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Properties of amorphous carbon layers for bio-tribological applications

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ABSTRACT

This paper analyses the influence of composition, structure and adhesion of amorphous coatings with high wear resistance, low friction coefficient and good adhesion to coated CrCoMo material for parts of implants. By different deposition techniques, different mechanical and tribological properties were obtained. This work reviews amorphous carbon (a-C) films deposited by magnetron sputtering and diamond-like carbon (DLC) films grown by glow arc discharge technology on CrCoMo substrates. Films were investigated under static load under dry conditions (nanohardness, elastic module), and also with dynamic load (coefficient of friction, wear resistance). The following topics were investigated: surfaces and subsurface properties of a-C films, namely adhesion in connection with different techniques, different film properties in dependence on various technology conditions.

1. Introduction

Diamond-like carbon (DLC) coatings cover a wide range of different types of carbon-based coatings, which generally have properties such as low friction and high wear resistance. The low friction coefficient and good wear resistance of DLC coatings make them suitable for many tribological applications such as wear-resistant coatings, e.g. cutting tools, magnetic storage systems [1]. Also many applications of amorphous carbon (a-C) films are permanent actual for bio-tribological applications. In order to use DLC coatings reliably in different applications, it is important to understand the coating tribological behaviour at different operating conditions. This has been studied intensively by many scientists during the last few years. The friction and wear performance of a-C coatings greatly depend on the deposition method and the deposition parameters used as well as the test environment [2,3]. As a general trend, a-C:H films can provide low friction performance in sliding conditions [4–6]. In particular, in a vacuum or in inert atmosphere (e.g. in dry nitrogen) the friction coefficient can be very low, namely in the range of 0.04–0.006 [7–9]. This contribution deals with the study of DLC films with different contents of Ar and N_2 to grow as nanocomposite materials like β-C_3N_4 or nanocrystalline diamond particle in amorphous graphitic matrix.

2. Experimental setup

The films were deposited by low arc discharge UVNIPA-1-001 vacuum system with three sources (gas ion source for cleaning, electric arc source for non-magnetic metal sputtering and pulse arc carbon source for DLC deposition). The pulse sputtering of graphite target is a possible setup in wide range. Entered samples were sputtered in one vacuum cycle. All substrates were cleaned for 10 min with Ar ions. DLC layer was deposited at temperature down to 150 °C. Nitrogen and Ar gasses were added during the DLC deposition into working chamber, which is described in Table 1. The substrates were planetary rotating through all the deposition steps to achieve homogeneity.

The coatings were produced on a highly polished flat CrCoMo substrate material with $R_a = 0.05\,\mu m$. One fine polished face of each CrCoMo substrate was coated with DLC film. The hardness and other mechanical characteristics were determined from depth sensing indentation (DSI) curves measured with Nano TEST NT 600. Raman measurements were conducted in DILOR-JOBIN YVON-SPEX Raman spectrometer, type LabRam. The excitation source was a He–Ne laser with 632.8 nm wavelength operated at 15 mW. The spectrometer was calibrated to 520.7 cm^{-1} band of single crystalline Si and 1332 cm^{-1} band of natural diamond. Scanning electron microscope (SEM) LEO 1550 operating in the secondary electron mode was used to study the microtopography of DLC layers.

3. Results and discussion

The adhesion behavior of carbon coatings has been characterized by scratch tests. Scratch experiments with diamond Rockwell

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Table 1
Deposition parameters of DLC layers deposited by UVNIPA-1-001

No.	Ar (sccm)	N_2 (sccm)	Dep. technique
U II	70	60	Arc discharge
U III	80	60	Arc discharge
U IIII	80	50	Arc discharge

Table 2
Results from nanoscratch tests

No.	L_{c1} (nM)	L_{c2} (nM)	L_{c3} (nM)
U II	46.0	53.5	57.5
U III	40.5	79.0	120.0
U IIII	42.0	62.5	115.0

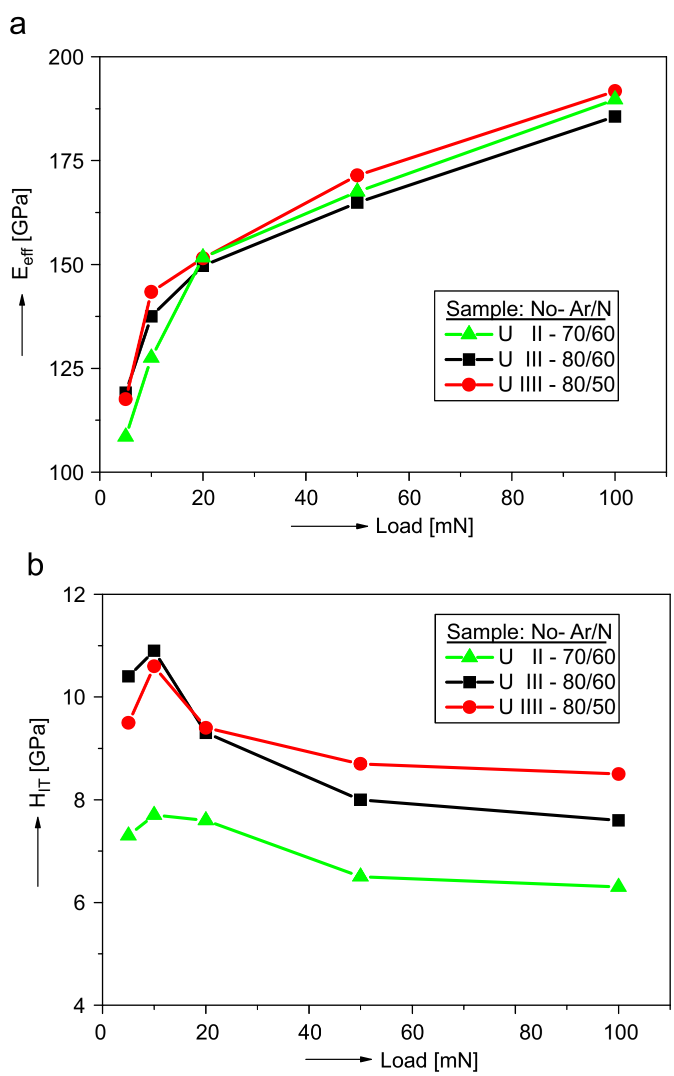

Fig. 1. (a) Resulted E_{eff} for tested coatings under different loads and (b) resulted H_{IT} for tested coatings under different loads.

sphere–conical tip of $\varnothing = 25\,\mu m$ with scratch length of 1 mm; load in the range from 0 to 150 mN; scan speed of 0.75 mN/s were conducted. The results from nanoscratch tests are in Table 2. Loading in location where the first failure of coating occurred (cracks) is marked as L_{C1}, the first adhesive failure of coating (flaking) is marked as L_{C2}, the first adhesive coating failure in greater measure is marked as L_{C3}. During scratch test the sample feed speed dx/dt was recorded at loads with continuously increasing force. The acoustic emission signal is also recorded with a camera.

The hardness H, elastic modulus E_{eff} and mechanical characteristics were determined from depth sensitive indentations (DSI curves measured by the NanoTest NT 600 apparatus at different maximal loads from 5, 10, 20, 50, and 100 mN with diamond Berkovich tip using the analysis developed by the Oliver–Pharr procedure [8]. Each indentation cycle (uploading to the maximal load and downloading to 0) was repeated five times in slightly different places for each maximal load.

The load dependence of E_{eff} and H_{IT} ($1/E_{eff} = [(1-\nu^2)/E] + [(1-\nu_i^2)/E_i]$, where index i means material of the indenter; for diamond $\nu_i = 0.07$ and $E_i = 1141$ GPa) is shown in Fig. 1a and b. Values of E_{eff} for all types of DLC coatings are almost constant (Fig. 1a). Values of H_{IT} for coatings of type U III and U IIII deposited under conditions given in Table 1 are comparable, the lowest value was observed for coating U II, what can be connected with lower content of N. Values of H_{IT}^3/E_{eff}^2 (Fig. 2a) and also of H_{IT}/E_{eff} (Fig. 2b) for type of films marked U III and U IIII are almost similar. The lowest value for H_{IT}^3/E_{eff}^2 and of H_{IT}/E_{eff} was observed for coating marked U II.

Friction tests were performed on the same samples as for indentations by applying a microtribometre dry sliding point

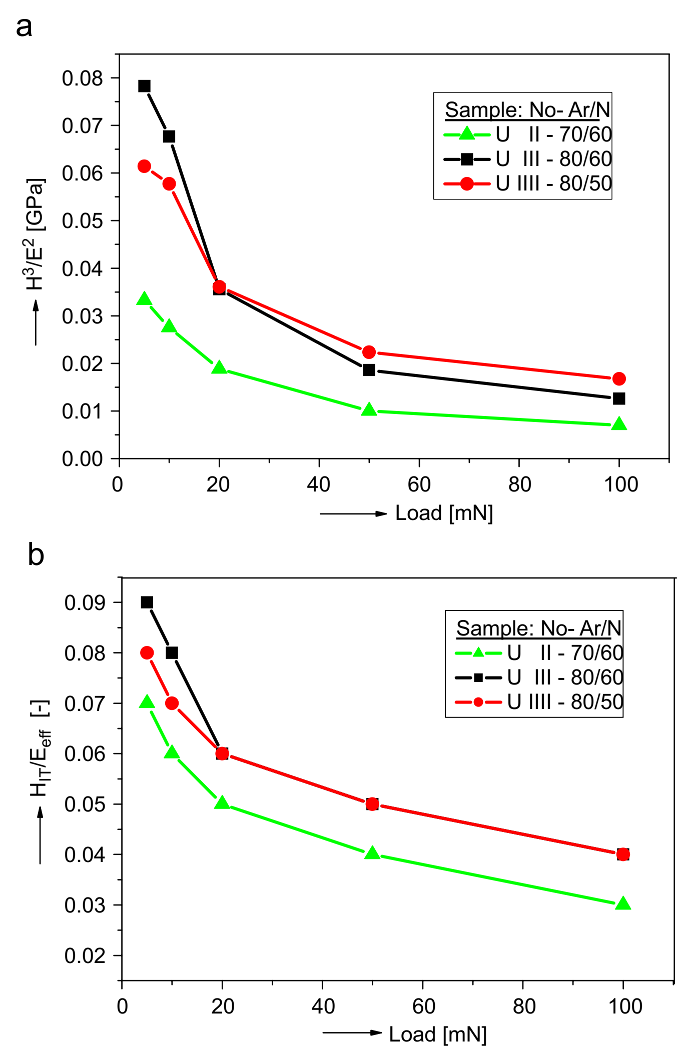

Fig. 2. (a) Dependence of H_{IT}^3/E_{eff}^2 on different loads and (b) dependence of H_{IT}/E_{eff} on different loads.