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ASSESSMENT OF THE PROPERTIES OF DIAMOND-LIKE CARBON COATINGS (DLC) USED IN THE LIME INDUSTRY

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The aim of the study was to analyze the properties of diamond-like carbon coatings - DLC in machines operating in the lime industry. DLC coatings were deposited by the Plasma-Enhanced Chemical Vapor Deposition PECVD method on 100Cr6 steel samples. Characterization of the geometric structure of samples was carried out on an optical profilometer. The friction junctions were tested in harsh conditions, i.e., corrosive environment and high temperature. The tribological tests were performed using a sliding ball-on-disc tribological tester. The static contact angle for selected lubricants was measured using an optical tensiometer. The summary presents the possibilities of using diamond-like coatings in selected friction junctions in the lime industry.

Key words: 100Cr6 steel, coatings a-C:H:Si, mechanical properties, friction, tribology

INTRODUCTION

In the lime industry, hardware is subject to tribological and non-tribological wear [1, 2]. Lime plant equipment includes kilns, crushers, mills, screens, belt conveyors, etc. [2].

Since virtually all the equipment and mechanical assemblies have bearing systems, it is crucial to increase the durability of their surface layer, thereby enhancing their reliability. Counteracting the adverse effects of friction, corrosion and thermal energy around friction junctions has become an important task [3,4]. Improved reliability of classical engineering materials and the required durability of friction pairs rely on the application of the most appropriate materials, considering the type of external loads transferred or the impact of the environment [5 -8].

Diamond-like carbon (DLC) coatings of a-C:H type and doped with selected elements have been found to be a suitable material for this purpose [9, 10]. Their superior properties and functional characteristics match well with the requirements for a surface modification material across industries [2, 10]. Some of the typical properties of DLC coatings include low coefficient of friction, high hardness, chemical durability, and high wear resistance. DLC coatings are obtained by physical vapor deposition (PVD) and chemical vapor deposition (CVD). These processes are often assisted by plasma enhanced chemical vapor deposition (PECVD), which allows coatings to be produced at lower temperatures [11, 12]. Thin films can be deposited on both conductive and non-conductive materials [10-12].

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Figure 1 Friction junction – a bearing inside the housing

Figure 1 shows a tribosystem (a bearing inside the housing) operating in a belt conveyor system.

MATERIALS AND METHODS

The specimens used in the study were 100Cr6 steel discs with a diameter of 38 mm and a height of 6 mm, coated with a-C:H and a-C:H:Si coatings. The composition of the 100Cr6 steel is shown in Table 1.

DLC coatings were deposited by the PECVD method.

UNI 3 was used as a lubricant. It is a multipurpose grease made from highly refined mineral oil and lithium soap-thickened 12 -hydroxystearic acid. Selected properties of the lubricant are shown in Table 2.

Mechanical properties of the deposited DLC coatings were determined using the instrumental indentation method. The tests were performed with the use of an Anton Paar nano-hardness tester and a Berkovich indenter. A loading force of 20 mN and a pause of 5 s were applied.

Table 1 **Chemical composition of 100Cr6 steel / wt. %**

Element	Value
C	0,95 -1,10
Mn	0,20 - 0,50
Si	max -0,35
P	max -0,025
S	1,30 -1,60
Cr	1,30 -1,60

Table 2 **Selected properties of UNI 3**

Property	Unit	Value
Hue	-	amber
Dropping point	°C	>190
Viscosity of base oil at 40°C	mm^2/s	100
Operating temperature range	°C	-30 ÷ +130

Tribological tests were carried out on an Anton Paar TRB3 tribometer in rotary motion under dry friction and lubricated friction with UNI 3 at a temperature of 23 °C and a humidity of 50 %. A ball made of 100Cr6 steel 6 mm in diameter was the counter specimen. The friction junction was loaded with a force of 10 N. After the tribological tests, the geometric structure of the frictionally interacting surfaces was examined.

RESULTS AND DISCUSSION

Figure 2 shows the results of the mechanical properties tests: instrumental hardness - H_{IT}, Young's modulus - E_{IT}, maximum depth of the indenter penetration - h_m, plastic work - $W_{plastic}$ and elastic work - $W_{elastic}$. Averaged values of the results of five measurements were summarized and compared.

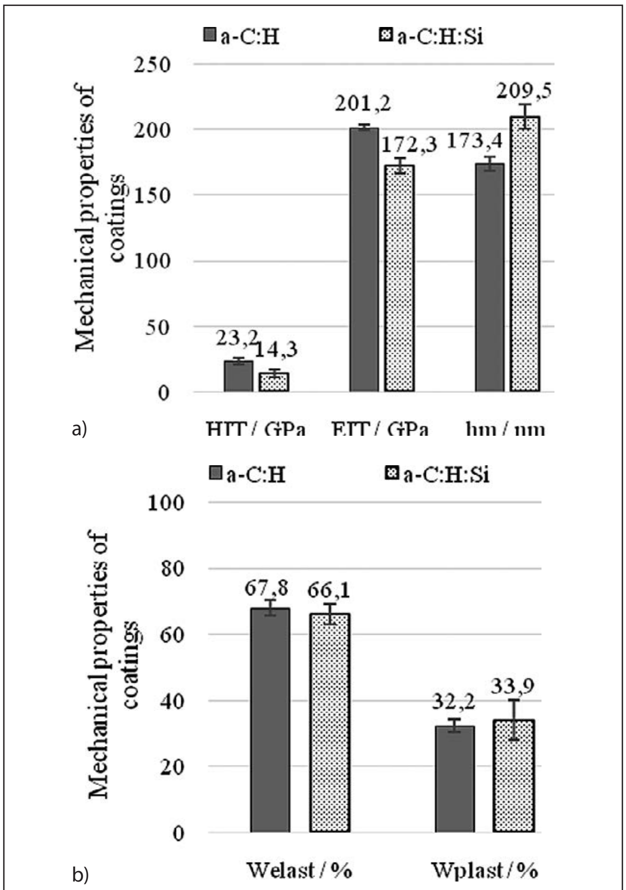

Figure 2 Mechanical properties of coatings

The results of the mechanical tests indicate that the a-C:H coating had higher hardness and Young's modulus compared to the a-C:H:Si coating. The values of these parameters for a-C:H were 40 and 15 % higher than those for a-C:H:Si, respectively. In addition, both materials tested had similar values of plastic and elastic work.

Figures 3, 4 compile the average values of friction coefficients - μ and linear wear of the tested friction pairs calculated from three measurement series.

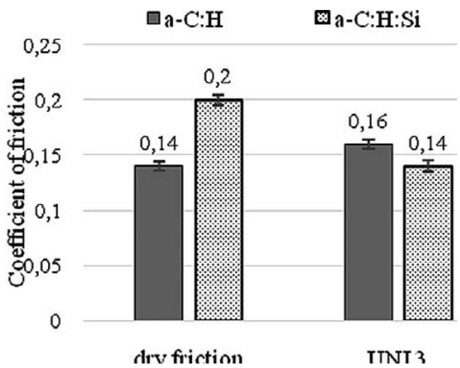

Figure 3 Average friction coefficient obtained under dry friction (TDF) and with the use of UNI 3 as a lubricant

The results of tribological tests indicate that the lowest coefficient of friction (μ) during lubrication with UNI 3 grease was recorded for the friction pair: a-C:H:Si coating - 100Cr6 steel (0,14). In contrast, under dry friction, better parameters were obtained for a-C:H coating (0,14). The application of UNI 3 lubricant improved the tribological properties of the a-C:H:Si coating, while contributing to their deterioration in the case of a-C:H.

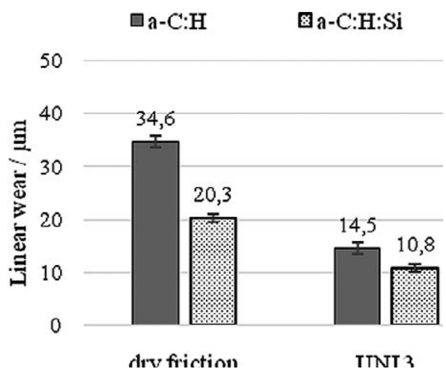

Figure 4 Linear wear of the tested friction pairs

The test results shown in Figure 4 indicate that in both cases under analysis, the application of UNI 3 resulted in a reduction in the linear wear values of the materials studied. The reduction was nearly 60 % in the case of a-C:H and nearly 50 % in the case of a-C:H:Si in relation to dry friction conditions. In order to perform

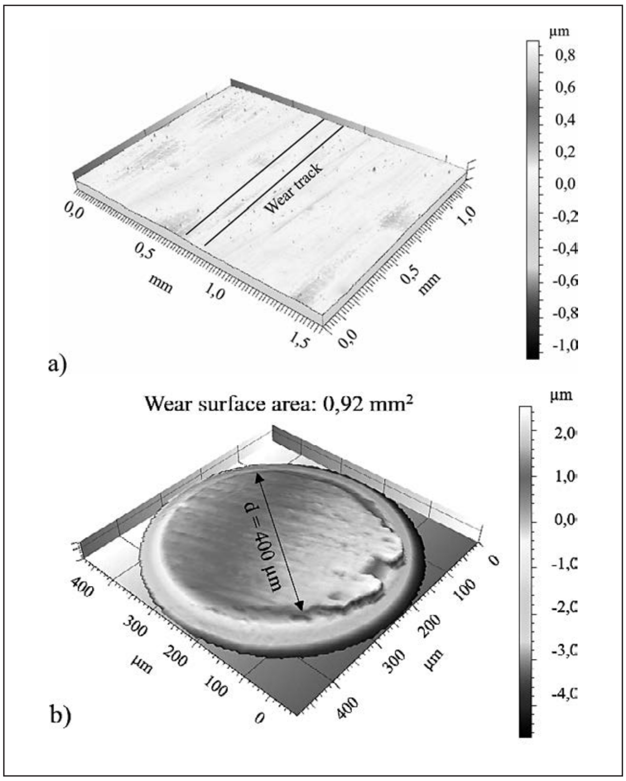

Figure 5 The a-C:H coating - axonometric images of wear tracks a) specimen, b) ball – dry friction

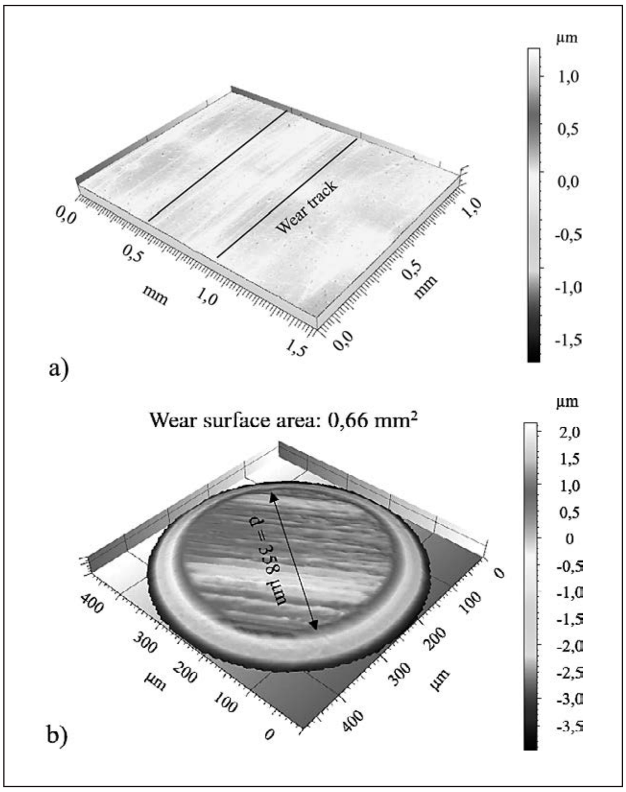

Figure 6 The a-C:H coating - axonometric images of wear tracks a) specimen, b) ball–UNI 3 lubricated friction

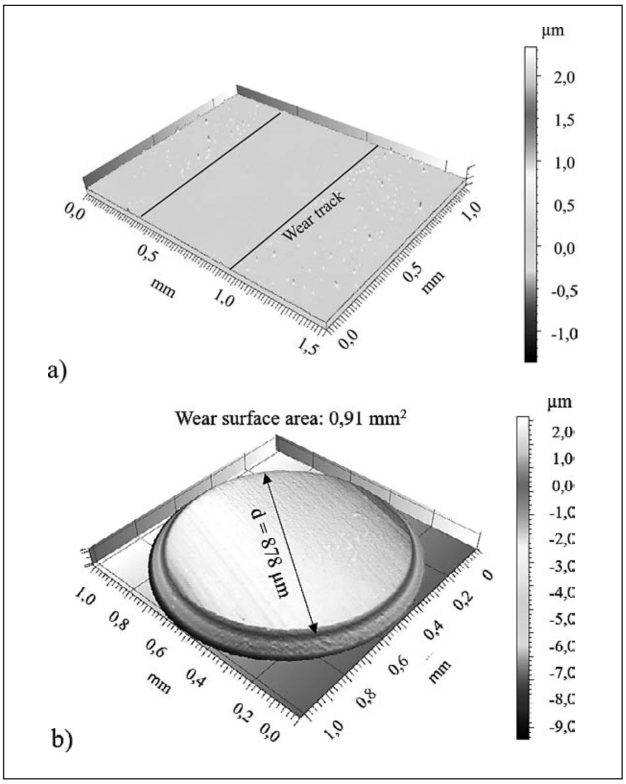

Figure 7 The a-C:H:Si coating - axonometric images of wear tracks a) specimen, b) ball– dry friction

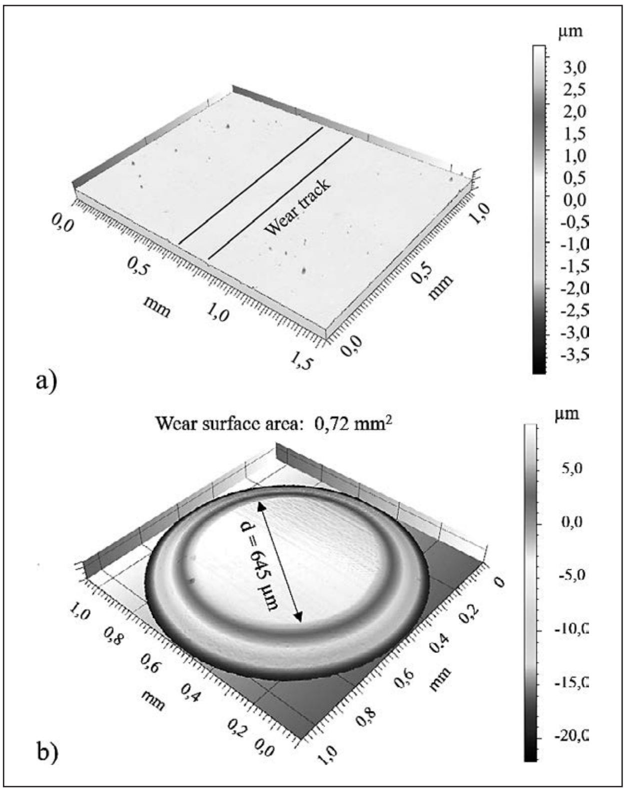

Figure 8 The a-C:H:Si coating - axonometric images of wear tracks a) specimen, b) ball–UNI 3 lubricated friction

a detailed wear analysis, the wear tracks were subjected to microscopic observations.

After tribological tests, the wear tracks of the specimens and counter specimens were measured using confocal microscopy. Figures 5 - 8 show examples of 3D axonometric images of wear along with the marked width of the wear track. Figures 9 - 10 summarize the most important wear indicators: cross-section profiles of the maximum depth and wear surface area determined based on five measurement series.

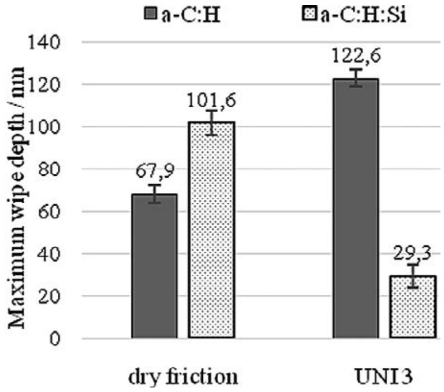

Figure 9 Cross section profile of the maximum wear track depth

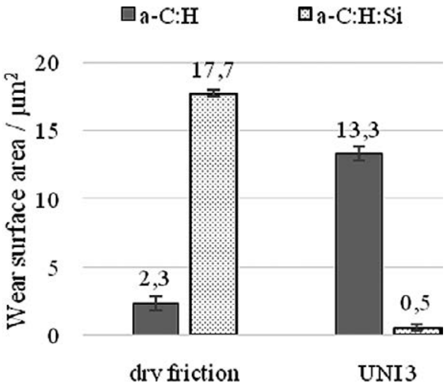

Figure 10 Cross section profile of the wear area

Analysis of the results of the geometric structure of the surface after tribological tests confirmed that the use of UNI 3 lubricant significantly improves the wear resistance of the a-C:H:Si coating. The wear area of the coating after tests with UNI 3 was more than 30-fold smaller compared to the wear area measured after dry friction. In the case of the a-C:H coating, the microscopic results are different from the linear wear results shown in Figure 3. The differences are due to the fact that the wear was predominantly observed on the counter specimens - 100Cr6 steel balls. Microscopic analysis showed that the UNI 3 lubricant caused 80 % higher wear of the a-C:H coating compared to that under dry friction. The UNI 3 grease also intensified the lubricating effect and reduced the ball wear.

CONCLUSIONS

The a-C:H coating had a higher hardness compared to the (a-C:H:Si) coating.

Greater efficiency in the use of UNI 3 grease as a lubricant was observed in the samples with a-C:H:Si coating.

At the same time, compared to a-C:H, the a-C:H:Si coating had a higher resistance to friction wear under UNI 3 lubrication, but a lower resistance under dry friction.

DLC coatings significantly improve the tribological properties of friction junctions.

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Note: Translated by Nina Kacperczyk, Kielce, Poland.