CHARACTERIZATION OF DIAMOND LIKE CARBON COATING

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Abstract

The paper presents the properties of diamond-like carbon (DLC) coatings deposited by PVD technique. Their properties were determined by the analysis of the structure and texture of the films and by hardness and tribological testing. The hardness of coated and uncoated parts was measured using a Matsuzawa microhardness tester. The coating structure was analyzed based on the topography of the surface and observation of the cross-sections with the aid of a JSM 7100F scanning electron microscope and EDS X-ray microanalysis. The results were used to determine the elementary composition, phase distribution and thickness of the coatings. Analysis of the chemical composition of the elements present in the samples was performed. The surface topographic maps were developed using the Talysurf CCI Lite optical profilometer. The wear resistance was established under dry friction conditions using a ball-on-disc tribometer, with the ball being made of 100Cr6 steel or 100Cr6 steel coated with DLC and with the disc being made of the 100Cr6 steel coated with DLC. The experimental data indicate that DLC coatings improve the service life of components. The results of structural analyses and tribological tests of DLC coatings were compared with those obtained for the substrate material, i.e. steel. The study aimed at assessing how the coating and the material used for the counter samples, i.e. a steel ball and a DLC ball affect the tribological properties of the parts operating under dry conditions. Compared with the substrate material (steel), the diamond-like carbon coatings showed lower linear wear, lower friction coefficient and higher hardness.

Keywords: Diamond - like carbon coatings, SEM, friction, wear

1. INTRODUCTION

Modern science has revealed limitations of mechanical, physical and chemical properties as well as performance characteristics of conventional materials [1]. During operation, tribological systems wear off substantially due to friction and processes accompanying friction [2,3]. The wear and friction processes can be minimized or eliminated by applying increasingly popular diamond-like carbon (DLC) coatings [4,5]. DLC coatings, first produced by Aisenberg and Chabot in 1971 [6], are becoming integral to a diverse range of areas, including medicine, automotive design, electronics and machinery manufacturing. The quality and functionality of many engineering materials are dependent on mechanical stress applied to them and on specific requirements regarding their surfaces, such as abrasive wear resistance and low friction coefficient. The ability of DLC coatings to self-lubricate makes them suitable for use whenever the improvement of tribological performance of machine components is necessary, e.g. when liquid lubricants cannot be applied [7,8]. DLC coatings can be doped with various dopants such as S, N, W, O, F, Ti, V, Mo, Co, Nb and their combinations without sacrificing the amorphous character of the films [8,9].

2. MATERIALS

2.1. Test materials

The test samples were produced of 100 Cr6 steel coated with a single layer of a-C:H diamond-like carbon film. The 100 Cr6 steel balls were used as counter-samples. The tests were performed on a ball-on-plate machine without a lubricant. The analysis focused on a-C:H coatings produced by PVD process at 250 °C.

3. RESULTS AND DISCUSSION

3.1. Scanning electron microscopy and EDS analysis

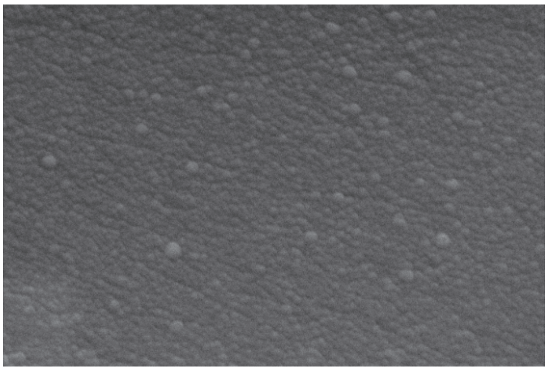


Figure 1 SEM image of the a-C:H coating

A JSM JEOL 7100F electron microscope with an EDS detector was used to observe the samples with DLC films. The structural investigations included surface topography observations (**Figure 1**).

Microstructural study of the a-C:H cross-section and points analysis of the chemical composition were performed at selected points, as shown in (**Figure 2**).

The investigations showed that the coating under analysis is diamond-like carbon. The DLC coating possesses a highly homogeneous structure; no defect or non-discontinuity was found. The results of a-C:H chemical composition analyses shows that in the surface layer is mainly carbon, whereas in the interlayers except carbon-based contains also tungsten. The layer at the interface between the substrate and the a-C:H coating contains carbon, tungsten, and chromium.

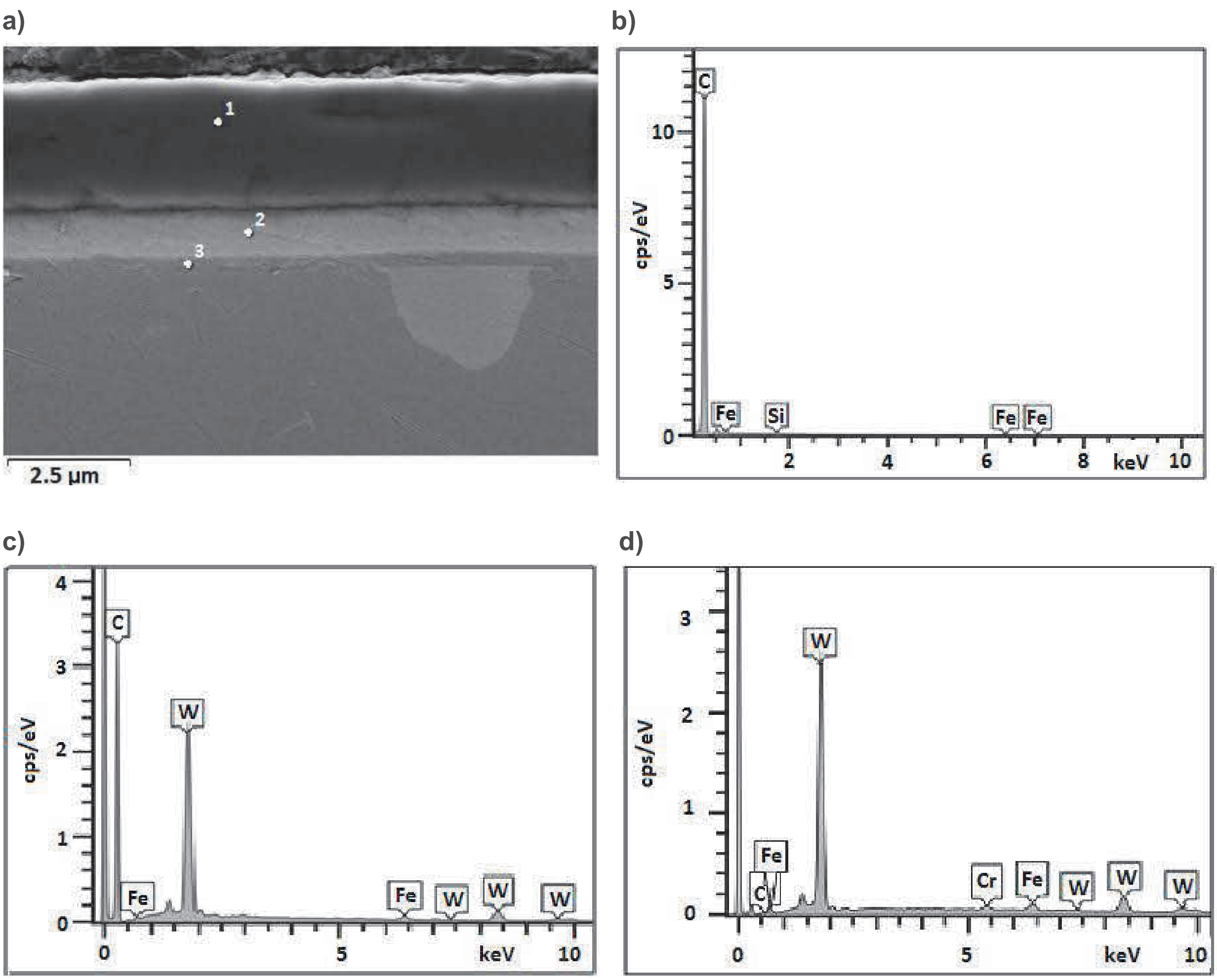


Figure 2 SEM image: a) cross-section of the a-C:H coating microstructure, b) analysis of the chemical composition at point 1, c) analysis of the chemical composition at point 2, d) analysis of the chemical composition at point 3

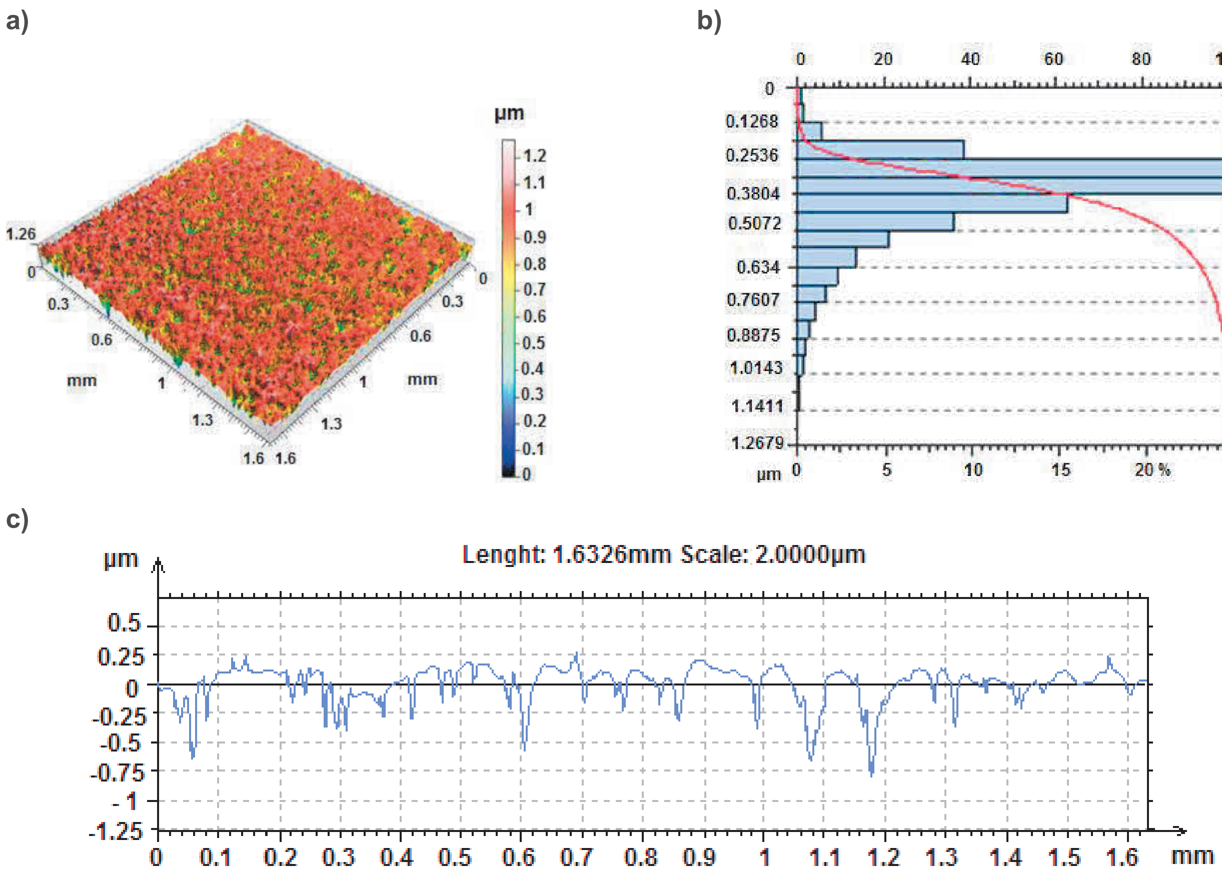
3.2. Surface geometric structure

Topographic study of the DLC-coated sample was supplemented with the measurements of the geometric structure of the surface. The non-contact profiler Talysurf CCI manufactured by Taylor Hobson was used. (**Figure 3**) shows the isometric image of the surface, the distribution of ordinates with the Abbott-Firestone curve, an example of a surface profile and a rose plot. (**Table 1**) compiles the key parameters of the surface geometric structure.

Table 1 Parameters of the a:C-H coating surface geometry structure

Surface geometry structure parameters	a:C-H coating
Sa (μm)	0.1034
Sq (μm)	0.1415
Ssk	-1.5525
Sku	6.6320
Sp (μm)	0.3826
Sv (μm)	0.8853
Sz (μm)	1.2679

The 3D image of the surface topography allows a more detailed identification of its geometric structure. Arithmetic mean of the absolute values of the surface departures from the mean plane, *Sa*, was 0.1034 μm. Additional information about the surface profile was derived from the amplitude parameters such as skewness, *Ssk*, and kurtosis, *Sku*. These parameters are sensitive to localized valleys or peaks resulting from inadequate preparation of the substrate.



d)

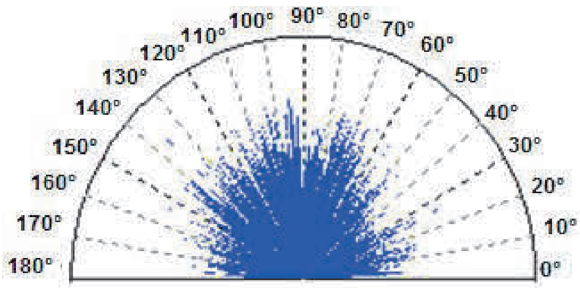


Figure 3 Surface geometric structure: a) topography, b) distribution of ordinates and the bearing area curve, c) surface profile, d) rose plot

Knowledge of the surface geometric structure is helpful in evaluating the quality of a given sample, as it is possible to observe the directionality of the surface structure [10] and analyse the results of tribological investigations. The surface being studied is smooth and uniformly directional, as confirmed by the rose plot.

3.3. Hardness

Different chemical compositions, design and topographies of surfaces are reflected in their different mechanical properties such as microhardness and adhesion. Mechanical properties were evaluated based on microhardness measurements conducted with a Matsuzawa tester. A Vickers indenter was subjected to a force of 98.07 mN. **(Table 2)** compiles averaged hardness values from five measurements of substrate material and a-C:H coatings.

Table 2 Hardness of substrate material and DLC coatings

Material	Hardness, $HV_{0.01}$	Standard deviation
substrate - steel 100 Cr6	770	18.3
a-C:H coating	1908	30

The results above show that the a-C:H diamond-like carbon coating is noticeably, nearly three times harder than the substrate material.

3.4. Tribological tests

Tribological properties of DLC coatings were tested on a T-01M ball-on-disk tribometer. The tester, used for evaluation of the materials operating under friction conditions, is optimised for determination of wear resistance and coefficient of friction in sliding wear tests for any material pairs, depending on sliding velocity and surface pressure. The system is composed of a stationary pin or ball held under applied loading force P against a disc rotating at a set velocity n. The ball 10 mm in diameter was made of 100 Cr6 steel. The discs were made of 100 Cr6 steel and 100 Cr6 steel with a diamond-like carbon coating. Tribological quantities were determined under dry friction at the following parameters:

- load P = 10 N, 50 N, 100 N,
- sliding velocity $v = 0.1\ m \cdot s^{-1}$,
- friction path D = 500 m,
- relative humidity 55 ± 5 %,
- temperature $T_0 = 22 \pm 1\ ^0C$,
- humidity: 55 Rh ± 1 %.

The tribological tests evaluated friction character and wear as a function of friction path at a constant load, temperature and humidity of the ambient on the basis of the recorded friction force/friction coefficient and wear quantities. The results are included in (**Figure 4**) (coefficient of friction) and in (**Figure 5**) (linear wear).

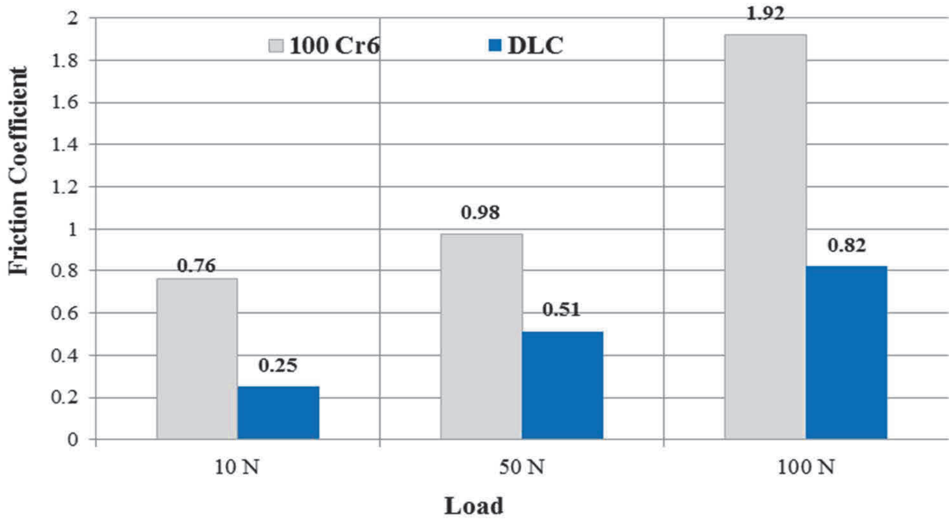


Figure 4 Coefficient of friction

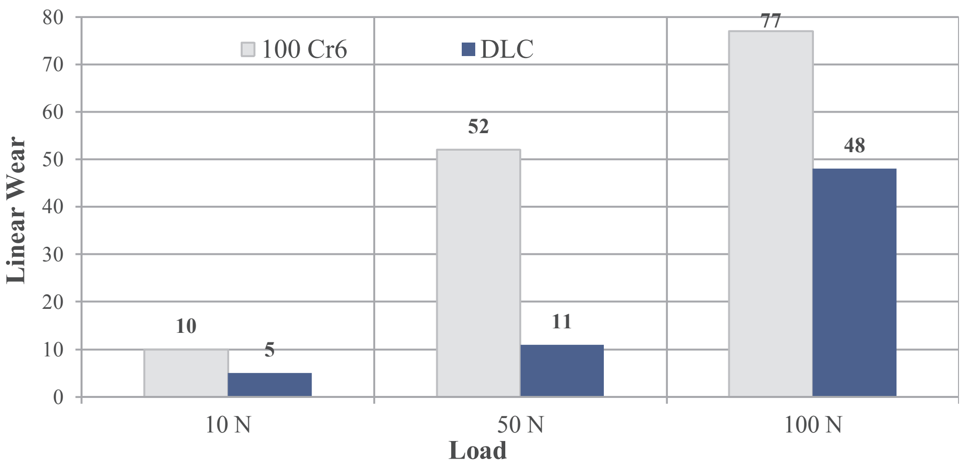


Figure 5 Changes in linear wear of the friction nodes under equal load

The results summarised in (**Figures 4, 5**) indicate that the lowest coefficients of friction and linear wear values were recorded for steel-DLC system under the load of 10 N. The coefficient and wear values increased with increasing load but in the case of all the systems with DLC films being studied, these values were substantially lower than in the case of the steel 100 Cr6 substrate.

4. CONCLUSION

DLC coatings are becoming increasingly popular due to their excellent mechanical properties such as strength and hardness. Their friction-reducing properties noticeably outclass the classical engineering materials, contributing to the energy reduction trend observed over the last several years.

From the SEM analyses it is clear that the DLC coatings deposited by the PVD method possessed a more homogeneous structure. Tribological testing indicates that owing to low coefficient of friction, linear wear and high hardness, DLC coatings can be used in a variety of high friction applications. Incorporating a dopant into the microstructure of the DLC provides a possibility of developing desired tribological characteristics, suitable for the given working environment. The DLC coatings showed better tribological properties and more stable operating conditions than the base material.

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