M. MADEJ, K. RADOŃ-KOBUS, K. MILEWSKI, S. DRABIK,
K. PIOTROWSKA, J. KOWALCZYK

ISSN 0543-5846
METABK 63(1) 85-88 (2024)
UDC – UDK 669.15.26:621.793.784.788.292:620.178.1:539.26=110

TRIBOLOGICAL PROPERTIES OF DIAMOND-LIKE-CARBON COATING DOPED WITH TUNGSTEN

Received – Primljeno: 2023-04-10
Accepted – Prihvaćeno: 2023-08-25
Original Scientific Paper – Izvorni znanstveni rad

This paper presents the tribological properties of diamond-like-carbon coatings (DLC) doped with tungsten. The hardness of the DLC coating was determined using a micro-hardness tester. Friction tests were carried out on a tribometer in rotational motion in a 100Cr6 steel ball-disk association with a-C-H:W tungsten doped hydrogenated DLC coating. Tests were carried out with loads of 10 N, 25 N and 50 N under technically dry friction conditions. Using a scanning electron microscopy (SEM), the surface morphology was observed, and with a confocal microscope, the geometric structure of the surface was observed before and after the friction tests. The wetting angle of the samples was examined on an optical tensiometer for distilled water and diiodomethane. The results indicated that DLC coatings of the a-C:H:W type obtained by the PVD technique can be used in unlubricated high-load tribological systems.

Keywords: 100Cr6 steel, a-C-H:W, hardness, tribological properties, SEM

INTRODUCTION

Diamond-like-carbon coatings obtained through the processes of Plasma-Enhanced Chemical Vapour Deposition – PECVD are distinguished by very good parameters: resistance to brittle fracture, chemical stability, high hardness and elastic modulus, resistance to corrosion and tribological wear [1, 2].

In addition, they show very good adhesion to the substrate, additionally improved through the formation of intermediate layer between the DLC coating and the substrate (interlayers) [3]. Their high bio-compatibility and antibacterial properties are an additional advantage [14]. They have found use in numerous applications in the electronics, tooling, automotive, textile and medical industries, among others [4, 5].

DLC coatings applications are introduced for the purpose of increasing the service life of components exposed to tribological wear, in particular steel. They are used in injection moulding machines and in the textile industry for coating matrices [6, 7], as well as in the automotive industry as components for clutches, engines or wrist pins [8, 9].

DLC coatings are also applied to machine and equipment components subject to tribological wear [10]. DLC coatings also find extensive use in medicine, as components that come into contact with blood. These include blood pumps, hip, knee or shoulder implants, valves and stents [11 – 13].

M. Madej, K. Radoń-Kobus (kradonkobus@tu.kielce.pl), S. Drabik, K. Piotrowska, J. Kowalczyk, Kielce University of Technology, Faculty of Mechatronics and Mechanical Engineering, Poland, K. Milewski, Trzuskawica S.A. Sitkówka, Poland

MATERIALS AND EXPERIMENTAL METHODS

The test specimens were manufactured from 100Cr6 steel with a 2,18 µm DLC coating. The wettability of the coating surface was investigated with distilled water and diiodomethane with an optical tensiometer. Tribological tests were carried out under technically dry friction conditions. Detailed tribological test parameters are presented in Table 1. The images of the geometric structure of the surface before and after friction tests were obtained through a confocal microscope with a 20x magnification. The morphology of the surface after testing was visualised through a scanning microscope with 300x magnification. The hardness was tested using an ultra nanoindentation tester.

Table 1 **Parameters of the tribological test**

Normal load	10 N, 25 N, 50 N
Speed	0,1 m/s
Radius	8 mm
Distance	1 000 m
Temperature	25 ± 2 °C
Humidity	50 ± 5 %
Friction pair	Counter-sample: 100Cr6 steel ball with a diameter of 6 mm Sample: 100Cr6 steel disc with DLC coating
Lubrication	no lubrication

RESULTS AND DISCUSSION

Figure 1 shows an exemplary view of distilled water droplets and diiodomethane on the surface of the DLC coating, while Figure 2 on the surface of 100Cr6 steel. Figure 2 shows the values of the average wetting angles.

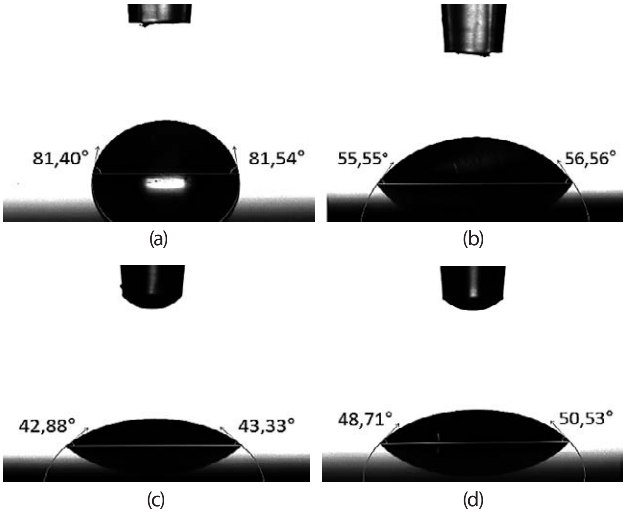


Figure 1 A view of a drop of distilled water (a, c) and diiodomethane (b, d) on the surface of 100Cr6 steel and DLC coating

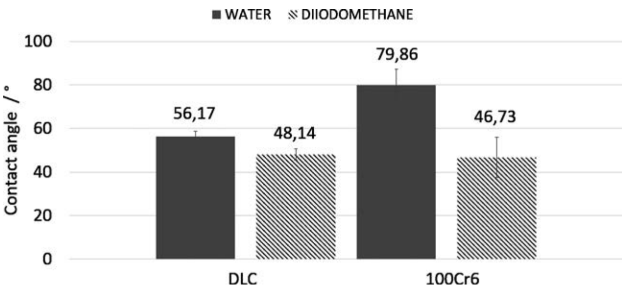


Figure 2 The average wetting angles

The mean value of the wetting angle with distilled water was 55,32 ° for the DLC coating, while for 100Cr6 steel – 79,86 °, indicating that the wettability of the DLC coating was worse than that of the 100Cr6 steel. The average values of the wetting angles for the coating and steel are similar, at 48,86 ° and 46,73 °.

Figure 3 shows an isometric view of the DLC coating before tribological testing.

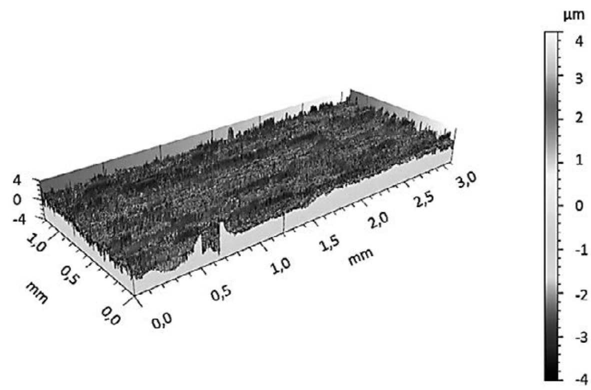


Figure 3 Isometric images of the surface before the tribological test

Amplitude parameters were determined for the analysed surface (Sv, Sp, Ssk, Sku). Based on these parameters, the surface was found to have indentations of 4,59 µm and elevations of 3,15 µm. A negative value for the Ssk parameter is evidence of a plateau-like structure of the surface.

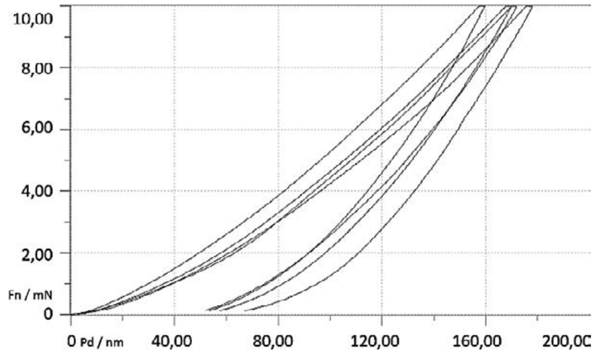


Figure 4 Loading–penetration depth curve from nanohardness tests for DLC coating and mechanical parameters

Figure 4 shows the load-unload curve as a function of indenter penetration depth during the hardness test for the DLC coating, while Table 2 presents the mechanical properties obtained from the test performed.

Table 2 **Mechanical properties of DLC coating**

Parameters	Unit	Mean	SD
Instrumental hardness - H_{IT}	GPa	22,5	1,9
Young's module - E_{IT}	GPa	213,3	31,5
Identer penetration - h_m	nm	170,0	9,5
Plastic work - W_{plast}	%	259,8	48,2
Elastic work - W_{elast}	%	430,5	38,9

The obtained results show that the DLC coating was found to have high elasticity. This is evidenced by the prevalence of resilient over plastic deformation. During the microhardness test, the indenter penetrated to a depth of 170 nm, which is less than 10 % of the coating thickness. Comparing the hardness of the DLC coating and the literature data, the hardness of 100Cr6 steel

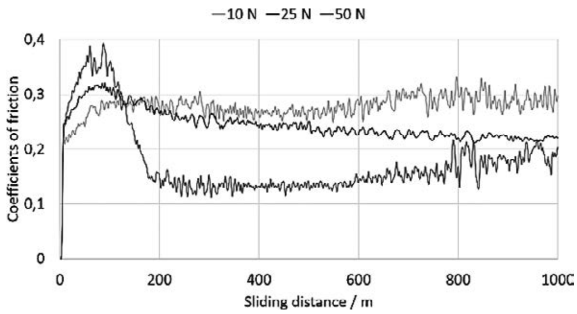


Figure 5 The course of exemplary coefficients of friction of DLC coating during technically dry friction

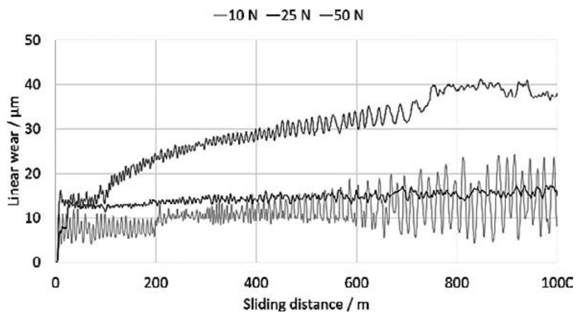


Figure 6 The course of exemplary linear wear of DLC coating during technically dry friction

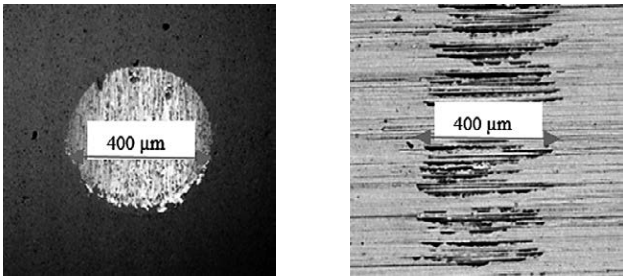
measured by instrumental indentation is 4,9 GPa, which means that it is over 5 times higher.

Figure 5 shows examples of the variation of the friction coefficient as a function of distance during technically dry friction. Figure 6 presents an example of the variation of linear wear.

The graphs shown above prove to be an evidence that the coefficient of friction decreases with the increase of the applied load. This may be indicative of the self-lubrication of the DLC coating. The graph of the change in linear wear of the friction pair shows different values. Under a load of 50 N, the linear wear nearly double compared to a load of 10 N. Microscopic observations (through SEM and confocal microscopes) were carried out for a more detailed analysis.

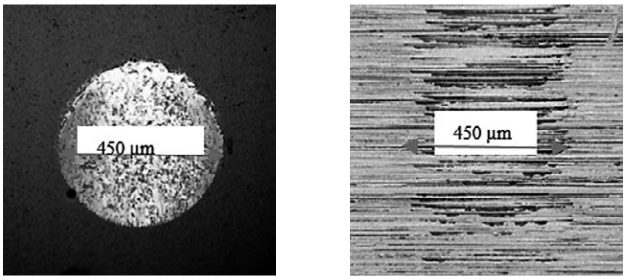
Figures 7 - 9 show the surface morphology of the specimens and counter-specimens after tribological testing for 10 N, 25 N and 50 N loads, respectively.

The level of tribological wear of the materials tested increases together with the increasing load. At a load of 10 N, the width of the wear mark of the counter-specimen – a steel sphere was approximately 400 µm, at a load of 25 N – 450 µm, and at a load of 50 N – 600 µm.



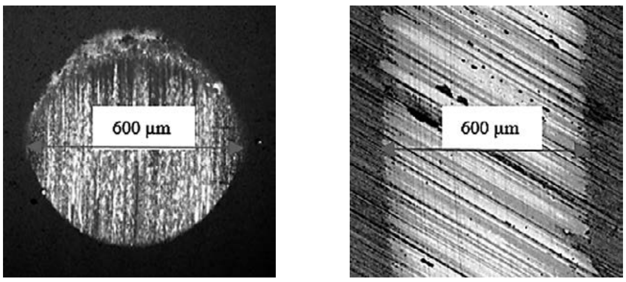
(a) (b)

Figure 7 View of the wear trace of the ball (a) and disc (b) after tribological test with 10 N load



(a) (b)

Figure 8 View of the wear trace of the ball (a) and disc (b) after tribological test with 25 N load



(a) (b)

Figure 9 View of the wear trace of the ball (a) and disc (b) after tribological test with 50 N load

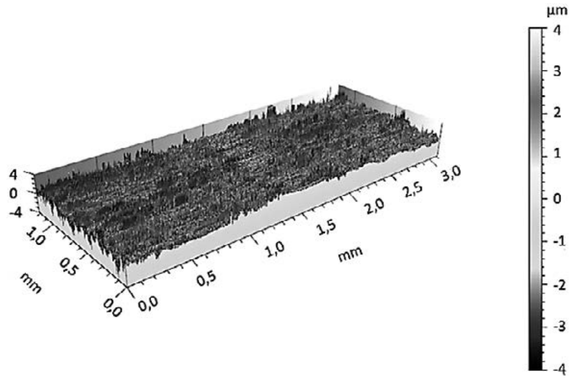


Figure 10 Isometric images of the surface after the technically dry friction test with 10 N load

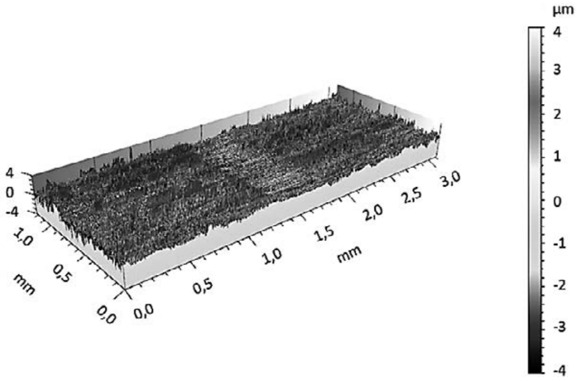


Figure 11 Isometric images of the surface after the technically dry friction test with 25 N load

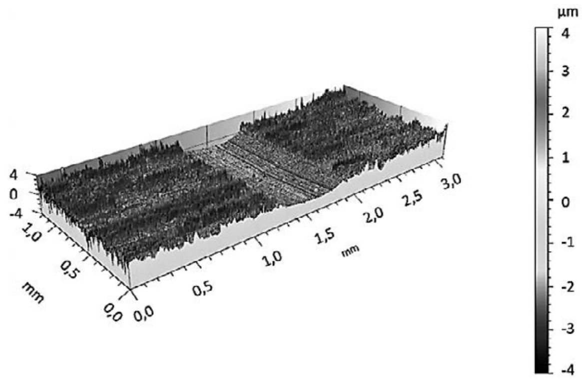


Figure 12 Isometric images of the surface after the technically dry friction test with 50 N load

Table 3 **Parameters of the wear track**

Parameters	Max. depth	Wear track area
Unit	µm	µm^2
10 N	0,54	59,65
25 N	0,6	88,27
50 N	1,7	850,5

An analogous increase in the width of the wear mark was observed on the specimens covered with DLC coat.

Figures 10 - 12 show isometric views after tribological tests for the applied loads and Table 3 shows the wear track parameters of the DLC coatings.

Isometric views of the wear track indicate that together with the load increase, specimens coated with DLC suffer an increased wear. The wear rates shown in Table 3 indicate that none of the analysed cases showed a total wear of the coating. A small margin of approximately 0,3 µm remained before the complete tearing of the layer. This demonstrates the very good anti-wear performance of the tested coating.

CONCLUSIONS

The following conclusions have been drawn from the research carried out:

- the surface of the tested coating is characterised by hydrophilicity, as indicated by the wetting angle value with distilled water of 55,32 °. The wetting angle with diiodomethane was 48, 86 °,
- the results of the mechanical tests indicate a high elasticity of the coatings, as evidenced by a predominance of elastic deformation over plastic deformation of approximately 65 %,
- the results of friction tests show that the coefficient of friction decreased progressively subject to increasing load applied (10 N, 25 N, 50 N),
- analysis of the obtained images of surface morphology after tribological tests showed an increase in the area of the abrasion trace of the specimen and the counter-sample with increasing load (in the range of 400 µm ÷ 600 µm),
- isometric images after friction tests indicate very good anti-wear properties of the tested coating. The results of the model tribological tests show that they can be successfully applied in tribological systems subject to high stress.

REFERENCES

[1] L. Wang, X. Nie, X. Hu, Effect of Thermal Annealing on Tribological and Corrosion Properties of DLC Coatings, Journal of Materials Engineering and Performance 22 (2013) 3093–3100

[2] A. Czyżniewski, Powłoki DLC w zastosowaniu do pokrywania elementów maszyn, Inżynieria Materiałowa 6 (2003) 435-438.

[3] M. Niemczewska-Wójcik, Concept for a research methodology of Surface topography – testing and analysis of tribological wear traces, Tribologia 4 (2022), 31-38

[4] M. Kot, P. Lacki, Contact mechanics of coating-substrate systems: I – Methods of analysis and FEM modeling of nanoindentation tests. Journal of the Balkan Tribological Association 18 (2012) 598–614.

[5] M. Madej, D. Ozimina, K. Kurzydłowski, T. Płociński, P. Wieciński, M. Styp-Rekowski, M. Matuszewski, Properties of diamond-like carbon coatings deposited on CoCrMo alloys, Transactions of FAMENA 39 (2015), 79-88

[6] M. Madej, K. Marczewska-Boczkowska, D. Ozimina, Effect of tungsten on the durability of diamond-like carbon coatings in the chemical industry, Przemysł Chemiczny 93 (2014) 4, 500-505

[7] B. Kržan, M. Kalin, J. Jože, Tribological behaviour of tungsten-doped DLC coated gears, Metalurgija 47 (2008) 4, 290-298.

[8] R. Samur, A. Demir, Wear and corrosion performances of new friction materials for automotive industry, Metalurgija 51 (2012) 1, 94-66.

[9] J. Du, T. Hao, X. Zhang, G. Su, P. Zhang, Y. Sun, J. Zhang, C. Xu, Finite element investigation of cutting performance of Cr/W-DLC/DLC composite coated cutting tool, The International Journal of Advanced Manufacturing Technology 118 (2022) 2177–2192

[10] M. H. Sulaiman, R. N. Farahana, M. N. Mustaffa, K. Bienk, Tribological properties of DLC coating under lubricated and dry friction condition, Materials Science and Engineering 670 (2019) 1-4

[11] F. Z. Cui, D. J. Li: A review of investigations on biocompatibility of diamond-like carbon and carbon nitride films. Surface and Coatings Technology 131 (2000) 481-487

[12] S. Mitura, P. Niedzielski, B. Walkowiak, Nanodiam, New technologies for medical applications: studying and production of carbon surfaces allowing for controlable bioactivity. PWN, Warszawa.

[13] D. Batory, J. Grabarczyk,, W. Kaczorowski: Mechanical characterization of carbon-based layers onto UHMWDPE. Engineering of Biomaterials 76 (2008) 24-27

Note: The responsible for English language is Dawid Kowalski EnglishCloud