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The Influence of Diamond-Like Coatings on the Properties of Titanium

PAWELEC Katarzyna[1,a,*],BARANOWICZ Paweł[2,b], WYSOKIŃSKA-MISZCZUK Joanna[3,c], MADEJ Monika[1,d]

[1] Kielce University of Technology, Faculty of Mechatronics and Mechanical Engineering, Tysiąclecia PP 7, 25-314 Kielce, Poland

[2] Medical University of Lublin, Karmelicka 7, 20-081 Lublin, Poland

[3] NZOZ Ekstradent, Juliusza Słowackiego 21/1U, 25-365 Kielce, Poland

[a]kpawelec@tu.kielce.pl, [b]pawel.baranowicz@ekstradent.pl, [c]periodontologia@tlen.pl, dmmadej@tu.kielce.pl

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Abstract: The paper compares the morphology and geometric structure of the surface and the results of tribological tests of polished titanium discs and PACVD diamond-like coatings deposited on them. Observations of surface morphology and determination of chemical composition were carried out using scanning microscopy and EDS analyzers. The geometric structure of the surface was investigated using an optical profilometer. Tribological properties were investigated by ball-on-disc testing under dry friction and under lubrication regime using Ringer's solution. The results obtained during the tests showed that the use of DLC coatings significantly improves the performance of titanium.

Introduction

Modern biomedical materials are to a large extent based on metal alloys, among which titanium occupies more and more space. The first applications of titanium in bone surgery date back to the forties of the last century. The choice of titanium is due to its good mechanical properties and corrosion resistance in the tissue environment. For this reason, it is widely used for various types of implants. Intraosseous implants allow obtaining satisfactory results in a very wide range of indications. Due to the physicochemical and mechanical properties of titanium and its alloys, they play an important role in implantology and dental prosthetics [1]. Titanium shows domination over other metallic materials owing to better biocompatibility in the environment of a living organism, and contributes to rapid osseointegration [2].

Titanium is characterized by high resistance to wear and high mechanical strength, showing the highest ratio of mechanical strength to its specific weight among all metal biomaterials [3, 4, 5]. In order to increase the service durability and to improve the quality of the surface, protective coatings are deposited.

Diamond-like carbon (DLC) coatings are one of the most durable varieties of protective layers. Their characteristics include a high modulus of elasticity, resistance to brittle fracture, high thermal conductivity, low coefficient of thermal expansion and chemical stability. These unique features make DLC coatings suitable for use in the surface engineering to control tribological damage as material with a low coefficient of friction and high resistance to friction wear [6]. The coatings are widely applied in medicine for the production of biomaterials [7, 8]. DLC coatings can be obtained by many techniques, including PACVD. In its essence, the PACVD process is a CVD process assisted by a glow discharge plasma, aimed at producing hard surface layers or layers exhibiting

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special surface and volume related properties (e.g., protective, anti-corrosion, tribological properties). In general, the PACVD technique uses the advantages of CVD, such as uniform deposition of layers on different materials with simultaneous elimination of their defects (high temperature at which the CVD process takes place). Applied treatments allowed obtaining surfaces with different topography and morphology [9, 10].

Materials and methods:

The tests were carried out on titanium discs with a diameter of 18 mm and a height of 6 mm. Before measurements and observations were made, the specimens were sanded and polished using a Bühler Automet 250 grinding and polishing machine. The surface preparation process was carried out in accordance with polishing techniques recommended by the manufacturer. Then, a PACVD coating was applied to some of the specimens.

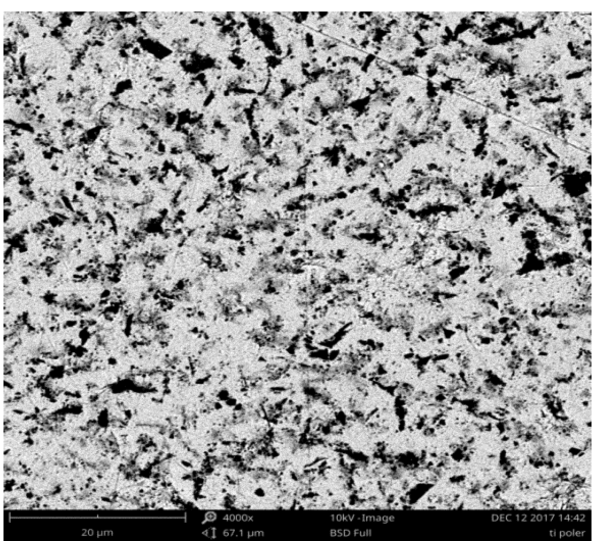
Observation of surface morphology was carried out using a Phenom ProX scanning electron microscope, while a JEOL scanning microscope JEOL 7100F, equipped with an X-ray dispersion energy spectrometer was used to determine the chemical composition.

A Taylor Hobson coherent Talsurf CCI Lite co-op interferometer analyzed the geometric structure of the specimen surfaces before and after tribological tests.

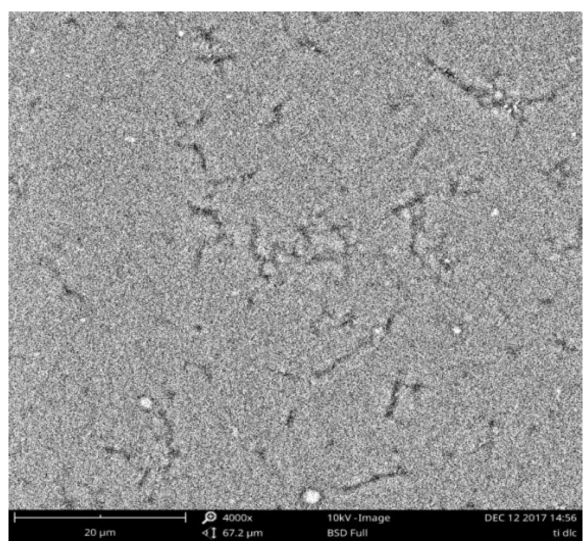
Tribological ball-on-disc tests were performed using Tester T-01. A titanium specimen subjected to physicochemical treatment and an Al_2O_3 ball with a diameter of 10 mm constituted the friction pair. The motion resistance was determined under technically dry friction (TDF) and with the use of Ringer’s solution (RS) as a lubricant. Ringer's solution was chosen because its chemical composition resembles that of the body fluid. The Ringer solution consisted of 8.6 kg/m^3 of NaCl, 0.30 kg/m^3 of KCl and 0.48 kg/m^3 of CaCl. The test load was P = 20 N over the sliding distance of 200 m. The tests were carried out in laboratory atmosphere at a relative humidity of 50±5% and a temperature of 23±1ºC.

Results

Surface morphology and chemical composition analysis. Figure 1 shows the morphology of the surface of the polished specimen and of the specimen with a DLC coating at x4000 magnification.



a)



b)

Fig.1. SEM- morphology of titanium surfaces of discs a) polished b) with a:C-H coating

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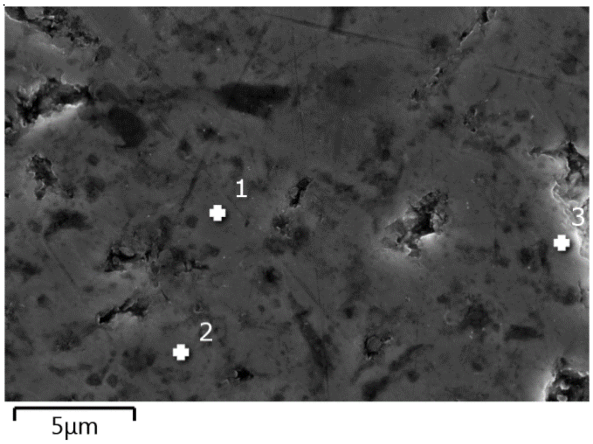
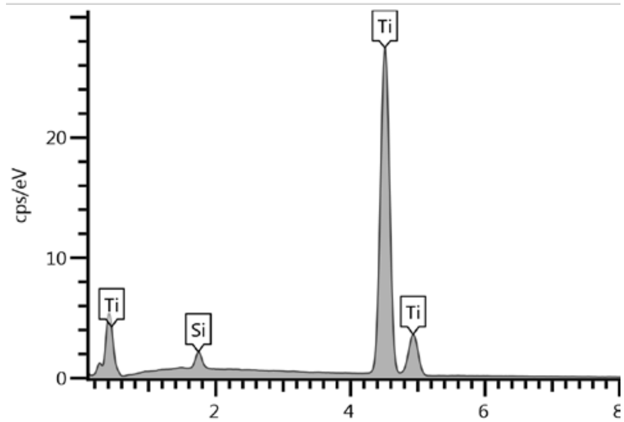
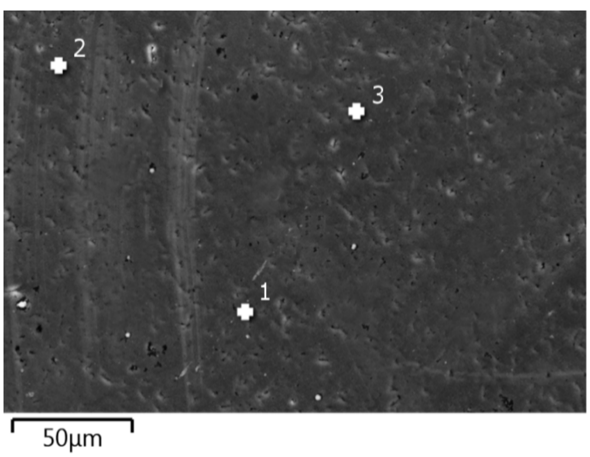
Observations made with the use of a SEM microscope showed that both the polished specimen and that with the a:C-H coating had a homogeneous morphology. The discs had a smooth surface with no visible traces of machining or defects. Figure 2 shows the chemical composition analysis in micro-areas.



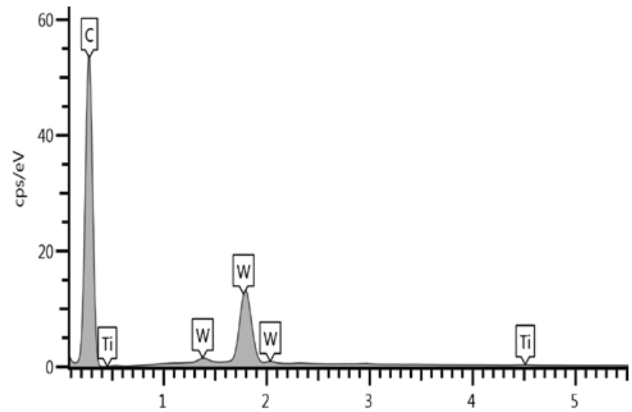
Point	[Ti]	[Si]	Total
1	96.45	0.60	97.05
2	96.47	1.19	97.66
3	99.90	3.0	99.90



a)



Point	[Ti]	[C]	[W]	Total
1	0.19	80.35	19.46	100.00
2	0.24	80.76	19.01	100.00
3	0.09	81.71	18.19	100.00



b)

Fig. 2. Analysis of the chemical composition of titanium discs
a) polished, b) with a:C-H coating

Analysis of the chemical composition performed for the micro-areas of the polished specimen showed the presence of titanium and silicon. The presence of silicon in the polished specimen resulted from the SiC discs grinding and polishing processes. In the case of the DLC specimen, the analysis revealed a low content of titanium and a high content of carbon and tungsten.

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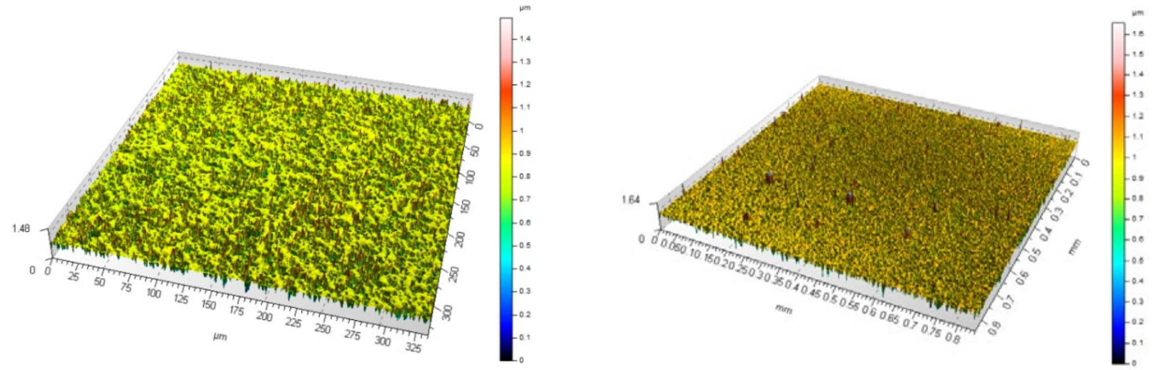
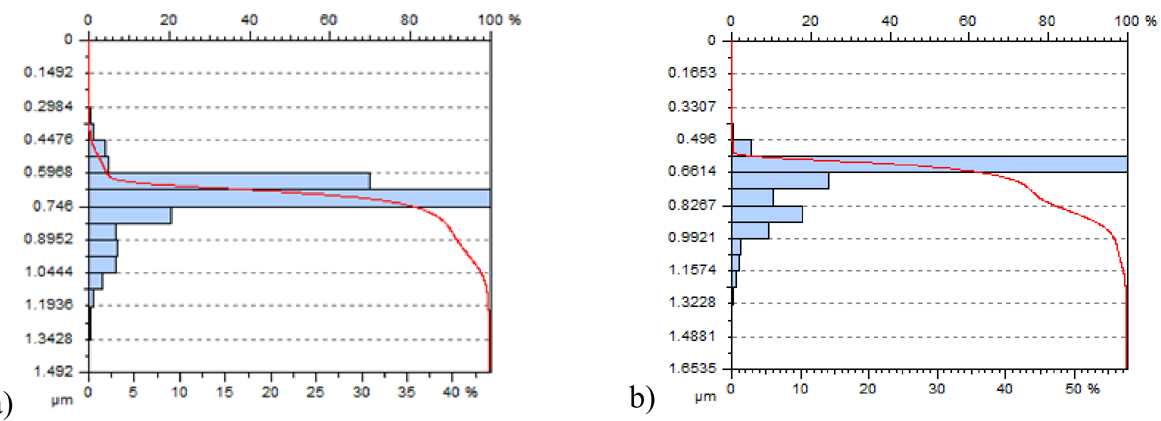
Assessment of the geometric structure of the surface. Figures 3 and 4 show isometric images and ordinate distribution with the Abbot-Firestone curve.



a) b)

Fig. 3. Isometric images of titanium discs a) polished, b) with a:C-H coating



a) b)

Fig. 4. Distribution of ordinates with the bearing area curve of the specimen a) polished, b) with a:C-H coating

Tab. 1. Parameters of the surface geometry

Specimen	**Parameters**					
	[µm]					
	Sa	***Sp***	***Sv***	***Sz***	***Ssk***	***Sku***
polished	0.0730	0.7134	0.7786	1.4920	- 1.6956	8.6480
with a: C-H coating	0.1039	0.6939	0.9595	1.6535	-1.5709	7.1455

Three-dimensional images allowed the analysis of the geometrical structure of both specimens. Knowledge of surface geometry is very useful when assessing its quality. The test results revealed that the DLC coated disc has a more developed geometric surface structure. Additional information about the surface topography included the amplitude parameters shown in Table 1.

For the specimens with the DLC coating, the Sa, Sv and Sz values were higher than those for the polished specimen. This indicates greater surface roughness. The Ssk surface asymmetry coefficient (skewness) describes the symmetry of height distribution with respect to the mean plane [1]. The negative value of this coefficient indicates a surface with deep valleys in a smoother plateau. The analysis of the results presented in Table 1 shows negative skewness in both cases.

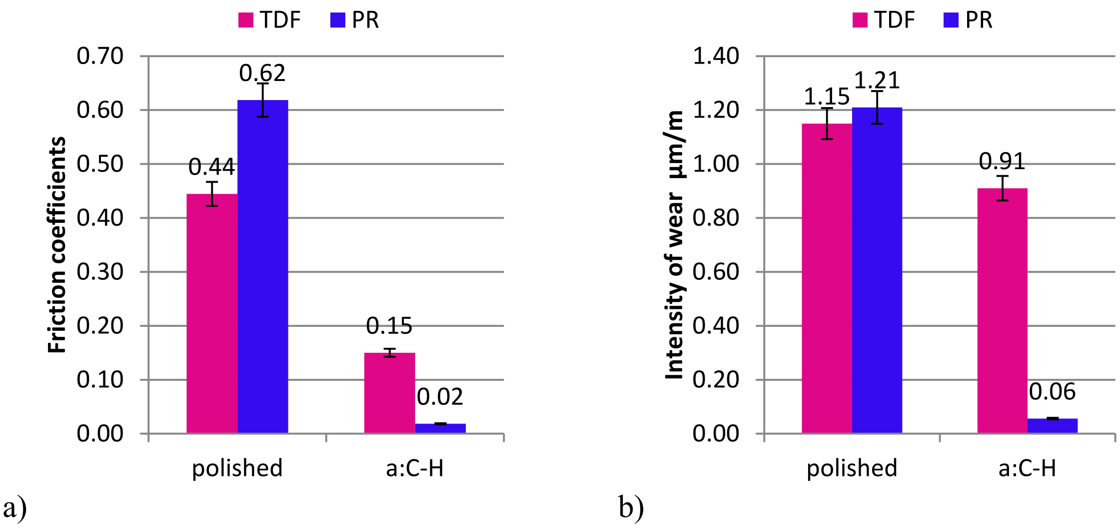
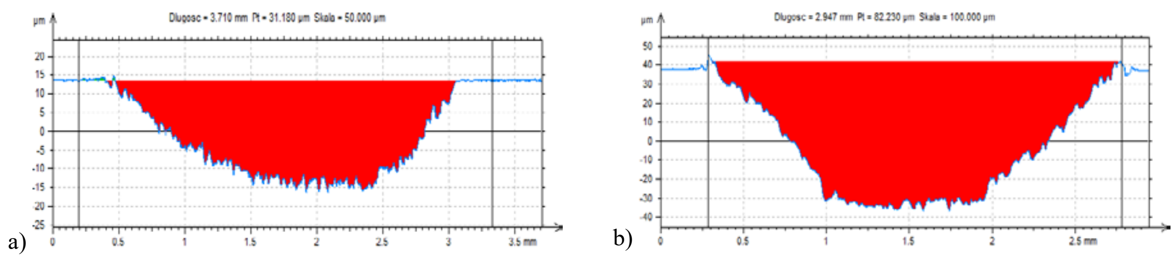
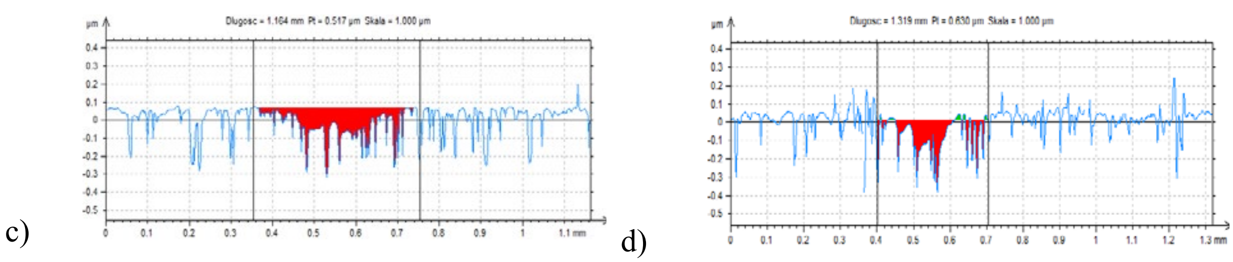


Fig.5. Coefficient of friction (a) and intensity of wear (b)



Max. depth: 30.107 µm Area: 51 550.090 µm^2 Max. depth: 78,843 µm Area:122 841,66 µm^2

Fig. 6. Wear depth of the polished disc
a) technically dry friction, b) Ringer's solution lubricated friction



Max. depth: 0,390 µm Area:41,633 µm^2 Max. depth: 0,402 µm Area:29,695 µm^2

Fig. 7. Wear depth of the disc with a:C-H coating
a) technically dry friction, b) Ringer's solution lubricated friction

Tribological tests. The results of the tests are presented as a comparison of the coefficient of friction (Fig. 5a) and intensity of wear (Fig. 5b) of the test elements depending on the types of friction pair materials and the lubricants used.

The lowest coefficients of friction were recorded for the diamond-like coating, both during technically dry friction and with Ringer's lubrication. The lowest wear intensity value was observed

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for the specimen with a:C-H coating during lubricated friction. After the tribological tests, wear depths were measured. Figures 6 and 7 summarize the measurement results.

The comparison of the maximum depths shows that the polished disc was a faster wear material in the Al_2O_3 friction pair. In the case of the specimen with the diamond-like coating, the smallest maximum wear depth was recorded during technically dry friction. However, when comparing the values of the hole surface area, the smallest wear was observed on the specimen with the a:C-H coating under the lubricated friction. The obtained results indicate that the use of the diamond-like carbon (DLC) coating ensured tribocorrosion protection of the titanium disc in the environment of the solution simulating body fluid.

Conclusions

The results of morphology, topography tests, chemical composition and geometric structure analysis were the bases for the following conclusions. The microscopic studies showed that the observed discs had different surface morphologies and geometric structures depending on the physico-chemical treatments used. Tribological tests revealed that the best tribological characteristics were obtained for surfaces with the diamond-like carbon (DLC) coating. Compared with the polished disc, the coefficient of friction recorded during technically dry friction was three times lower and 30 times lower during Ringer's lubricated friction. The comparing of wear scars showed that the DLC coated disc was the least worn material in the friction pair with the Al_2O_3 ball. The results obtained during the tests showed that the use of DLC coating improves tribological properties and significantly increases the service life of titanium.

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