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NICKEL COMPOSITE COATINGS MODIFIED BY DIAMOND NANOPARTICLES

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Abstract: *The study deals with composite Ni electro-chemical coatings on steel containing diamond nanoparticles with grain size up to 100 nm. Coatings were obtained at various concentrations of the nanoparticles in the electrolyte and at various process time.*
A procedure is developed for the study of wear parameters of the coatings under conditions of dry friction with abrasive surface. Experimental results for linear wear, wear rate, wear intensity and wear-resistance have been obtained. The study is related and financed under the Technical University - Sofia Contract DUNK-01/3 "University R&D Complex for innovation and transfer of knowledge in micro/nanotechnologies and materials, energy efficiency and virtual engineering" funded by the Bulgarian Ministry of Education and Science.

Keywords: *tribology, wear resistance, abrasive wear, Ni-coatings, diamond nanoparticles*

1. INTRODUCTION

The deposition of nickel coating on steel is applied in industry to increase the corrosion resistance and the wear resistance of the surfaces [1].

There is a lot of work done in the recent years on the application of nanoparticles of different materials and with various concentrations. This leads to improvement of the mechanical and tribological characteristics [2] [3].

The objective of the present work is to study the influence of the diamond nanoparticles concentration on the wear parameters of electrochemical nickel coatings. The wear is performed in dry friction conditions on surface with firmly embedded abrasive particles.

2. MATERIALS AND METHODS

Electrochemical nickel coatings deposited on substrate of carbon steel C45 are studied.

The electrochemical nickel depositing is performed on cylindrical samples with diameter 30 mm and height 10 mm. Standard electrolyte with composition: $NiSO_4.7H_2O$ - 240 g/l, $Na_2SO_4.10H_2O$ – 150 g/l, NaCl - 15 g/l, H_3BO_3 - 20 g/l, is used. The pH of the solution is 5.0 - 5.5. The anode is made of nickel. The temperature of galvanization is 25 - 30^{0}C.

The diamond nanoparticles (ND) are produced by detonation synthesis and the grain size is up to 100 nm. The nanoparticles are added in the electrolyte as water suspension. The nickel deposition is carried out with concentrations of the diamond nanoparticles 1, 5, 10 and 20 g/l at 3 A/dm^2 current density. The time of the electrochemical nickel deposition is 10 and 15 min.

The galvanization process is performed after the activation of the nanoparticles in the electrolyte and at continuous vigorous stirring during the nickel deposition. The studied parameters are the Ni yield, the thickness of the layer, the microhardness and especially the wear resistance of the coating. Their changes related to the parameters of the galvanization as current density, deposition duration and the concentration of the diamond nanoparticles (C_{NDDS}) are studied.

The data concerning the studied samples of electrochemical nickel coatings are presented in table 1. The coatings are obtained at different diamond nanoparticles concentration.

Table 1. Parameters of the electrochemical nickel coatings

Sample No	Coating	Nanoparticles concentration, g/l	Current density, A/dm^2	Process duration, min	Yield of nickel, mg/cm^2
8	Ni	-	3	10	4,87
9	Ni	-	3	15	8,06
17	Ni+nDi-1%	1%	3	10	11,18
18	Ni+nDi-1%	1%	3	15	8,89
28	Ni+nDi-5%	5%	3	15	8,31
38	Ni+nDi-10%	10%	3	15	5,66
48	Ni+nDi-20%	20%	3	15	7,05

3. DEVICE AND METHOD OF INVESTIGATION

3.1 Device for investigation of the abrasive wear at dry friction on surface with fixed particles

The experimental investigation is carried out according to the method and with the device for accelerated test by the kinematic scheme "thumb – disc". The device is presented schematically on figure 1. The method is in conformity with the existing standards [4].

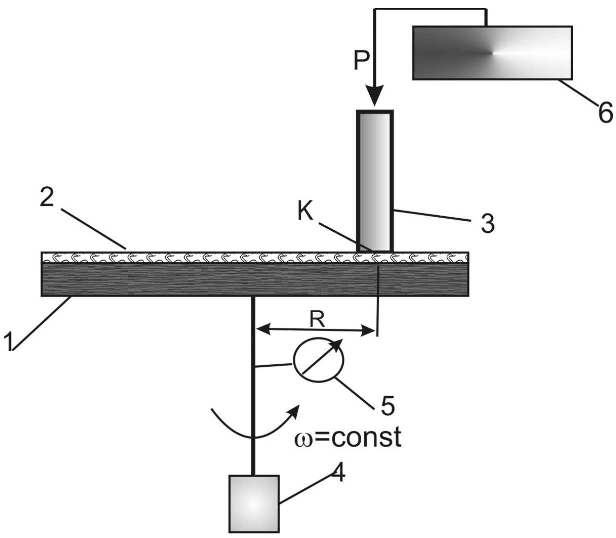

Figure 1. Functional scheme of the device "thumb – disc"

The studied cylindrical sample 3 (body) with the deposited coating K is installed immovably in suitable holder of the loading head 6. It is positioned in such a way that its front surface contacts the abrasive surface 2 of the horizontal disc 1 (counter body). The horizontal disc 1 rotates with constant angular velocity $\omega = const$ around its vertical axis. The number of cycles of disc 1 is measured with a cyclometer 5.

The device permits change in the relative sliding speed between the sample 3 and the disc 1 in two ways: by changing the angular disc velocity by control bloc and by changing the distance *R* between the rotation axis of the counter body 1 and the axis of the sample 3.

The abrasive surface 2 of the counter body 1 is molded by surfaces of impregnated carbo corundum with hardness at least 60 % more than that of the tested coatings which corresponds to the requirements of the standard [4].

2.2 Method for investigation of the abrasive wear

The method for investigation is performed in the following sequence of operations:

- Cleaning, degreasing and drying of cylindrical samples with equal dimensions and roughness;
- Measurement of the mass of the sample before m_0 and after m_i covering definite friction distance *S* (number of cycles). The measurement is done with electronic balance WPS 180/C/2 with precision 0.1 mg. The samples are dipped in special solution to prevent accumulation of static electricity. The mass wear *m* is determined as the difference of the two measurements;
- Measurement of the thickness of the coating before h_0 and after h_i the wear at definite friction distance *S* with the device Pocket LEPTOSKOP 2021 Fe at 10 points of the surface and calculating the average of the measured values;
- The normal loading *P* is applied along the sample axis by a lever system in the loading head and the cycle number *N* is read on the cyclometer which correspond to the friction distance *S*.

The abrasive wear of all coatings is fixed at one and the same working conditions which are presented on Table 2.

Table 2. Experimental parameters

Parameters	Values
Nominal contact pressure, p_a	1,46 [N/cm^2]
Average sliding speed, V	15,5 [cm/s]
Nominal contact area, A_a	7,065 [cm^2]
Abrasive surface	Corundum P 320

3.3 Wear parameters

The following parameters of mass and linear wear are studied:

- Absolute mass m (linear h) wear;
- Average rate of mass dm/dt, [mg/min] (linear dh/dt, [μm/min]) wear;
- Absolute intensity by mass wear i_m ,$[mg/m]$ as per the formulae:

$$i_m = m / S \tag{1}$$

- Absolute intensity by linear wear i_h, $[\mu m / m]$, correspondingly:

$$i_h = h / S \tag{2}$$

- The friction distance S is calculated by the corresponding number of cycles N and the distance R between the axis of rotation and the mass center of the nominal contact site by the formulae:

$$S = 2\pi RN \tag{3}$$

- Absolute wear resistance by mass I_m, $[m / mg]$:

$$I_m = 1 / i_m = S / m \tag{4}$$

- Absolute wear resistance by linear wear I_h, $[m / \mu m]$:

$$I_h = 1 / i_h = S / h \tag{5}$$

- Comparative wear resistance $\varepsilon_{i,e}$ - dimensionless value, representing the ratio between the absolute wear resistance of the tested sample I_i and the absolute wear resistance of a standard sample I_o.

$$\varepsilon_{i,e} = I_i / I_o \tag{6}$$

Sample with electrochemical nickel coating without diamond nanoparticles is accepted as a standard in the present study.

The index i indicates the percentage of the diamond nanoparticles.

3. EXPERIMENTAL RESULTS

The obtained experimental results of the mass and linear wear, the rate of wear, the absolute and the comparative wear resistance are presented in the form of graphical relations, tables and diagrams.

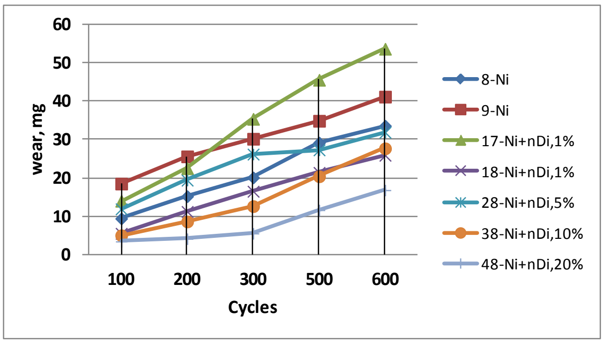

Figure 2. The relation of the mass wear m [mg] from the number N of the friction cycles

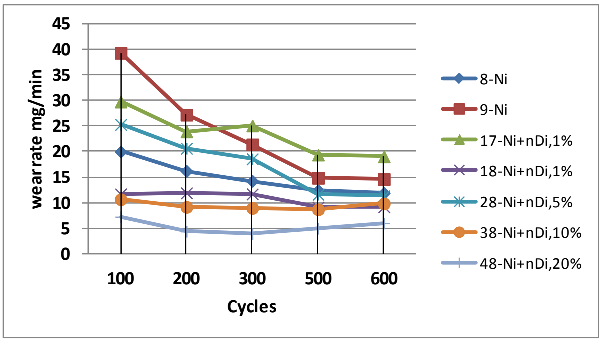

Figure 3. The relation of the rate of mass wear from the wear distance

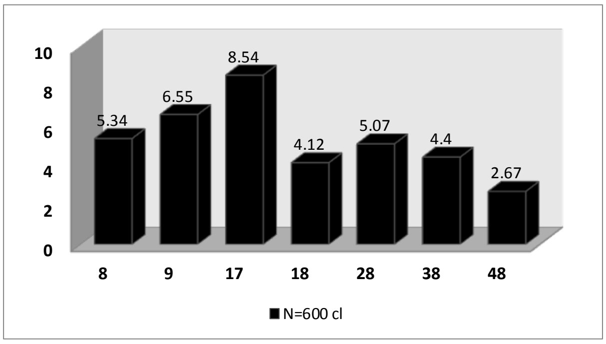

Figure 4. Linear wear in [μm] at N = 600 cl. for each sample

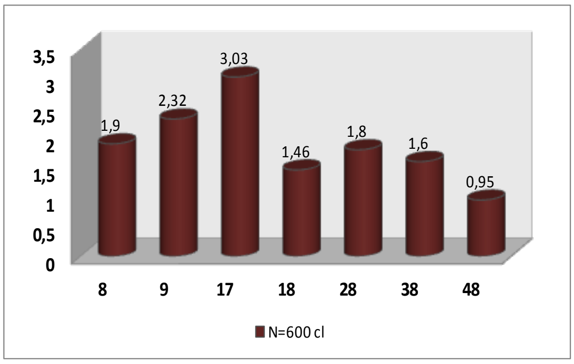

Figure 5. Rate of linear wear in [μm/min] at N = 600 cl. for each sample

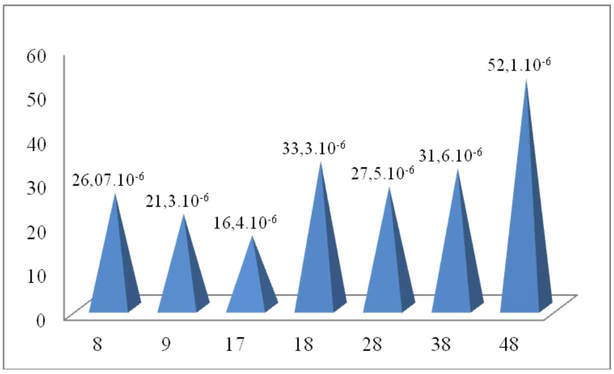

Figure 6. Wear resistance by linear wear I_h, [µm/m] at N = 600 cl. for each sample

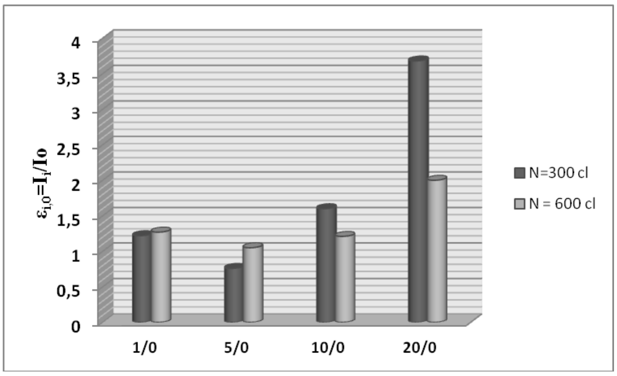

Figure 7. Diagram of the comparative wear resistance $\varepsilon_{i,0} = I_i/I_0$

Table 3. Comparative wear resistance of the samples compared to the standard – electrochemical nickel coating without diamond nanoparticles.

Number of cycles N	Comparative wear resistance, $\boldsymbol{\varepsilon_{i,e}}$			
	$\varepsilon_{1,0}$	$\varepsilon_{5,0}$	$\varepsilon_{10,0}$	$\varepsilon_{20,0}$
N = 300 cl	1,22	0,76	1,60	3,68
N = 600 cl	1,27	1,05	1,21	2,00

4. ANALYSIS OF THE RESULTS

It is found that the nickel yield decreases with the increase of the diamond nanoparticles concentration in the electrolyte. The Ni yield acquires its highest values of about 12.0 mg/cm^2 at diamond nanoparticles concentration C_{NDDS} = 1g/l, current density I = 3 A/dm^2 and process duration t = 10 min.

It is found also that the microhardness of the coating at concentration of the diamond nanoparticles C_{NDDS} = 1g/l is 4800 MPa or 2.5 times more than that of pure nickel coating (1950 MPa) and 1.7 times more than that of coating at concentration of the diamond nanoparticles C_{NDDS} = 5 g/l (2800MPa).

The increase of the abrasive wear with the friction distance has nonlinear character and is different for the different coatings. This relation is linear only for coating derived from electrolyte with diamond nanoparticles concentration 5 %.

The abrasive wear rate is not constant value in time. The only exception is coating obtained from electrolyte with diamond nanoparticles concentration 10 %.

The presence of diamond nanoparticles in the electrochemical nickel coatings leads to increase of the wear resistance. The wear resistance is increased with the increase of the diamond nanoparticles content in the electrolyte and the relation is of nonlinear character.

Coating with 20 % content of diamond nanoparticles possesses the highest wear resistance – 52,1.10^{-6} at N = 600 cycles. This wear resistance is 2 times higher than the wear resistance of coating without nanoparticles.

Out of the studied coatings the coating containing 1 % nanoparticles and deposited with current density 3 A/dm^2 and process duration 10 minutes possesses the lowest wear resistance.

Comparing the wear resistance of the coatings obtained at equal diamond nanoparticles concentration 1 % and current density 3 A/dm^2, the coating obtained at process duration 15 minutes has 2 times higher wear resistance.

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