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TRIBOLOGICAL PROPERTIES OF SPUTTER DEPOSITED CARBON-COPPER COMPOSITE FILMS

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Abstract: Carbon-copper composite coatings were deposited using high power magnetron sputtering technique. Tribological tests were performed using ball-on-disk type tribometer. Friction coefficient and wear rate were determined at 40 N load. It was found that an increase in the percentage composition of carbon in C-Cu coating, reduces the coefficient of friction value. But at higher concentrations of C coating it becomes more brittle, that reduces wear resistance.

Keywords: nanocoatings, magnetron sputtering, carbon-copper composite

1. INTRODUCTION

Many enterprises that specialize in mechanical engineering are confronted with short life span of equipment and instruments that leads to high maintenance costs and low productivity. Friction causes the wear of machinery, accelerates decay of moving parts and decreases performance of instruments. Thus, decreasing of coefficient of friction (CoF) is necessary for low-cost, durable and energy-efficient machinery.

Physical vapour deposition magnetron sputtering technique [1], which does not affect the properties of the base material and biochemical functionality, is used for depositing tribological coatings for friction reduction and wear resistance. Such coatings have good adhesion and serve as a protective layer. Carbon-copper (a-C/Cu) coatings are in particular interest [2-4]. Such coatings have composite structure in which copper and graphite do not constitute carbide directly - copper nanoparticles are built in graphite matrix. a-C/Cu coatings are characterized with high mechanical and tribological quality index [5], therefore, the present article researches these nanocoatings, aiming at obtaining the coefficient of surfaces with a low friction and, in compliance with it, the wear resistance.

2. EXPERIMENTAL

2.1. Preparing substrates for deposition experiment

The substrate material is 31 mm dia. x 5mm carbon steel C45 (DIN, EN) plates were used as substrates. Prior to deposition procedure, an ultrasonic cleaning of all samples using "Lotonaxe" degreasing bath was performed; then the water-alcohol mixture cleaning and drying with hot air was made.

Deposition equipment scheme is shown on Fig.1. Base pressure of vacuum chamber is $1*10^{-3}$ Pa. Substrates were fixed on two-fold rotating table and its' surface was activated in argon atmosphere using ion-beam gun at 500 V bias potential and heated to a temperature of 350 ± 20 °C.

a-C/Cu nanocomposite films were deposited by high power DC magnetron sputtering process using high-performance industrial unit VU-SMA 600/4 [6]. Substrate-target distance of 100 mm and argon pressure 0.4 Pa were used during deposition. Cu/C mosaic type target with a 14 - 44 % carbon content supplied 7 - 20 at. % of carbon in the coatings. –100 V bias voltage was provided for deposition experiment. Power density on Cu/C 70 mm dia. targets (see Fig. 2.) reached 50 W/cm2, which ensured a deposition rate up to 0.10 µm/min.

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In all the experiments, the coating is made of several layers: the first one is a 300 nm titanium layer, which provides coating adhesion, and the others are C/Cu nanolayers. After deposition three different C/Cu coatings, which differ mainly in the carbon content at 7 %, 14 %, 20 %, marked accordingly samples $C_{7\,\%}$ $C_{14\,\%}$ $C_{20\,\%}$ and substrate marked S. The coating thickness after sputtering is $C_{7\,\%}$ - 5.3±0.2 µm, $C_{14\,\%}$ - 6.4±0.2µm, $C_{20\,\%}$ - 5.2±0.2µm. Coating thickness was determined by Calo test method. Other information about sputtering technological specifics is limited.

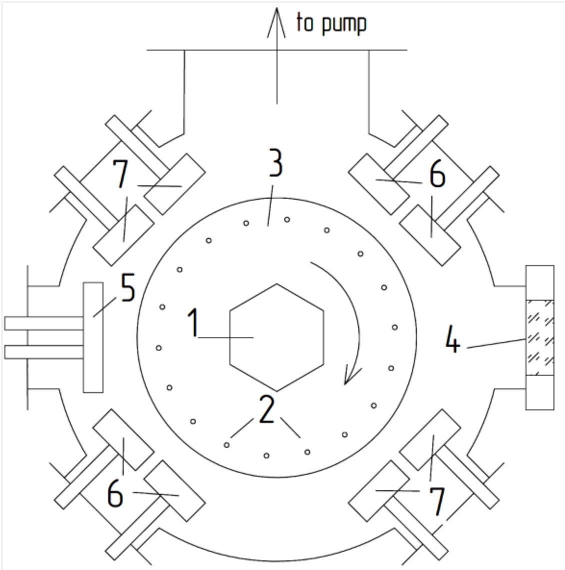

Figure 1. Scheme of vacuum sputtering system, 1 - heater, 2 - substrate holders, 3 - rotating table, 4 - view port, 5 - ion-beam gun, 6 - magnetrons with Ti targets, 7 - magnetrons with mosaic Cu-C targets (or Cu targets).

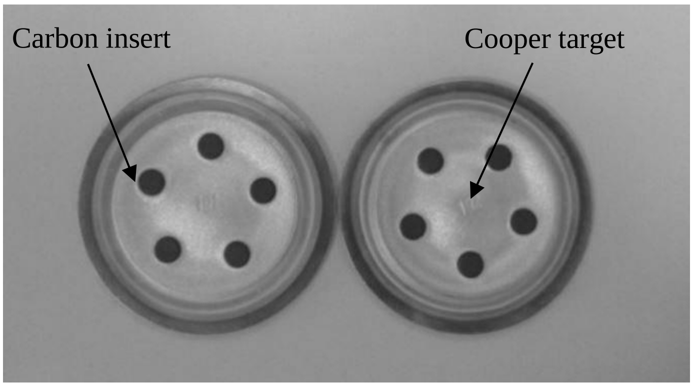

Figure 2. Combined copper-carbon targets with five carbon inserts.

2.2. Coefficient of friction measurement

To obtain information about tribological properties of the samples studied in the article, CoF measurements of all three investigated samples were taken. The present slip friction experiments were carried out using the ball-on-disc tribometer, following scheme (see Fig. 3), where the disk is represented with the sample substrate with the coating, which is rotating, but the ball is a stationary tribometer element. This method complies with ASTM G99 [7] tribology test standard. The CoF μ was measured in ambient air, dry friction with a 100Cr6 ball (Ø=6 mm) under a 40 N load at velocity v=0.1 m/s for a sliding distance up to 180 m (1000cycles). The wear tests were carried out under the same conditions as CoF tests.

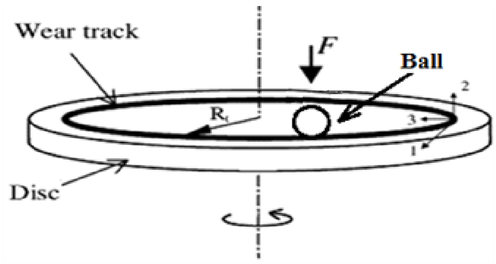

Figure 3. "Ball-on-disc" principal test scheme.

2.2. Wear rate determination

To gain information about the studied sample wear resistance, wear resistance experiments were carried out, which resulted in getting wear tracks – tribological tracks. In order to evaluate the wear resistance of the samples, it is necessary to know tribological track cross-sectional areas. The parameter which is of interest may be obtained using contact type Surtronic 25 profilometer. The measurements are carried out following the provided algorithm: 1) the researched sample is placed on the profilometer table; 2) three independent cross-sectional areas measurements with the following profilometer settings are performed. Measurement track length l_t – 1mm and resolution range (for Surtronic 25 profilometer) – 10 µm. The following figure 4 shows measurement positioning on the sample:

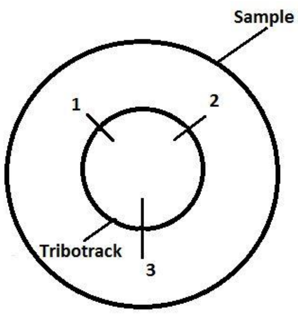

Figure 4. Tribological track cross-section area (A) measurement positioning on the sample.

1) perform profile chart post-treatment following the provided algorithm:
   - make profile chart leveling using the tool *Leveling*;
   - bring closer the profile chart part, which is of interest, using *Zoom* function;
   - calculate tribological track cross-sectional area via *Surface of a Hole/Peak* function.
2) calculate the average tribological track cross-sectional area value. This value is used for further calculations.

Wear rate (W_r, $mm^3/N{\cdot}m$) were calculated from tribotrack cross-sectional area (A, μm^2) measurement, see Fig.5.

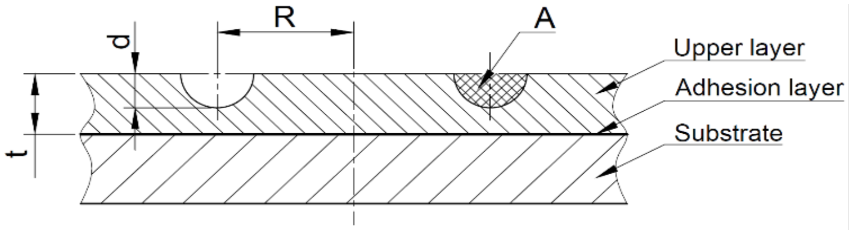

Figure 5. Schematic image of sample cross-section after measurement A – tribotrack cross-section area (μm^2); R – tribotrack radius (mm); t – coating thickness (µm); d – tribotrack depth (µm).

Cross-sectional area was measured using *Taylor Hobson Surtronic 25* profilometer with *standard pick up 112/1502*, and values were calculated with *Talymap Gold 4.1* software built-in function *Surface of a Hole/Peak*. Final cross-sectional area result was calculated as an average from 3 independent measurements (angle between measurements ~ 120º), see Fig. 4. Wear rate was calculated using the following equation (1):

$$W_r = \frac{W_v}{F \cdot l} \tag{1}$$

where W_v – tribotrack volume, mm^3; F – load on ball, N; l – total wear experiment distance, m.

3. RESULTS AND DISCUSSION

3.1. Coefficient of friction and wear rate results

The CoF of a summary graph showing a substrate and three investigational coating CoF values versus time (See Fig. 6). The schedule of the first twenty seconds characterized a friction pairs run-in process, next is observed CoF stabilizes - period of normal wear (20-100 s), until observed a sharp increase in the CoF that occurs in the substrate, it shows the coating disruption or critical wear. Assessing three investigational coatings CoF values, can be concluded that the investigated C/Cu coatings can reduce friction coefficient of up to three times the cases with 14 % and 20 % carbon content and up to two times 7 % carbon in the case in relation to the substrate material. The table 1 below shows the average CoF values that characterize coating (at normal wear period, i.e. 20-100 s), and the wear rate values.

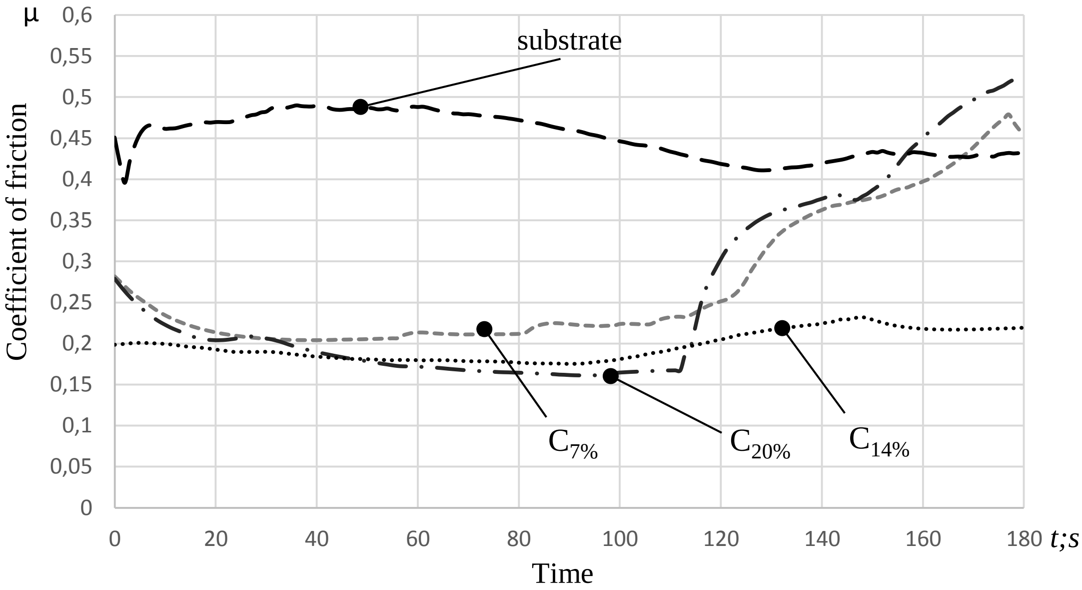

Figure 6. CoF summary schedule.

Table 1. Average CoF values that characterize coating.

Sample	CoF average values	Wear rate *Wr*; *mm*^{3}/*N·m*
S	0.49	1.33E-02
$C_{7\%}$	0.21	2.02E-03
$C_{14\%}$	0.18	3.23E-03
$C_{20\%}$	0.17	1.07E-02

Looking at the summary table of wear rate *Wr*, can be concluded that the increasing concentration of carbon coating decrease wear resistance. Images obtained from the microscope (see fig. 7), seen wear track, for each of the investigated coatings. The sample $C_{7\,\%}$ seen in homogeneous wear track, without substantial coating defects. Coating $C_{14\,\%}$ seen pitting on wear track in some places, but in the case of $C_{20\%}$, practically around the entire wear track, seen pitting of the coating. The sample tribotrack image obtained Hirox KH-7700 digital laboratory microscope. Coating $C_{20\,\%}$ tribotrack results, are not considered, to be correct in relation, to the coating pitting and cracking occasional character.

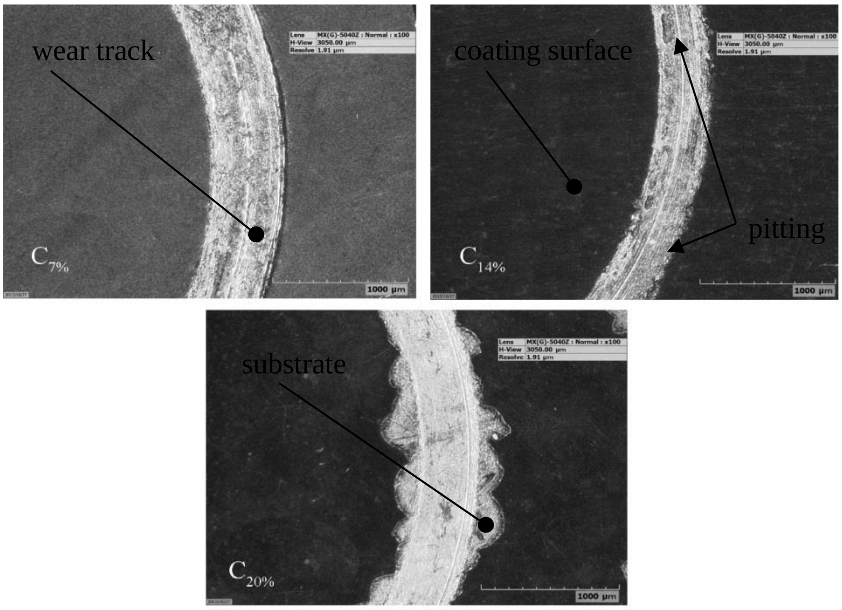

Figure 7. Three investigated coating tribotracks.

4. CONCLUSIONS

Investigational coatings CoF values, depending on the concentration of carbon in the coating, two to three times reduces CoF, compared to the substrate values. Sputter deposited coatings can be concluded that a higher percentage of carbon likely to get lower CoF value. Lowest CoF value of the three samples was investigated sample $C_{20\,\%}$. However, the carbon concentration increases, decreases coating wear resistance. At given friction experimental conditions, wear rate value measurement was not correct, the weak adhesion of the coating, causing the coating ($C_{20\,\%}$) secession from substrate.

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