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THE INTERACTION BETWEEN DIAMOND LIKE CARBON (DLC) COATINGS AND IONIC LIQUIDS UNDER BOUNDARY LUBRICATION CONDITIONS

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The aim of the study was to analyse antiwear DLC coatings produced by physical vapour deposition. The a-C:H coatings were deposited on steel elements designed to operate under friction conditions. The coating structure was studied by observing the surface topography with a scanning electron microscope (SEM) and a profilometer. The friction and wear properties of the coatings were examined using a ball-on-disc tribotester. The lubricants tested were two types of ionic liquids (1-butyl-3-methylimidazolium tetrafluoroborate and trihexyltetradecylphosphonium bis(trifluoromethy-lsulphonyl) amide). The experimental data was used to select ionic liquids with the best tribological properties to operate under lubricated friction conditions and interact with DLC coatings.

Keywords: DLC coatings, ionic liquids, SEM, friction, tribotester

INTRODUCTION

Most components in machines and mechanical systems operate under very high time-varying loads. Examples of friction pairs operating under such conditions include bearings, gears and cam-and-follower mechanisms [1, 2]. It is thus crucial that researchers strive to improve their durability, reliability and energy-efficiency. Elements of kinematic pairs subjected to loads are usually made of alloy steel. Today, friction pairs use surfaces coated with thin tribological films and new-generation lubricants containing special-purpose additives, e.g. extreme pressure (EP) or antiwear (AW) additives, designed to reduce shear stresses [1, 3]. The latest trends in the world market for tribological coatings have been to use high-end complex-structure materials, to reduce the thickness of coatings and to apply multi-layer coatings [4]. Before a decision is made on what coating to select, it is vital to analyse the conditions under which it will operate. The selection process concerning antiwear coatings to be deposited on mechanical elements needs to be preceded by extensive studies including a complex analysis of operating conditions [5]. Nowadays, there is a growing interest in thin diamond-like carbon (DLC) coatings produced by physical or chemical vapour deposition (PVD and CVD, respectively) with a thickness remaining within dimensional tolerance [6]. Another important area of research related to friction pairs is new-generation lubricants, particularly ionic liquids, with partial results being available for steel surfaces.

Nearly 50 years have passed since DLC coatings were first produced by Aisenberg and Chabot [7]. Since 1971 this technology has been evolving and now carbon-based materials constitute a large group of constantly improved materials with a wide range of properties and applications. Today, thin diamond-like carbon coatings are of interest to both researchers and industrial practitioners mainly because of their good mechanical properties such as high hardness and modulus of elasticity as well as excellent tribological properties, including a low friction coefficient and high resistance to wear. They also exhibit good fracture toughness, a low coefficient of thermal expansion, high thermal conductivity and chemical stability [2-5]. One of the major drawbacks of DLC coatings is their poor adhesion to the substrate, which is due to the occurrence of high residual stresses. As shown in this paper, the problem can be solved by applying thin metal interlayers – chromium and tungsten – prior to the deposition of a DLC coating. The coating properties are dependent on several factors, especially the technology used, the parameters of the deposition process, the sp^3/sp^2 bond ratio, the content of hydrogen, and the amounts of elements added. For example, amorphous carbon coatings containing boron carbide are suitable for surfaces in rubbing contact in gears; they are used to improve the tribological properties of elements by increasing their resistance to wear [2-4, 6, 7].

Nowadays some of the a-C:H type coatings containing tungsten and carbon are common in the automotive industry; they are used on vehicle subassemblies [4]. The addition of chromium causes an increase in their stability when exposed to corrosive environments and elevated temperatures [5].

Another important factor affecting the performance of a friction pair, apart from the material used for the elements in contact, is lubrication [1]. The lubrication industry is constantly looking for ways to improve the

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durability and reliability of machine parts. In recent years, there has been a growing interest in ionic liquids used as lubricants. The first research paper discussing this issue appeared in 2001; since then ionic liquids have been studied extensively [8].

Ionic liquids, *Ils*, are organic substances with a melting temperature lower than the boiling temperature of water. They are generally made up of a large asymmetric cation and a weakly coordinating anion, which can be both organic and non-organic in nature [9-12]. The most common cations and anions present in ionic liquids are discussed in [9]. An advantage of ionic liquids is their ability to form a lubricating film on metal surfaces as well as high polarity and reactivity under large loads. Such mechanisms may suggest that ionic liquids provide high antiwear resistance [12]. From the tribochemical reactions that occur at surfaces lubricated with ionic liquids it is clear that fluorine compounds exhibit good tribological properties [13, 14]. The major properties of ionic liquids are:

- appropriate viscosity,
- good wettability,
- good adherence to metal or ceramic surfaces,
- a wide range of temperatures over which they remain in the liquid state,
- high thermal resistance,
- non-volatility and non-combustibility,
- good thermal conductivity,
- reusability and recyclability [9, 15].

MATERIALS

The study was conducted for specimens made of 100Cr6 steel with and without diamond-like carbon (DLC) coatings produced by physical vapour deposition (PVD) at a temperature of 300 °C. The chemical composition of 100Cr6 steel is given in Table 1. The properties of the ionic liquids are described in [9].

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

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

RESULTS AND DISCUSSION

The specimens coated with DLC were analysed using scanning electron microscopy (SEM). Figure 1 shows an SEM view of an a-C:H type DLC coating and the corresponding Energy Dispersive Spectroscopy (EDS) spectrum. The cross-sectional analysis of the DLC coatings was performed by means of scanning electron microscopy. Figure 2 presents SEM elemental maps for an a-C:H type coating with Cr and W interlayers over a steel substrate Figure 3 shows an SEM cross-sectional view of a DLC coating and the corresponding EDS line scan results.

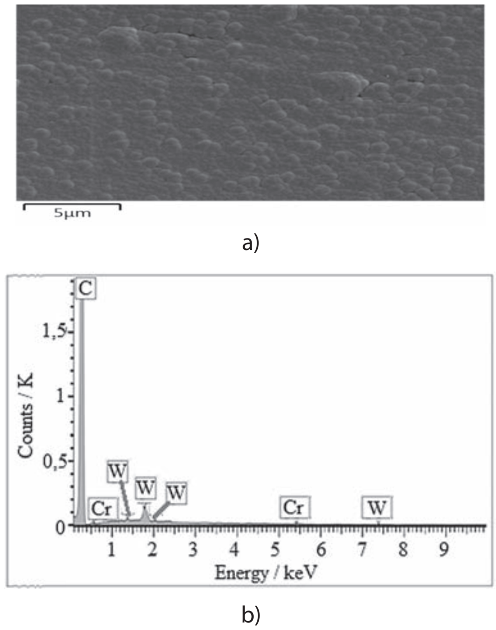

Figure 1 SEM analysis of an a-C:H type DLC coating a) image of the surface; b) EDS spectrum.

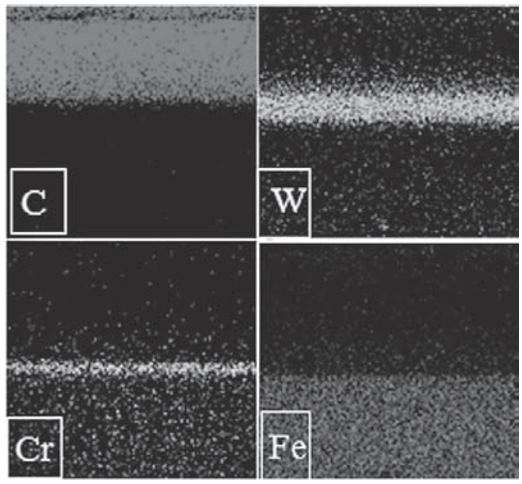

Figure 2 Elemental maps for an a-C:H type coating

The surface texture of the a-C:H type coatings was analysed with an optical profilometer. An isometric view of the coating surface can be seen in Figure 4.

The tribological properties of the 100Cr6 steel specimens with a-C:H type coatings were studied using a T-01M tester (ball-on-disc configuration). The tests were conducted under dry friction and lubricated friction conditions with ionic liquids (IL1 and IL2) as lubricants.

The experiments were carried out for a friction pair consisting of a 100Cr6 steel ball and a 100Cr6 steel disc with and without an a-C:H type diamond-like carbon coating at a load of 50 N, an ambient temperature of 21+/- 1°C and a relative moisture of 50 +/- 5%, with the sliding rate and the sliding distance being 0.1 m/s and 1000 m, respectively.

The diagram in Figure 5 shows that the lowest value of the friction coefficient was observed for the specimens with a-C:H type diamond-like carbon coatings

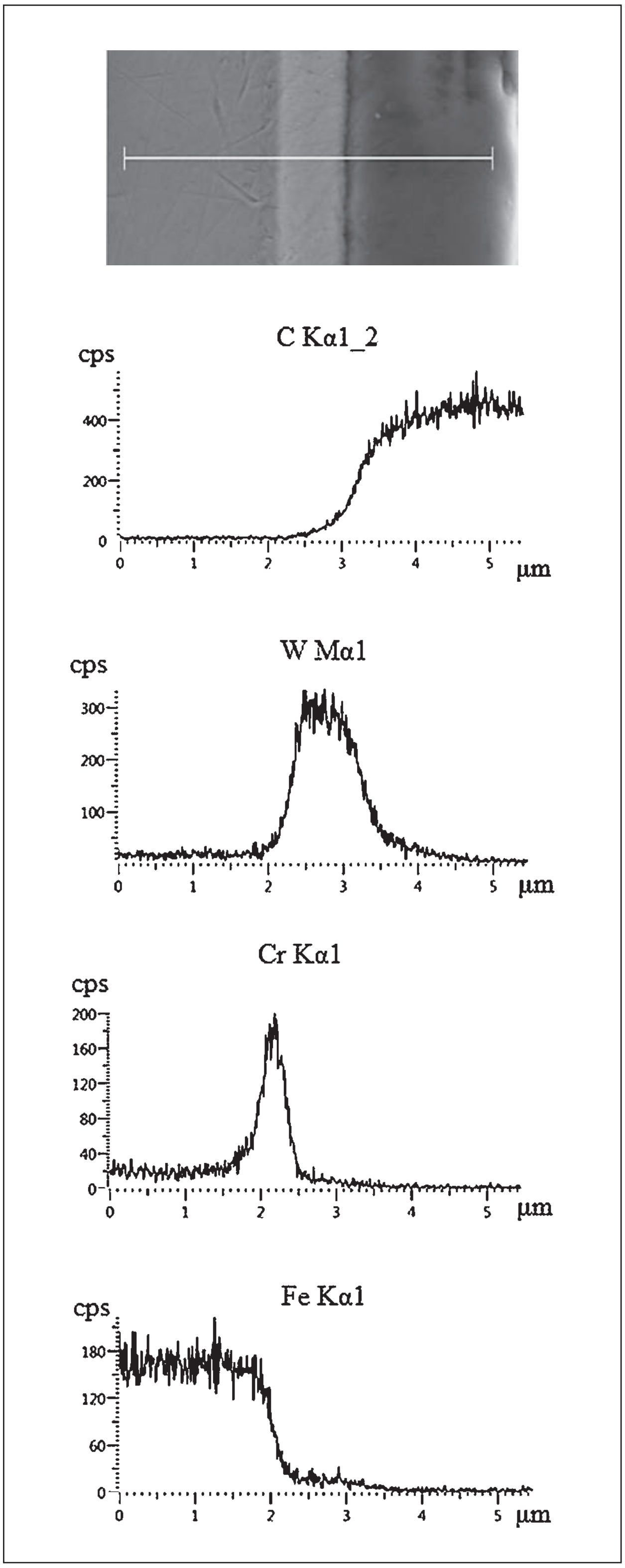

Figure 3 Cross-sectional view of a DLC coating and the corresponding EDS line scan results.

and the ionic liquid IL1 acting as the lubricant. The highest value of the friction coefficient was reported for the 100Cr6 steel specimens without coatings tested under dry friction conditions. It should be noted that under dry friction conditions the friction coefficient was much lower for the specimens with a-C:H type coatings than for the specimens without coatings, which was attributable to the excellent tribological properties of diamond-like carbon coatings.

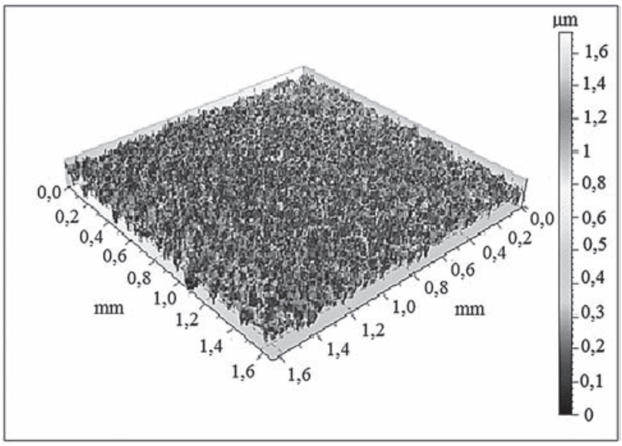

Figure 4 Surface topography of a DLC coating

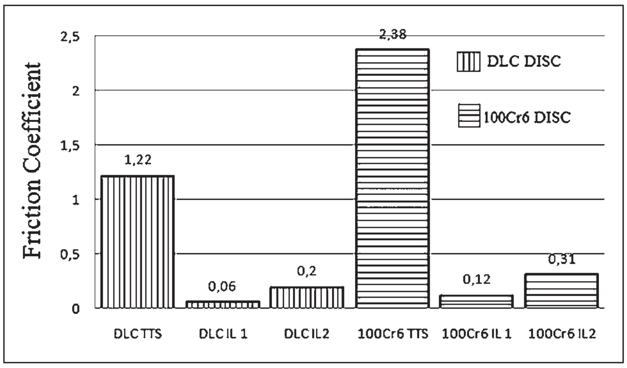

Figure 5 Friction coefficient for friction pairs with 100Cr6 steel elements coated with a-C:H DLC.

CONCLUSIONS

- The experimental results indicate that in the presence of ionic liquids the values of the friction coefficient were lower for the specimens made of 100Cr6 steel coated with DLC than for the uncoated specimens.
- As shown by tests performed with a T-01M analyser, ionic liquids contribute to a significant reduction in the friction coefficient, because of their excellent properties and good interaction with a-C:H-type DLC coatings.
- The use of environmentally-benign ionic liquids and low-friction anti-wear diamond-like carbon coatings in friction pairs provides an environmentally-friendly alternative to conventional lubricants, which are toxic.

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Note: Translated by Małgorzata Laczek, Kielce, Poland