies of laser textured Ti-6Al-4V wettability for implants

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Abstract. Wettability plays a notable role in success of any bio-implant. It influences tissue amalgamation, protein adsorption and cell attachment at the surface of an implant. Hence, wettability enhancement of the implant is a field of today’s dynamic research. In this work, laser based direct melting approach was employed to generate four separate surface patterns on Ti-6Al-4V by means of nanosecond pulse fibre laser. The modification of surface morphology was assessed by means of SEM. Wettability was measured by the help of goniometer. The obtained results revealed that pulsed laser irradiation can substantially improve the biocompatibility of Ti-6AL-4V by making its surface super hydrophilic.

1. Introduction
Owing to aging population and increasing average weight of the people, the field of biomaterials has been expanded immensely in recent years. Manufacturing of replacement implants for hips, knees, elbows, shoulders and teeth, stents for blood vessels, artificial valves for heart, all requires good biomaterials [1, 2, 3]. Thus active research is oriented in development of appropriate biomaterial which manifests better corrosion resistance in physiological fluids of body, high fatigue resistance, superior strength, high wear resistance, moderate Young’s modulus, outstanding biocompatibility and high life cycle [4, 5, 6]. Ti–6Al–4V has shown the great promise in this regard although; its bio-inertness and substandard adhesion at the interface create difficulties for extended use as bio-implant [7, 8]. When a Ti–6Al–4V implant is placed inside a human body, its wetting by the physiological fluids, protein adsorption, cell attachment and tissue integration occurs in succession [9]. For success of Ti–6Al–4V implant its wettability enhancement is very essential since better wettability leads better adhesion.

Wettability, the ability of a solid surface to reduce the surface tension of a liquid in contact with it such that it spreads over the surface and wets it, is often measured with the contact angle of the liquid on the surface. Contact angle between $0^\circ$-$90^\circ$ represent the hydrophilic nature whereas between $90^\circ$-$180^\circ$ represent the hydrophobic nature of the solid surface [10]. The control of surface wetting is essential for surface adhesion and biocompatibility. Hydrophilic surfaces are often preferred for better adhesion whereas hydrophobic surfaces are used for self-cleaning surfaces and stiction prevention. Some of the key theories, given by Young, Wenzel and Cassie-Baxter [11, 12, 13, 14, 15] regarding surface wettability, conclude that wettability mainly depends upon surface’s topography and chemical composition and can be improve through surface modification.

In the recent past, various conventional techniques such as grinding, sand blasting, honing, abrasive jet machining, chemical etching, electric-discharge machining and laser surface texturing are used for surface modification [16, 17, 18]. Among all, laser surface texturing is a technique that offers
unparalleled control of the surface microstructure with rapid speed, low environmental impact and repeatability [19, 20, 21]. In laser surface texturing, dense pulsed laser beam of high energy is used to melt as well as evaporate the material [22]. These high intensity beams change the topography as well as chemical composition of a surface on a nanometer scale, which in succession has an influence on surface wettability and cell attachment. Laser surface texturing not only reduce the release of metal ions by making the surface of the Ti-6Al-4V harder, high corrosive and wear resistant; but makes the surface more bioactive through enhancing its wettability as well [23].

Among the numerous scientific works, very little information is available regarding the effect of various surface patterns generated through laser surface structuring, on wetting characteristic of Ti-6Al-4V. The motive of this work is to explore the outcomes of laser surface structuring on improving the biocompatibility of Ti-6Al-4V by its wettability enhancement. Laser-based direct melting technique was used to generate four different patterns on Ti-6Al-4V surface by uses of nanosecond pulsed fibre laser of wavelength 1064 nm. The surface topographical features of the Ti-6Al-4V were modified via a gamut of laser operational parameters, and its consequences on surface wettability was examined. The modification of surface morphology was assessed by means of SEM. Goniometer was used for wettability measurement. The obtained results revealed that pulsed laser irradiation can substantially improve the biocompatibility properties of Ti-6AL-4V by enhancing its wettability.

2. Experimental

2.1. Material and Procedure
Titanium alloy (Ti-6Al-4V) sheets of 1.27 mm thickness were used for whole experiment whose chemical composition is listed in table 1. Initially, polishing was performed using 220, 400, 600, 800, and 1000 grit size silicon paper respectively. Polishing was done for 5 min in each case. The final polish was performed on a velpol polishing cloth using Hifin diamond paste of grade size 3-OS-40, 1-OS-47 and 1/4-OS-475 respectively.

| Table 1. Chemical composition of Ti-6Al-4V. |
|------------------------------------------|
| Substrate (Ti-6Al-4V) | C | N | Fe | V | Al | O | H | Ti |
|-----------------------|---|---|----|---|----|---|---|----|
| Ti-6Al-4V             | 0.029 | 0.029 | 0.360 | 3.8 | 6.1 | 0.138 | 0.00198 | Bal. |

In the next step, laser surface structuring was performed using nanosecond pulsed fiber laser. Experiments were conducted in open environment. Prior and after the laser surface structuring, samples were ultrasonically cleaned in acetone for 10 min and dried in air. The modification of surface morphology was assessed by means of SEM. Finally, wettability measurement was carried out using goniometer.

2.2. Laser Surface Structuring
A nanosecond pulsed fiber laser was used for surface texturing whose main specifications were listed in table 2. Its laser beam, with high quality (Beam quality factor M²= 1.5) and spatial energy distribution similar to TEM₀₀ (transverse electromagnetic mode), was characterized with nearly Gaussian profile. Laser beam was focused on the top surface to maintain the energy intensity on the surface. Whole texturing work was carried out at a low power of 1W. Aim was to melt an upper layer of Ti-6Al-4V rather than removing material to change the surface morphology. The calculated beam diameter on the work piece was 28 µm. Pulse frequency and pitch were kept constant, 20 kHz and 10 µm respectively, during whole texturing experiment.
Four different surface morphologies were textured on Ti-6Al-4V surface by varying the scan angle and number of passes as shown in figure 1. In order to enhance surface roughness, overlapping (figure 2) between the lines were increased using 10 µm pitch in all schemes. This overlapping (R %) was calculated using following equation [24]:

\[ R\% = \left(1 - \frac{v}{PRR \times d}\right) \times 100 \]  

Where, \( v \) = Scanning speed, \( PRR \) = Pulse repetition rate and \( d \) = beam diameter

![Figure 1](image1.png)

**Figure 1.** Four surface schemes (a) single pass with 0º scan angle (b) double pass with 0º and 90º scan angle (c) three passes with 0º, 90º and 135º scan angle and (d) four passes with 0º, 90º, 45º and 135º scan angle.

Eight distinct surface topographies of 1 cm\(^2\) surface area were generated using different laser surface structuring parameters as listed in table 3. Experiments were conducted at different scanning speeds whereas other parameters such as power, pitch and pulse repetition rate were remained fixed. The entire laser texturing experiments were carried out in ambient conditions.

![Figure 2](image2.png)

**Figure 2.** Schematic of nano second laser pulse overlapping
Table 3. Laser parameters used to generate the four different surface schemes.

| Surface Name | 1a | 1b | 1c | 1d | 2a | 2b | 2c | 2d |
|--------------|----|----|----|----|----|----|----|----|
| Structure    |    |    |    |    |    |    |    |    |
| Power (W)    | 1  | 1  | 1  | 1  | 1  | 1  | 1  | 1  |
| Pitch (µm)   | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| PRR (kHz)    | 20 | 20 | 20 | 20 | 20 | 20 | 20 | 20 |
| Scanning Speed (mm/s) | 50 | 50 | 50 | 50 | 100 | 100 | 100 | 100 |
| Overlap on scan direction, R% | 91 | 91 | 91 | 91 | 83 | 83 | 83 | 83 |

3. Results And Discussion

The SEM images of laser structured surfaces were demonstrated in figure 3. Different amplitudes of surface morphological modifications have been clearly visible. Notable change in the surface roughness and surface area were observed due to variation in pattern, passes and scanning speed. Surface roughness increases as we move towards the more energetic laser texturing conditions (from scheme 1a to 1d and 2a to 2d respectively due to increase in no of passes and surface pattern complexity).

For the determination of contact angle, water droplets were dropped on the laser structured Ti-6Al-4V through 5 µm diameter needle of goniometer and studied as illustrated in figure 4. Three reading were taken in each case in order to minimize measurement error. Contact angle of Ti-6Al-4V was measured as 51° before laser surface structuring. It can be observed from figure 4 that contact angle highly depends on laser processing parameters. It gradually decreases when we move from surface 1a toward 1d. Similar trend were also observed when we moved from surface 2a towards 2c since these surfaces comes under the Wenzel’s model (the contact angle of an already hydrophilic surface can be further decreased by increasing surface area) of wettability. Surface 1a and 2d were hydrophobic in nature. These surfaces following the Cassie-Baxter model of wettability by allowing air entrapment in
the surface micro-geometry. Although surface pattern of scheme 1a and 1b was same, a sudden change in contact angle was observed because of change in scanning speed. Similar tendency was also visible between scheme 1d and 2d. It indicates that wettability mainly depends on surface topography as compare to surface chemistry at low power laser surface structuring. Parameters used for laser surface structuring of scheme 2c were best suited for achieving super hydrophilic surfaces on Ti-Al-4V.

Figure 4. Contact angles of laser structured Ti-6Al-4V

4. Conclusion

The present work addressed the effect of nanosecond pulsed fiber laser pretreatment on Ti-6AL-4V surface for enhanced wettability. Experiments were conducted at low laser power to melt an upper layer of Ti-6Al-4V rather than removing material to change the surface morphology. Laser irradiation shown substantial modifications of surface topography and was able to produce not only the super hydrophilic but also hydrophobic surfaces. Laser parameters used for scheme 2c was best suited for producing biocompatible Ti-Al-4V implants. Results confirmed the potentiality of single step laser surface structuring to boost surface adhesion of Ti-6Al-4V by control of surface wettability.

References

[1] Park J B, Bronzino J D 2002 Biomaterials: principles and applications (crc press)
[2] Ramakrishna S, Mayer J, Wintermantel E and Leong K W 2001 Composites Science and Technology 61 1189-224
[3] Wise D L, Trantolo D J, Lewandrowski K U, Gresser J D and Cattaneo M V 2000 Biomaterials Engineering and Devices: Human Applications: Vol 2: Orthopedic, Dental, and Bone Graft Applications (Springer)
[4] Geetha M, Singh A K, Asokamani R and Gogia A K 2009 Progress in Material Science 54 397-425
[5] Long M and Rack H J 1998 Biomaterials 19 1621-39
[6] Wang K 1996 Materials Science and Engineering: A 213 134-7
[7] Meletis E I, Cooper C V and Marchev K 1999 Surface and Coatings Technology 113 201-9
[8] Budinski K G 1988 Surface engineering for wear resistance (Prentice Hall)
[9] Dahotre N B, Paital S R, Samant A N and Daniel C 2010 Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences 368 1863-89
[10] Demir A G, Furlan V, Lecis N and Previtali B 2014 Biointerphases 9 029009
[11] Whyman G, Bormashenko E and Stein T 2008 Chemical Physics Letters 450 355-9
[12] Wenzel R N 1936 Industrial & Engineering Chemistry 28 988-94.
[13] Luo B H, Shum P W, Zhou Z F and Li K Y 2010 Surface and Coatings Technology 205 2597-604
[14] Cassie A B and Baxter S 1944 Transactions of the Faraday Society 40 546-51
[15] Milne A J and Amirlazif A 2012 Advances in colloid and interface science 170 48-55
[16] Liu X, Chu P K and Ding C 2004 Materials Science and Engineering: R: Reports 47 49-121
[17] Manivasagam G, Dhinasekaran D and Rajamanickam A 2010 Recent Patents on Corrosion Science 2 40-54
[18] Zhao G, Raines A L, Wieland M, Schwartz Z and Boyan B D 2007 Biomaterials 28 2821-9
[19] Kurella A and Dahotre N B 2005 Journal of biomaterials applications 20 5-0
[20] Etsion I 2005 Journal of tribology 127 248-53
[21] Majumdar J D and Manna I 2003 Sadhana 28 495-562
[22] Pfleging W, Kumari R, Besser H, Scharnweber T and Majumdar JD 2015 Applied Surface Science 355 104-11
[23] Chikarakara E, Naher S and Brabazon D 2012 Surface and Coatings Technology 206 3223-9
[24] Prakash S and Kumar S 2015 International Journal of Precision Engineering and Manufacturing 16 361-6.