K. PIOTROWSKA, M. MADEJ, J. KOWALCZYK, K. RADOŃ-KOBUS ISSN 0543-5846
METABK 63(1) 53-56 (2024)
UDC – UDK 669.295.293.296:621.892:531.4.620.178.1:620.197.6=111

THE INFLUENCE OF ENVIRONMENTAL CONDITIONS ON THE TRIBOLOGICAL PROPERTIES OF THE Ti13Nb13Zr ALLOY

Received – Primljeno: 2023-06-16
Accepted – Prihvaćeno: 2023-08-10
Original Scientific Paper – Izvorni znanstveni rad

The paper presents the results of tribological tests of the Ti13Nb13Zr titanium alloy - carried out in the conditions of lubrication with liquids simulating body fluids. Artificial saliva solutions were used for the tests. Two pH values were used – 7,0 characteristic of a healthy organism and 4,9 - typical for the presence of inflammation. The counter-sample in the tested friction nodes were Al_2O_3 balls with a diameter of 6 mm loaded with a normal force of 1 N. The tests obtained showed a strong influence of environmental conditions on the tribological properties of the Ti13Nb13Zr titanium alloy. This applies to both the value of the coefficient of friction and linear wear. In the case of tests carried out under lubrication conditions with an artificial saliva solution at pH 7,0 they were 0,47 and 31,1 μm, respectively; in the case of a fluid at pH 4,9 they were 25 % and 45 % higher (0,62 and 65,6 μm).

Key words: Ti13Nb13Zr, lubrication, friction, wear, surface texture

INTRODUCTION

The pursuit of enhancing the operational durability of materials employed in medical products is one of the challenges faced by contemporary engineering. Dental implants intended for use must meet specific requirements, including mechanical and tribological properties, biocompatibility, and resistance to physiological fluids. Within this domain, metallic biomaterials, such as titanium and its alloys, are among the most commonly investigated material classes. In the realm of implant materials, the Ti13Nb13Zr alloy warrants notable attention. This is due to its specific properties [1,2]: biocompatibility, corrosion resistance in tissue and bodily fluid environments, non-toxicity, and good mechanical properties.

The human organism is widely acknowledged as an environment with aggressive properties, primarily due to the presence of high levels of chloride ions and fluctuating pH values. The salivary fluid is a crucial factor in the functioning of the dental biotribological system. Its purpose is not only to reduce the resistance to movement between moving components, but also to reduce wear and tear. The research conducted by [3,4] has demonstrated that reduced saliva quantity in the oral cavity is a contributing factor to the increased intensity of enamel, dental, orthodontic, and prosthetic materials wear and tear. Within the oral cavity, there exists a phenomenon of friction between dissimilar surfaces, specifically hard dental tissues and dental fillings [5,6]. The entire process occurs in the presence of saliva, which serves as a natural lubricant.

K. Piotrowska (kpiotrowskapsk@gmail.com), M. Madej, J. Kowalczyk, K. Radoń-Kobus, Kielce University of Technology, Kielce, Poland

Implantation constitutes a distinctive procedure whereby the implanted material is subjected to the influence of diverse physiological fluids. Dental implants that are situated within the oral cavity maintain continuous interface with saliva, whose chemical composition and pH levels are susceptible to variations that are induced by the type of ingested food and the presence of inflammatory states. The salivary composition of humans exhibits a high salinity and a broad pH spectrum ranging from 2 to 10 [7,8].

For this reason, an investigation was conducted into the tribological properties of the titanium alloy Ti13Nb13Zr in a physiological solution of artificial saliva at a temperature of 37 °C and neutral pH 7,0 and acidic: 4,9 and free access to oxygen.

MATERIALS AND METHODS

Samples of titanium alloy Ti13Nb13Zr with a chemical composition presented in Table 1 were cut into disks with a diameter of 30 mm and a height of 6 mm. Subsequently, the specimens were ground and polished utilizing a Pace Technologies grinder-polisher. The study employed abrasive papers made of silicon carbide with a gradient of grain size ranging from 320 to 2 500 μm, which increased incrementally. The final processing step entailed the use of a diamond paste with a 6 μm grain size for polishing on a cloth surface. Following the procedure of grinding and polishing, surface roughness values of the specimens were attained in the S_a = 500 nm range.

Within the realm of tribology research, a multitude of kinematic associations are applied to replicate frictional processes within the human stomatognathic sys-

Table 1 **Chemical composition of Ti13Nb13Zr titanium alloy / wt. %**

Element	Value
Ti	reszta
Nb	13,15
Zr	12,99
Fe	0,02
C	0,005
N	0,01
O	0,053
H	0,001

tem. The most frequently utilised configurations are the pin-on-disc and ball-on-disc [9-11]. Based on the literature review [4, 12-13], it can be inferred that the utilization of various friction pairs, such as metal-metal, metal-glass, ceramic-glass, dental filling-glass, metal-polymer, is prevalent in this particular type of investigation. Frictional tests were carried out under rotational motion conditions, employing technically dry friction (DF) and lubricated friction with solutions mimicking bodily fluids - artificial saliva (AF) solutions with pH values of 7,0 and 4,9 were selected for this purpose. The chemical composition of lubricants is presented in Table 2, while the test parameters are listed in Table 3.

Table 2 **Chemical composition of artificial saliva / g/dm3**

	pH of 7,0	pH of 4,9
NaCl	0,4	0,4
KCl	0,4	0,4
$CaCl_2$	–	–
$CaCl_2 * 2H_2O$	0,795	0,795
$NaH_2PO_4 * 2H_2O$	0,780	0,780
$Na_2S * 9H_2O$	0,005	0,005
Urea	1,0	1,0
Lactic acid	–	to obtain the desired pH

The artificial saliva solution was subjected to a temperature of 37 °C in order to establish a neutral operating environment with a pH value of 7,0. A simulated inflammatory state was induced by heating an artificial saliva solution with a pH of 4,9 to a temperature of 40 °C.

Table 3 **Tribological test parameters**

Parameter	Unit
Friction pair	ball Al_2O_3 – Ti13Nb13Zr
Movement	rotational
Load	5 / N
Linear speed	0,1 / m/s
Friction road	1 000 / m
Humidity	50 ± 1 / %
Temperature environment	23 ± 1 / °C
Lubricant temperature	37 ± 1 / °C i 40 ± 1 / °C

RESULTS AND DISCUSSION

Figure 1 illustrates the exemplary profiles of the friction coefficients (a) and linear wear (b) of a titanium alloy under conditions of technically dry friction and friction in an artificial saliva environment. Meanwhile, Figure 2 provides a comparison of their mean values.

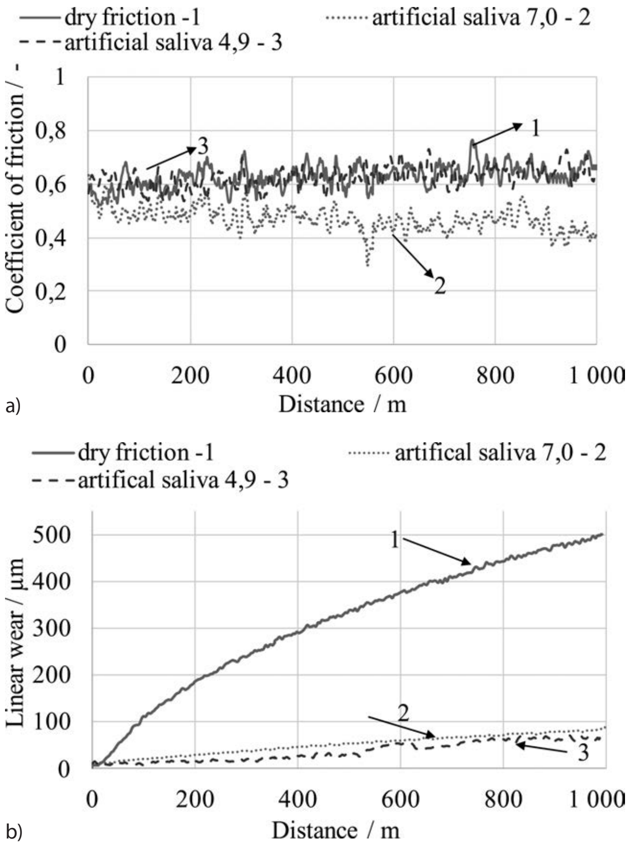

Figure 1 Average friction coefficient (a) and linear wear (b) obtained under dry friction and with the use of artificial saliva as a lubricant

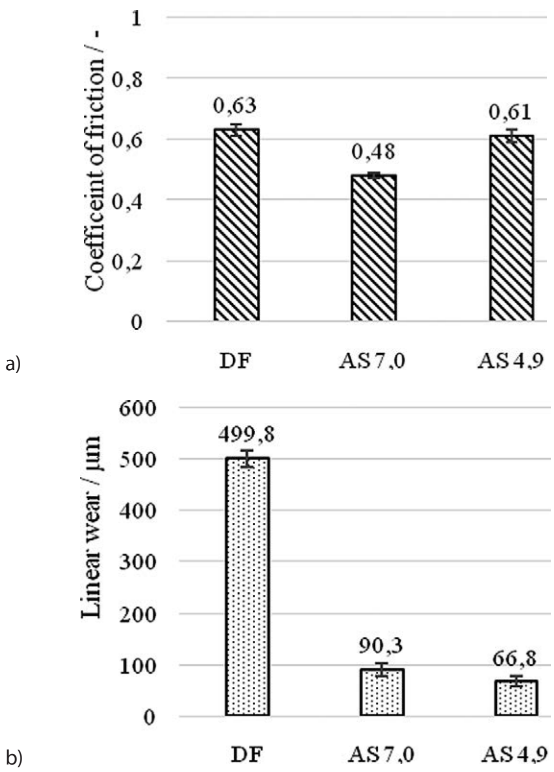

Figure 2 Average friction coefficient (a) and linear wear (b) obtained under dry friction (DF) and with the use of artificial saliva (AF) as a lubricant

The results of the tribological test indicate that the rubbing pair has exhibited the lowest coefficient of friction (μ). Ti13Nb13Zr-Al_2O_3 coated with artificial saliva

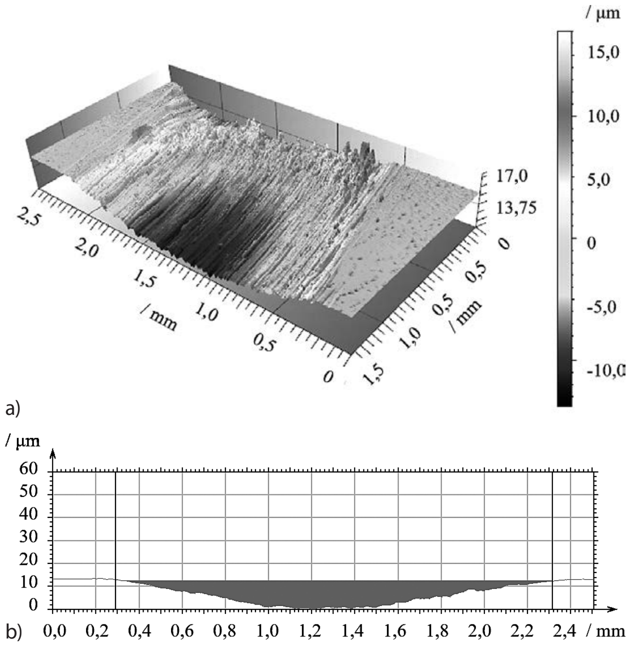

Figure 3 The Ti13Nb13Zr wear track after dry friction: a) axonometric images of wear tracks, b) profile

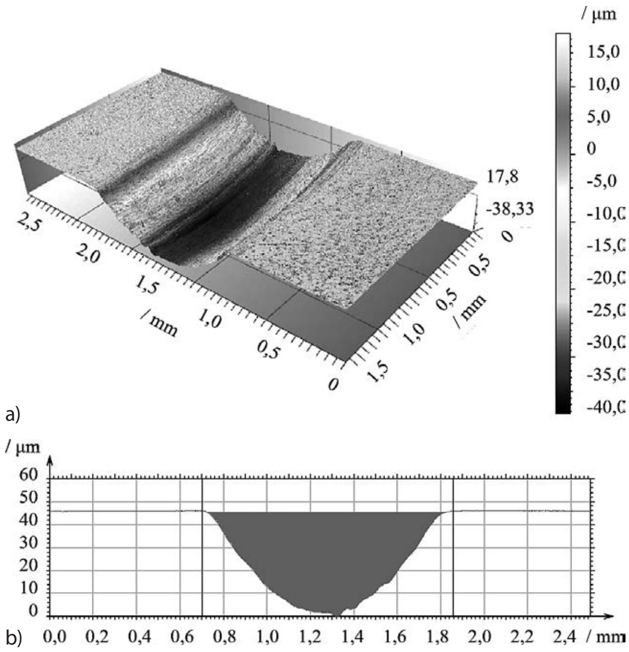

Figure 4 The Ti13Nb13Zr wear track after friction with artificial saliva pH 7,0: a) axonometric images of wear tracks, b) profile

solution of pH 7,0. The obtained result was quantified as 0,48, demonstrating a significant decrease of 23 % and 21 % compared to the values attained for technically dry friction and friction lubricated with a solution of artificial saliva at pH 4,9 respectively. The results of the experiment depicted in Figure 2b suggest that the application of an artificial saliva solution led to a decrease in the linear wear of the materials under investigation, with the optimal lubrication performance being observed for the artificial saliva solution with a pH of 4,9. The results demonstrate a significant reduction in wear by 86 % in technically dry friction and 26 % in

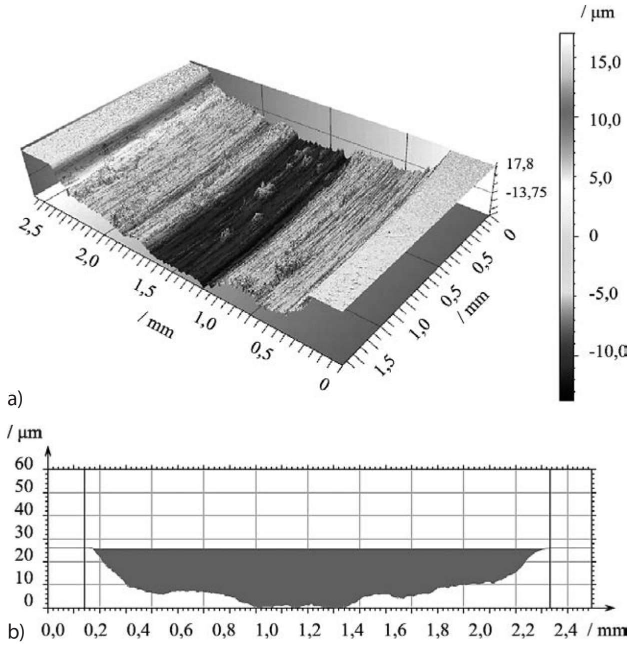

Figure 5 The Ti13Nb13Zr wear track after friction with artificial saliva pH 4,9: a) axonometric images of wear tracks, b) profile

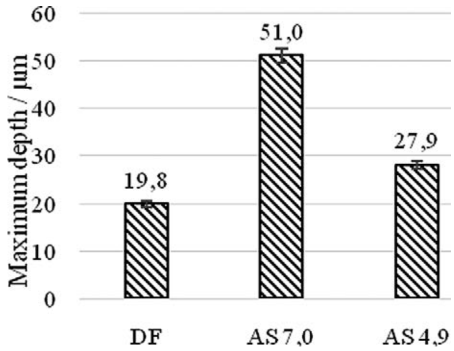

Figure 6 Maximum depth of wear track on cross-section

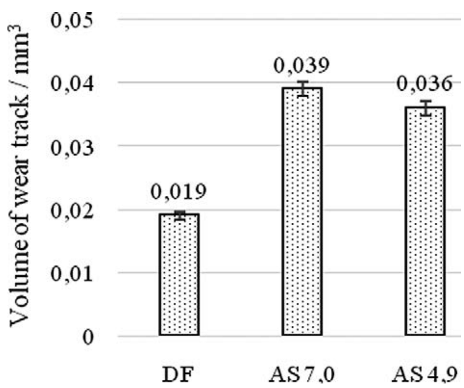

Figure 7 Volume of wear track in the cross-section.

friction lubricated by artificial saliva with a pH of 7,0. In order to perform a detailed wear analysis, the wear tracks were subjected to microscopic observations.

After conducting tribological research, microscopic wear marks were observed on the samples. Figures 3 - 5 show examples of 3D axonometric images (a) of wear and tear and wear profiles (b). Figures 6 - 7 summarise the most important wear indicators: maximum depth and wear volume determined from the three measurement series.

The examination of the geometric structure of surface properties in the context of tribological tests has demonstrated that the utilization of artificial saliva solutions with differentiated pH values has resulted in an intensification of wear of the Ti13Nb13Zr alloy. The maximum wear depth and volume were observed during the application of artificial saliva with neutral pH, while the minimum was recorded during technical dry friction. They amounted to 51,0 μm and 0,039 mm^3 and 19,8 μm and 0,019 mm^3, respectively The observed phenomenon can be attributed to the corrosive effect of chloride ions present in the utilized lubricant, which leads to an intensified wear process of the studied material.

CONCLUSIONS

The smallest coefficient of friction was obtained for the Ti13Nb13Zr-Al_2O_3 sliding pair lubricated with an artificial saliva solution with a pH of 7,0, whilst the lowest linear wear occurred during lubrication with an artificial saliva solution of pH 4,9. The tribological investigations have demonstrated that the application of lubricants in the form of an artificial saliva solution has contributed to the elevation of both linear and volumetric erosion of the Ti13Nb13Zr titanium alloy.

Due to the high biocompatibility of the Ti13Nb13Zr alloy, it is advisable to carry out further research and apply surface engineering methods, e.g. coatings [14-15], to improve its tribological properties and thus extend its service life.

REFERENCES

[1] Piotrowska K., Madej M., Granek A., Assessment of Mechanical and Tribological Properties of Diamond-Like Carbon coatings on the Ti13Nb13Zr Alloy, Open Eng. 10 (2020) 536-545.

[2] Geetha M., Kamachi U., Gogia A.K., Asokamani R., Baldev R., Influence of microstructure and alloying elements on corrosion behaviour of Ti13Nb13Zr alloy, Corros. Sci. (2004) 877-892.

[3] Andrysewicz E., Mystkowska J., Dąbrowski J.R., Krawczyk-Dembicka E., Investigations of tribological and physicochemical properties of human saliva and its substitutes. Engineering of Biomaterials 118 (2013) 23-29.

[4] Andrysewicz E., Dąbrowski J.R., Leonow G., Aspekty metodyczne badań reologicznych śliny, Twój Przegląd Stomatologiczny 2008 10-15.

[5] Sajewicz E., Effect of saliva viscosity on tribological behaviour of tooth enamel, Tribology International 42 (2009) 327-332.

[6] Andrysewicz E., Mystkowska J., Kolmas J., Jałbrzykowski M., Olchowik R., Dąbrowski J.R., Influence of artificial saliva compositions on tribological characteristics of Ti-6Al-4V implant alloy, Acta of Bioengineering and Biomechanics 14(4) (2012) 71-79.

[7] Loch J, Krawiec H., Corrosion behavior of cobalt alloys in artificial saliva solution, Archives of Foundry Engineering 13 (2013) 3, 101-106.

[8] Chang, H., Tomoda, S., Silwood, C. J. L., Lynch, E. & Grootveld, M., 1H NMR investigations of the molecular nature of cobalt (II) ions in human saliva., Arch. Biochem. Biophys. 520 (2012) 51-65.

[9] Bongaerts J.H.H., Rossetti D., Stokes J.R., The lubricating properties of human whole saliva. Tribology Letters 27 (2007) 277-287.

[10] Gierzyńska-Dolna M., Biotribologia, Wyd. Politechniki Częstochowskiej, Częstochowa 2002,

[11] Holmes D., Sharifi S., Stack M.M., Tribo-corrosion of steel in artificial saliva, Tribology International 75 (2014) 80-86.

[12] Macakova L., Yakubov G.E., Plunkett M.A., Stokes J.R., Influence of ionic strength on the tribological properties of pre-adsorbed salivary films, Tribology International 44 (2011) 956-962.

[13] Li H., Zhou Z.R., Wear behaviour of human teeth in dry and artificial saliva conditions, Wear 249 (2002) 980-984.

[14] K. Piotrowska, M. Madej, Influence of tio2 coating deposited with the atomic layer deposition (ALD) technique on the properties of Ti13Nb13Zr titanium alloy, Metalurgija 61 (2022) 3-4 665-668

[15] M. Madej, The properties of diamond-like carbon (DLC) coatings on titanium alloy for biomedical application, Metalurgija 61 (2022) 3-4 669-672

Note: Translated by Dawid Kowalski, EnglishCloud, Kielce, Poland.