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LASER SURFACE TEXTURING OF TITANIUM ALLOYS FOR BIOMEDICAL APPLICATIONS

LASEROWE TEKSTUROWANIE ELEMENTÓW ZE STOPÓW TYTANU DO ZASTOSOWAŃ BIOMEDYCZNYCH

A b s t r a c t

The article presents the methodology and results of laser surface texturing of the Ti6Al7Nb alloy. Laser treatment was carried out by means of a laser TruMicro 5325c Trumpf with a wavelength of 343 nm and a pulse duration of 6.2 ps. The impact of pulse frequency, scanning speed of a laser beam and laser power on the shape and dimensions of texture was studied. By selecting a suitable shape, size and density of laser texture for the surface of titanium alloys applied in knee replacement it is possible to reduce the coefficient of friction and wear of polyethylene to increase the osseointegration and adhesion of the coatings.

Keywords: laser micromachining, texturing, titanium alloys

S t r e s z c z e n i e

W artykule przedstawiono metodykę oraz wyniki badań laserowego teksturowania powierzchni elementów ze stopu Ti6Al7Nb. Obróbkę laserową wykonano z zastosowaniem lasera TruMicro 5325c Trumpf o długości fali 343 nm i czasie trwania impulsu 6,2 ps. Badano wpływ częstotliwości, prędkości skanowania oraz mocy wiązki laserowej na kształt i wymiary elementu tekstury. Poprzez wybór odpowiedniego kształtu, wymiarów oraz zagęszczenia elementów tekstury możliwe jest zmniejszenie współczynnika tarcia oraz zużycia panewki polietylenowej w protezie stawu kolanowego, w ten sposób można też poprawić osteointegrację i przyczepności powłok.

Słowa kluczowe: mikroobróbka laserowa, teksturowanie, stopy tytanu

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1. Introduction

The knee joint is one of the most loaded biobearing in the human body, which is prone to injuries. In order to treat rheumatoid arthritis, osteoarthritis, high distortion and post--traumatic conditions, total knee arthroplasty is performed. The use of implants reduces pain and improves the quality of life of patients suffering from the described health problems.

In the metal-polymer friction pair, mainly the polymer component is destroyed. Typical kinds of destruction of an element made of UHMWPE include: abrasive friction, plastic deformation and creep, pitting, change of chemical composition, color and structure, loosening and cracking [1–3].

Laser micromachining has a huge potential for functionalizing the surface of biomaterials. Application of a laser surface texturing enables the use of a wide range of materials for which different shapes and sizes of textures can be produced on the surface in a reproducible, rapid and economical way. In addition, it allows avoiding the formation of impurities, it is easier in control and more precise; there is a reduced heat-affected zone and only minor adverse concentric zones of deposition of evaporated material are formed around the elements of texture [4, 5].

Laser surface texturing greatly reduces friction and wear of titanium and its alloys. In the generated textures there are accumulated impurities, which have a positive effect on reducing the abrasive friction of prostheses. Qin et al. [6] compared round, square and triangular textures of different sizes. Round textures had the most stable and the most favourable tribological parameters, but for all of the samples the reduction of the coefficient of friction and wear was reported to be comparable with the non-textured ones. Tianchang et al. [7] compared textures in the form of holes with a diameter of 150 microns, a depth of 40 microns and a density of 13%, 23%, 44%. It was observed that the friction coefficient was lower and more stable for textures with the highest density. Density and the shape of texture are the most important factors affecting tribological properties [7, 8].

Laser micromachining has also a beneficial effect on cell adhesion, biological fluids spreading, osseointegration and the strength of the implant-bone joint. Mirhosseini et al. [8] observed a better adhesion of osteoblasts and their more even distribution on the laser surface texturing of titanium alloys. The cells on the texturing surface had a tendency to cluster [8]. Chem et al. [9] report that bioactivity is a function of surface chemistry and surface topography. The study shows that surfaces undergoing laser texturing have a better osseointegration, because the cells grow into the prosthesis [9]. Götz et al. [10] indicated that in order to improve osseointegration, the optimal diameter of textures for alloy Ti6Al4V is 200 microns. Bobyn et al. [11] studied prosthesis of different sizes and textures and they indicated the values of 100–400 microns as the optimal diameter. Other studies confirm that the minimum diameter of textures should be about 140–200 microns.

Wettability is an important factor determining biocompatibility. Cell adhesion is increased on hydrophilic surfaces [4, 12–14]. The oxidised surfaces of titanium alloys are considered to be hydrophilic [4]. The laser surface modification of titanium improves wettability. Dahotre al. [15] observed improvement in wettability for all the tested textures (in the form of columns and grooves). Hao et al. [16] compared the properties of the samples after texturing to the non-textured ones by means of a high power diode laser

(HPDL). They noted improvement in wettability, which indicates a better integration with biological fluids.

Obtaining fully functional biomaterials is possible by modifying their surface. Among methods of surface engineering, surface laser texturing has an enormous potential. Laser surface texturing has a beneficial effect on cell adhesion, osseointegration, distribution of biological fluids and improves tribological properties. Many authors present the results of experiments in which spherical textures provide improvement in tribological properties. As shown in the literature, there are divergent results of studies on the impact of the density and dimensions of textures on the improvement of wear resistance. The dimensions of the textures produced on the surface of titanium alloys should be the subject of further research.

The purpose of this study is to choose operating parameters of the laser to produce spherical textures of different depths in the titanium alloy.

2. Materials and methods

The study covered samples which were made of titanium alloy Ti6Al7Nb. The chemical composition of the alloy was in accordance with ISO 5832-11: Fe max. 0.25%, max. 0.2%, N max 0.05% C max. 0.08% H max. 0.009% Al 5.5-6.5% 6.5-7.5 Nb, Ta max. 0.5%, remainder Ti.

Laser surface texturing of Ti6Al7Nb alloy was carried out at the station equipped with a laser TRUMPF TruMicro 5325c with the following characteristics:

– laser type: diode-pumped disk laser pulse with harmonic generation 3,
– wavelength: 343 nm,
– average power: 5 W,
– pulse duration of 6.2 ps,
– pulse frequency of 400 kHz can be divided by a natural number from 1 to 10,000,
– the maximum pulse energy of 12.6 μJ,
– mod TEM_{00},
– $M^2 = 1.3$,
– fluence 4.8 J/cm^2.

At such short laser pulses of a few picoseconds, the “cold ablation” takes place. The shape and diameter of the textures were chosen based on literature review. In order to select the depth of textures, a plan of experience was prepared – a static determined poly-selective rotatable PS/DS-P: λ. On the samples surface, spherical texturing with a diameter of 250 microns was made. For this purpose, software provided with the above-described laser device was used, which allows, inter alia, drilling holes. This is a standard procedure in which we can ask specific dimension values expected for texture.

3. Results

Laser micromachining was carried out in argon. In selecting parameters for laser texturing two parameters were changed: the power and speed of the scanning beam. Figure 1 shows 4 rows of textures produced with the following laser parameters:

- row 1: power 50%, the laser beam scanning speed of 50 mm/s,
- row 2: power 50%, the laser beam scanning speed of 100 mm/s,
- row 3: power 100%, the laser beam scanning speed of 50 mm/s,
- row 4: power 100%, the laser beam scanning speed of 100 mm/s.

The analysis of microscopic research showed that the smallest heat-affected zone, with the most regular edges and the lowest deposition of the vaporized material are the hollows formed at a laser power of 100% and a laser beam scanning speed of 50 mm/s (row 3). In order to assess the quality of the texture, the profile of the hole was analysed (Fig. 1).

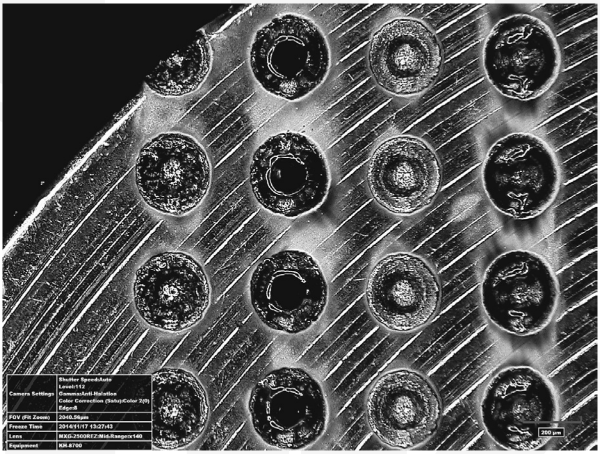

Fig. 1. General view of the textured surface (from left 1, 2, 3, 4 row)

After selecting the correct scanning speed of the laser beam and the power of laser, the impact of pulse frequency on the change of the depth of textures was analyzed. After scanning the surface by laser beam with a pulse frequency of 400 kHz, the texture with a depth of 40 microns was obtained. After double-scanning of the surface by a laser beam with a pulse frequency of 400 kHz, the texture with a depth of 79 microns was obtained (Fig. 2).

After scanning the surface by a laser beam with a pulse frequency of 400 kHz and then scanning the surface by alternate pulse, a texture with a depth of 63 microns was obtained. When choosing the pulse frequency of 133 kHz, the textures of 16 microns depth was obtained. When choosing the pulse frequency of 80 kHz, the textures of 10 microns depth was obtained.

Microscopic analysis showed that the use of argon allows reducing oxidation of the surface. In the literature, there is divergent data on the effects of cover gases on the surface oxidation of titanium alloys. Laser micromachining which was carried out without a cover

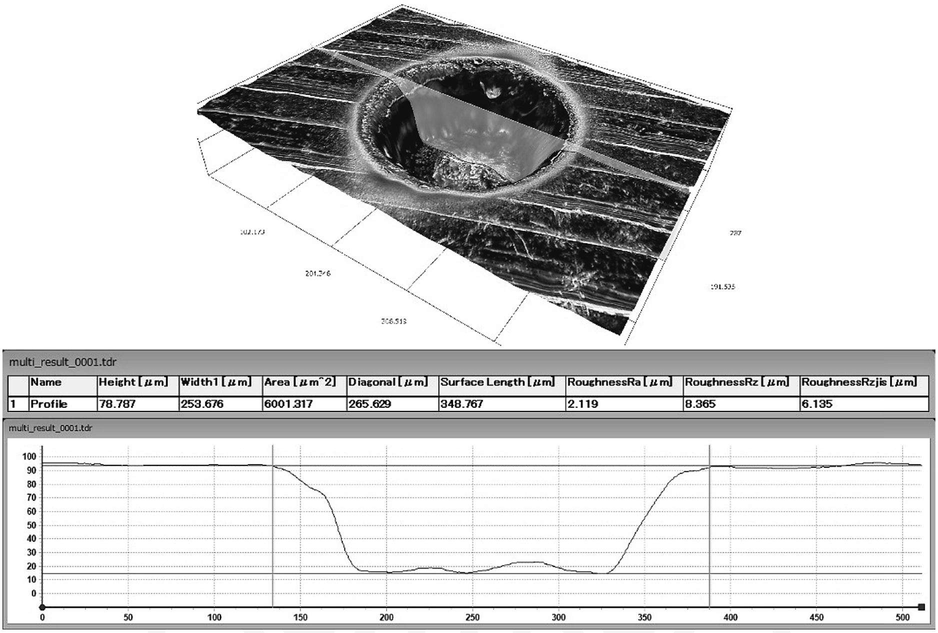

Fig. 2. The profile of a spherical texture with a diameter of 254 microns and a depth of 79 microns

gas leads to oxidation of the surface of Ti6Al4V alloy. The increase in the oxygen content improves wettability. Anselme [17] pointed out that surface texturing by laser reduces surface energy and makes the surface hydrophobic, and only the use of anodization causes hydrophilic properties.

4. Conclusions

The results show that with properly chosen laser parameters and by means of a suitable automatic control, it is possible to produce textures of selected shapes and repeating geometrical dimensions on the surface of the titanium alloy. The change of pulse frequency influenced in direct proportion the change in the depth of textures. The use of argon leads to reduction of surface oxidation. The best texture quality was obtained at the maximum power of the laser and at the scan speed of laser beam of 50 mm/s.

The aim of further research will be to determine the influence of textures density on the properties of titanium alloys used in knee replacement.

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