www.czasopisma.pan.pl PAN www.journals.pan.pl

A R C H I V E S O F M E T A L L U R G Y A N D M A T E R I A L S

Volume 60 2015 Issue 2

DOI: 10.1515/amm-2015-0202

B. MAJKOWSKA*,♯, M. JAŻDŻEWSKA*, E. WOŁOWIEC**, W. PIEKOSZEWSKI***, L. KLIMEK**,****, A. ZIELIŃSKI*

# THE POSSIBILITY OF USE OF LASER-MODIFIED Ti6Al4V ALLOY IN FRICTION PAIRS IN ENDOPROSTHESES

# MOŻLIWOŚĆ ZASTOSOWANIA MODYFIKOWANEGO LASEROWO STOPU Ti6Al4V NA PARY CIERNE ENDOPROTEZ

The purpose of this paper is to show results of laser treatment at cryogenic conditions of the Ti6Al4V alloy used for orthopedic applications. That modification process ought to bring beneficial changes of microstructure and residual stresses in the surface layer. The paper presents the abrasive wear of the base and laser remelted material in association with ceramics $Al_2O_3$. Despite the surface cracking after laser treatment the tribological properties in simulated body fluid have been substantially improved.

*Keywords*: laser treatment, abrasive wear, titanium, endoprostheses

Celem artykułu jest pokazanie rezultatów obróbki laserowej w warunkach kriogenicznych stopu Ti6Al4V używanego w aplikacjach ortopedycznych. Tego rodzaju proces modyfikacji powinien przynieść korzystne zmiany w mikrostrukturze i naprężeniach własnych warstwy wierzchniej. Artykuł prezentuje badania odporności na zużycie ścierne materiału podstawowego i nadtopionego laserowo w skojarzeniu z ceramiką $Al_2O_3$. Pomimo pęknięć na powierzchni materiału po obróbce laserowej własności tribologiczne badane w roztworze symulującym płyn ustrojowy zostały znacznie ulepszone.

## 1. Introduction

Components of orthopedic endoprostheses undergo different forms of damage in the course of their use, such as mechanical damage, deformation and abrasive wear. Such damage results in loosening and loss of stability of a endoprostheses due to migration of wear products [1, 2]. The time of failure-free use of a endoprostheses depends on the friction processes. Lower frictional resistance and higher durability of materials increase the strength and extend the life cycle of a endoprostheses.

Therefore, new methods and technologies are being searched for strengthening biocompatible materials, mainly Ti alloys, which reduce the effects of wear of friction pair components.

The surface treatment can be proposed as a way to improve the corrosion resistance, wear resistance, fatigue strength, bioactivity. As such techniques, the oxidation and ion implantation are commercially used [3].

The laser treatment has been widely used for steels but less often for non-ferrous alloys. The laser remelting of Ti and its alloys has been used for different purposes: deposition of thin coatings [4, 5, 6], creation of oxides, nitrides and oxynitrides [7], micromachining [8-10], laser hardening [11-13], increase in intrinsic stresses [14].

This work has been aimed to verify whether such cryogenic laser treatment of the Ti6Al4V alloy could be suitable to improve wear properties in corrosive environment of simulated body fluid.

## 2. Experimental

The Ti6Al4V alloy was used in the researches. Chemical composition and mechanical properties are shown in the TABLES 1 and 2. Ti alloy in form of sheets in thickness 12 mm was used. Microstructure of the Ti6Al4V alloy contains $\alpha$ and $\beta$ phases.

TABLE 1
Chemical composition of the Ti6Al4V alloy (wt.%)

| Ti | Fe | V | Al | C | O | N | B | Y | H |
|---|---|---|---|---|---|---|---|---|---|
| rest | 0.16 | 4.05 | 6.40 | 0.01 | 0.185 | 0.005 | max 0.001 | max 0.001 | 0.0035 |

* GDANSK UNIVERSITY OF TECHNOLOGY, FACULTY OF MECHANICAL ENGINEERING, DEPARTMENT OF MATERIALS AND WELDING ENGINEERING, 11/12 NARUTOWICZA STR., 80-233 GDANSK, POLAND

** LODZ UNIVERSITY OF TECHNOLOGY, INSTYTUTE OF MATERIALS SCIENCE AND ENGINEERING, 1/15 STEFANOWSKI STR., 90-924 LODZ, POLAND

*** NATIONAL RESEARCH INSTITUTE - INSTITUTE FOR SUSTAINABLE TECHNOLOGIES, 6/10 PULASKI STR., 26-600 RADOM, POLAND

**** DEPARTMENT OF DENTAL TECHNIQUES, MEDICAL UNIVERSITY OF LODZ, 251 POMORSKA STR., 92-231 LODZ, POLAND

♯ Corresponding author: beata.majkowska@pg.gda.pl

TABLE 2
Mechanical properties of the Ti6Al4V alloy

| The rolling direction / Mechanical properties | longitudinal | transversal | ISO 5832/3 |
|---|---|---|---|
| $R_e$ [MPa] | 1050 | 1002 | min 830 |
| $R_m$ [MPa] | 1072 | 1023 | 900-1160 |
| $A_5$ [%] | 9.53 | 9.49 | min 10 |

The mechanical properties of Ti6Al4V alloy are based on the static tensile test according to PN-EN 10002-1-1998. Samples were prepared with the recommendations of the standards – they have been collected with and against to the rolling direction. In both cases, extending slightly deviate from the requirements of the standard – it was smaller, other values are compatible therewith.

The Ti6Al4V alloy surface was modified by the molecular $CO_2$ TRUMPF TLF 6000 Turbo laser at the Center for Laser Technologies of Metals in Kielce University of Technology. The laser beam dimension – 1×20 mm, power – 4000 W and scanning velocity – 1.0 m/min were used in this process. During the laser remelting process the specimens were immersed in liquid nitrogen (temperature about -195°C) and distance from laser head to sample was about 10 mm. Before laser treatment the samples were cleaned with acetone, and then coated with an absorber, the major component was graphite. Each of the sample was remelted in a single laser move.

After the laser remelting of the study material, its surface and cross-sections were observed by scanning electron microscope (Figs. 1, 2). The fine microstructure with cracks in the surface layer is observed. Thickness of the remelted layer is the sum of three zones: the subsurface, central and transition, differ in structure from the base material. The thickness of the surface layers depends on the laser parameters. When the laser power was 4000 W and scanning velocity – 1.0 m/min, the thickness of surface layer was 240 $\mu$m and the cracks penetrated to a maximum depth of 43 $\mu$m.

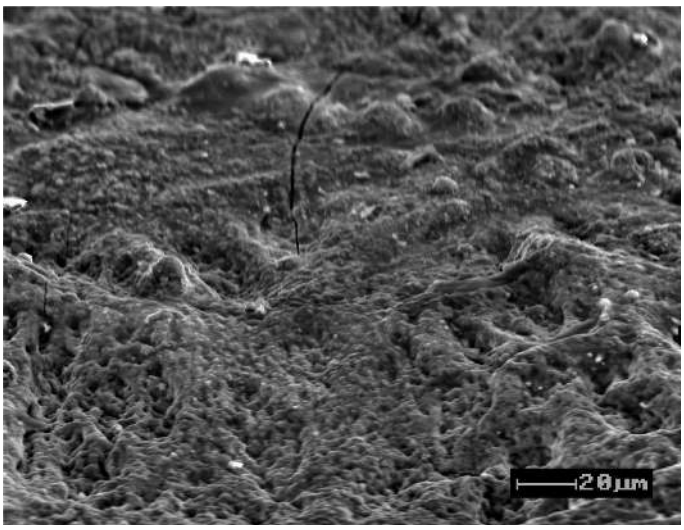

Fig. 1. Surface microstructure of the laser remelted Ti6Al4V alloy

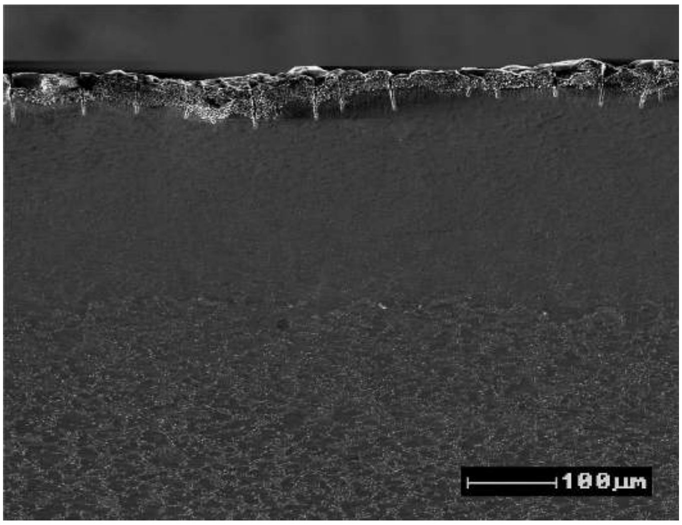

Fig. 2. Cross-section of microstructure of the laser remelted Ti6Al4V alloy (4000 W; 1.0 m/min)

The tribocorrosion tests were performed at sliding motion by means of a special tribometer PT-2. The samples of Ti6Al4V alloy in the rectangular shape 18x30 mm and height 5 mm were used in the study (Fig. 3). The ceramics specimen was used as the counter-specimen.


Fig. 3. A sample of the Ti6Al4V alloy used for tribocorrosion test

During tribocorrosion test the nominal load was 25 MPa and sliding motion rate of the average diameter of the counter-specimen 0.1 m/s. The test was interrupted several times in order to estimate the mass loss by weighting and wear depth by optical microscope. The samples were weighted by means of a digital, analytical scale type Radwag 40/160/c/1 WPA. During the test the load of a specimen, sliding motion rate, and fluid temperature were constantly measured. As a medium test was applied Ringer‘s solution (temperature 37±1°C) – standard simulated body fluid.

Measurements were conducted on three laser remelted samples at cryogenic conditions. For comparative purposes, studies were performed the three samples of the base material.

During the tests by means of the PT-2 tribometer for assumed load a friction torque has been measured, and next a friction coefficient for a tested materials combination (Ti6Al4V / $Al_2O_3$) has been calculated. The average values of friction coefficient, wear depth and mass loss after tribocorrosion tests were presented in Figs. 4-6.

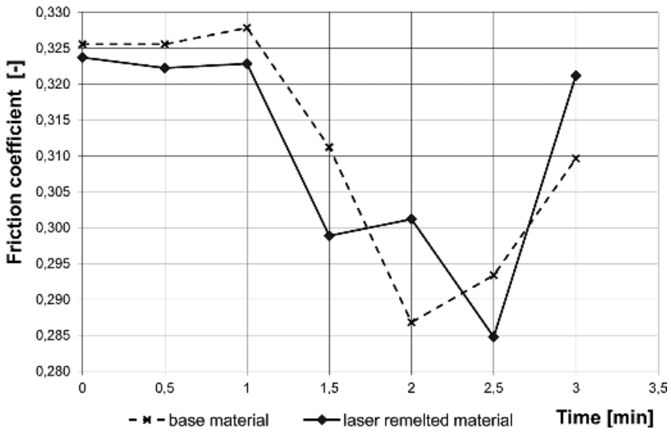


Fig. 4. Friction coefficient of base and laser remelted material (average values) after tribocorrosion test

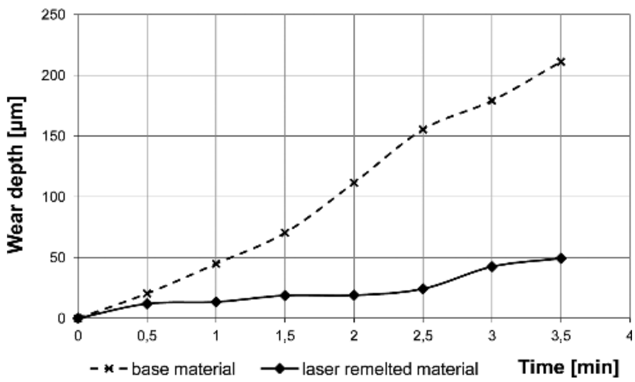


Fig. 5. Wear depth of base and laser remelted material (average values) after tribocorrosion test

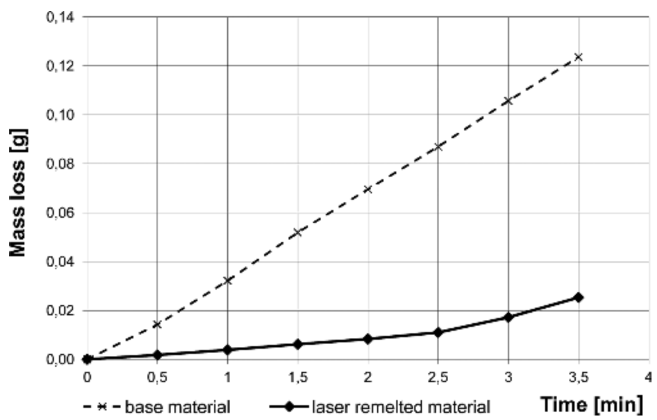


Fig. 6. Mass loss of base and laser remelted material (average values) after tribocorrosion test

Fig. 7 shows an example of the surface microstructure of base and laser remelted material, obtained after tribocorrosion test.

Examples of wear track roughness profiles of laser remelted Ti6Al4V alloy is shown in Fig. 8. $R_a$ parameter is 3.74 $\mu$m, while $R_z$ 26.89 $\mu$m.

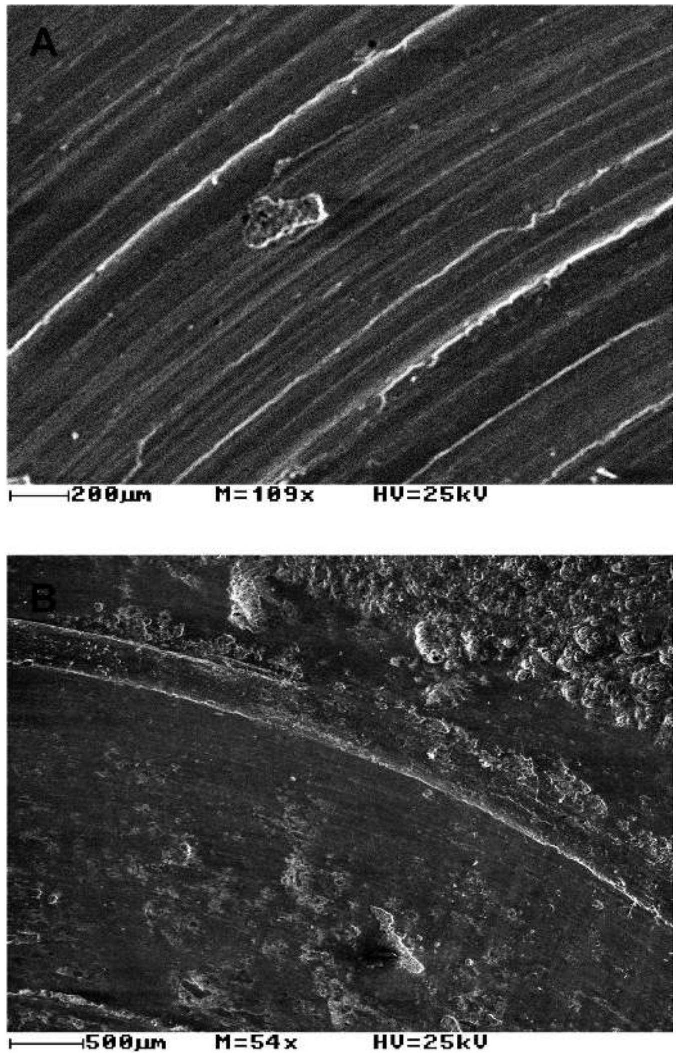


Fig. 7. The surface microstructure of base material (a) and laser remelted Ti6Al4V alloy (b) after tribocorrosion test

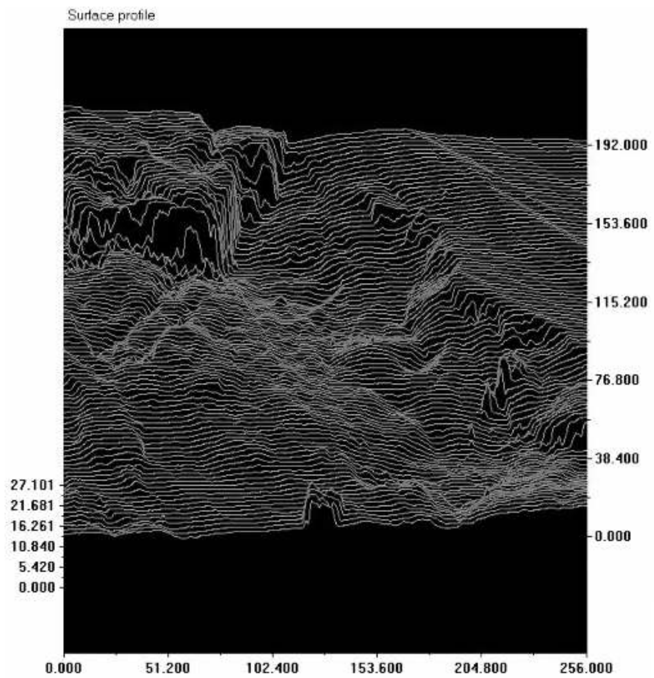


Fig. 8. Roughness profiles of friction track the laser remelted Ti6Al4V alloy (4000 W, 1.0 m / min)

## 3. Conclusion

1. After laser remelting at cryogenic conditions the increase of wear resistance of the Ti6Al4V alloy was obtained.
2. The tribocorrosion tests have shown 3-6 times lower mass loss and 5 times higher decrease of wear depth of remelted alloy in comparison to the base material.
3. Abrasive wear resistance tests at sliding motion have confirmed the beneficial effect of laser remelting of Ti6Al4V alloy.

**Acknowledgements**

The research was made in Gdansk University of Technology Faculty of Mechanical Engineering and Centre for Laser Technologies of Metals at Kielce University of Technology.

REFERENCES

[1] M. Podrez-Radziszewska, D. Bąkowski, M. Lachowicz, W. Głuszewski, W. Dudziński, Materials Engineering **2**, 75-78 (2006).
[2] P. Kowalewski, PhD thesis, Wroclaw University of Technology, Wrocław 2007.
[3] A. Zieliński, S. Sobieszczyk, T. Seramak et al., Adv. Mater. Sci. **10**, 4, 21-31 (2010).
[4] V. Nelea, C. Ristoscu, C. Chiritescu, et al., Appl. Surf. Sci. **168**, 127-131 (2000).
[5] Y.S. Tian, Q.Y. Zhang, D.Y. Wang, J. Mater. Proc. Tech. **209**, 2887-2891 (2009).
[6] B. Major, F. Bruckert, J.M. Lackner et al., Archives of Metallurgy and Materials **53**, 39-48 (2008).
[7] M. Gołębiewski, G. Krużel, R. Major et al., Mater. Chem. Phys. **81**, 315-318 (2003).
[8] A.Y. Vorobyev, C. Guo, Appl. Surf. Sci. **253**, 7272-7280 (2007).
[9] Y. Lin, M.C. Gupta, R.E. Taylor et al., Optics Lasers Eng. **47**, 118-122 (2009).
[10] M. Rozmus, J. Kusiński, M. Blicharski et al., Archives of Metallurgy and Materials **54**, 665-670 (2009).
[11] J.M. Robinson, R.C. Reed, B.A. Van Brussel, J.T.M. De Hosson, Mater. Sci. Eng. A **208**, 143-151 (1996).
[12] Z. Sun, I. Annergren, D. Pan, T.A. Mai, Mater. Sci. Eng. A **345**, 293-300 (2003).
[13] F. Guillemot, E. Prima et al., Appl. Phys. A **77**, 899-904 (2003).
[14] A. Charles, S. Montross, T. Wie, L. Ye et al., Int. J. Fatigue **24**, 1021-1036 (2002).

*Received: 20 April 2014.*