Friction and Wear of Ni Coatings with Nanosize Particles of SiC

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Introduction

Calendering technology is the process of passing of granulate between shafts (calenders) ending with production of foliar material – folio, paper, cardboard, leather, etc. Calender shafts operate under various temperature and dynamical regimes; hence, they are easily worn due to the complicated contact processes. [1], [2]. Improvement of their resource is usually obtained by means of thin wear-resistant coating of hard chromium. A joint team from the Institute for Information and Communication Technologies at the Bulgarian Academy of Sciences and from the Technical University of Sofia is working on a research project aiming replacement of the coatings of non-ecological industrial chromium by nickel chemical coatings. Enhanced tribological characteristics are obtained when in the coating are embedded micro- and nanosized particles, e. g. of silicon carbide, diamond, boron nitride, etc. [3], [4], [5].

The present paper deals with the comparative study of abrasive wear and starting friction of nickel chemical coatings containing nanosized particles of silicon carbide (SiC) of various sizes. The nanosized composite coatings are obtained by means of EFTTOM-NICKEL technology for deposition of electroless Ni coatings developed at the Technical University - Sofia [6].

Materials

Nickel chemical coatings, containing nanoparticles от silicon carbide with sizes 20, 100, 150, 300 and 700 nm have been studied. Specimens are obtained of each type of coating without heat treatment и with heat treatment at temperature 300°C during 6 hours. Nanoparticles concentration is in the interval 5÷7 vol. %.

The coatings are deposited on steel substrate with chemical content given in Table 1.

Table 1: Chemical content of specimens substrate

Chemical content, wt %							
C	S	Mn	P	Si	Cr	Ni	Fe
0.40	0.045	0.55	0.045	0.20	0.30	0.30	Balance

Table 2 shows the microhardness and the average thickness of all coatings. The specimens are designated by a number expressing the size in nanometers of SiC particles contained in the coating. Lack and availability of heat treatment are designated accordingly by (-) and (+).

The specimens are shaped in disks of 100 mm diameter and 3 mm thickness.

The thickness of the coating is measured by *Pocket LEPTOSKOP 2021 Fe* device in 10 points of the surface, assuming afterward the average of the measured values.

Table 2: Characteristics of the coatings

№	**Coating**	**Microhardness** HK 0,02	**Thickness** μm
0^-	without particles without heat treatment	450	26,5
0^+	without particles with heat treatment	860	26,5
20^-	20nm SiC without heat treatment	580	27
20^+	20nm SiC with heat treatment	1020	27
100^-	100nm SiC without heat treatment	540	26,5
100^+	100nm SiC with heat treatment	985	26,8
150^-	150nm SiC without heat treatment	515	28
150^+	150nm SiC with heat treatment	968	28
300^-	300nm SiC without heat treatment	495	27,5
300^+	300nm SiC with heat treatment	945	27,5
700^-	700nm SiC without heat treatment	473	28,5
700^+	700nm SiC with heat treatment	920	29

Abrasive wear

1.1. Device and procedure

Experimental study of the abrasive wear of the nickel coatings is carried out under dry friction conditions using TABER ABRASER device according to the kinematic scheme „disk-on-disk” (Fig.1).

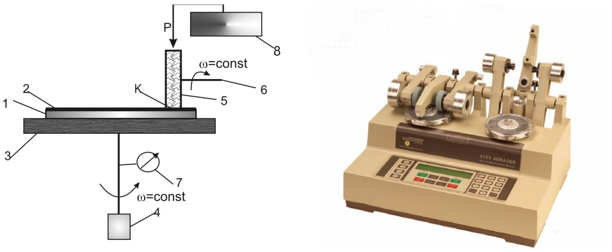

Figure 1 Device for abrasive wear study

The specimen 1 (the body) with deposited coating 2 is in the shape of disk and is fixed appropriately on carrying horizontal disk 3 driven by electrical motor 4 with a constant rotational speed ω = 1 [s^{-1}] =const. The counter-body 5 is an abrasive disk (roller) of special material CS 10 mounted on horizontal axis 6 in the device 8, by means of which the desired normal load *P* in the contact zone *K* is set. Thus, the body 1 and the counter-body 5 are located on two crossed axes. Because of the constant rotational speed of the body 1 and the constant nominal contact pressure p_a, the friction in the contact zone *K* supports constant speed of rotation of the counter-body 5.

The procedure of the experimental study on abrasive wear is realized in the following sequence:

- preparation of specimens: clean-up, cleaning of lubricants, drying of the specimens and measurement of the coating thickness before each test;
- determination of the linear wear *h* as difference between the thickness of the coating before and after a given friction path *L*. The friction path *L* is specified with the number of cycles read by the revolution counter 8 at equal working conditions – nominal contact pressure *p*, average sliding speed *V* and material of the abrasive roller 5.
- the linear wear intensity *i* is determined as linear wear for unit friction path

$$i = h / L \qquad (1)$$

- the wearresistance of the coating *I* is determined as the reciprocate value of wear intensity:

$$I = 1 / i = L / h \qquad (2)$$

The study of all specimens is carried out at the experimental conditions given in Table 3.

Table 3 Parameters of wear resistance experiments

Normal contact pressure	$p_a = 9{,}42$ N/cm^2
Average sliding speed	$V = 22{,}3$ cm/s
Abrasive material	CS 10

3. 2. Results and discussion

Experimental results are obtained for the wear, wear intensity and wear-resistance of 12 types coatings depending of the friction path (the time duration of friction).

Fig. 2 shows graphical relationship between wear and SiC particles size at equal friction path L = 223 m for the coatings without and with heat treatment.

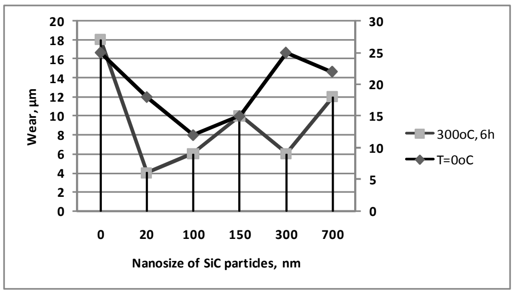

Figure 2 Wear dependence on the size of SiC nanoparticles at L=223 m

Fig. 3 shows diagrams of wear-resistance of all coatings at the same friction path.

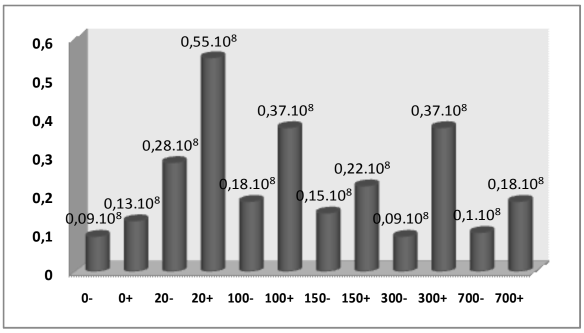

Figure 3 Diagram of wear-resistance of the coatings at friction path L=223 m

The analysis of above results leads to the following statements:

- all coatings with heat treatment exhibit higher microhardness and higher wear-resistance than the analogous coatings without heat treatment (Fig. 3, Table 2).
- SiC nanoparticles availability in the coatings leads to increasing of wear-resistance. Highest wear show the coatings without nanoparticles of SiC.
- the dependence of coating wear on nanoparticles sizes is of significantly nonlinear nature for coatings with and without heat treatment (Fig. 2). Nickel coatings with heat treatment show minimum wear when containing particles of sizes 20 nm and 300 nm; for the coatings without heat treatment the minimum of wear is for content of particles with sizes 100 nm. Wear increases with the increment of nanoparticles size.
- the highest wear-resistance among all studied coatings show those nickel coatings with heat treatment, containing SiC particles of size 20 nm. The maximum wear-resistance of these coatings is in correlation with their maximum microhardness (Table 2).

Friction at preliminary displacement

1.2. Characteristics, procedure and device

There are three stages in the process of friction when regarding the temporary cross-section: starting friction, kinetic friction and pathological friction.

Starting friction, known also as *static friction* or *friction at rest*, is realized under the conditions of preliminary micro-displacement in the contact body at the transition of the tribosystem from rest to motion. Friction at motion is usually designated as *kinetic friction.*

The paper presents the study of the influence of SiC nanoparticles size in the coatings upon the characteristics of starting friction – starting friction force T_o, starting friction coefficient μ_o and kinetic friction coefficient μ, as well as friction jump $\Delta\mu$ (Fig. 4).

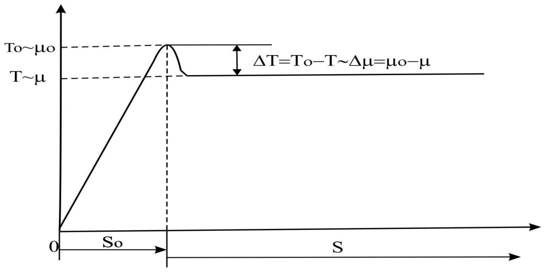

Figure 4 Principle curve of the relationship between friction force and displacement

The starting friction parameters are studied by means of the device whose functional scheme is shown in Figure 5.

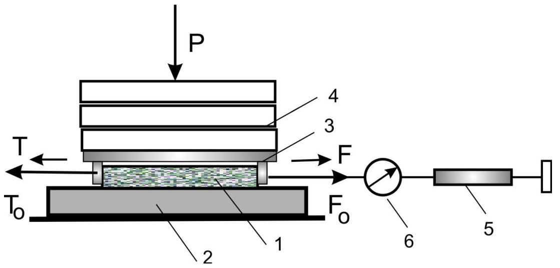

Figure 5 Functional arrangement of the experimental device for study of the starting friction

The experimental device consists of body 1 and counterbody 2, which form a contact between them. The body 1 is fixed in the holder 3, and is connected by means of non-elastic thread to the dynamometer 6 and the micrometric screw 5. Setting the wished normal load P = 45,1 [N] with the weights 4, and the slow rotation with the micrometric screw cause the formation of tangential force at the body 1 close to the contact surface.

The body 1 fixed in the holder 3 is shaped as prismatic sample with sizes 30 x 50 x 8 mm of various material. The counterbody 2 is the specimen with the investigated coating with roughness Ra = 0,417 µm. It is mounted in the bed of the foundation. After initial reset of the elastic dynamometer 6, the micrometric screw 5 is turned very slowly and the pointer of the dynamometer 6 drifts gradually and with ease. At the moment of flickering of the pointer in the sense of decreasing the value of the graduations, the indication of the dynamometer is read. The maximum value of the indication of the pointer corresponds to the value of the starting friction force To. The scale of the dynamometer is graduated with dimension of force in [N].

1.3. Results and discussion

The above described device has been used for obtaining results for the characteristics of the starting friction in the case of contact between the studied coatings and counterbodies of two types of materials – steel and bronze. In Table 4 are given the results of these characteristics.

Table 4 Friction parameters for heated coatings with SiC nanoparticles

Speci-men	**Tribosystem „Coating – Steel”**				**Tribosystem „Coating – Bronze”**			
	To	µo	µ	Δµ	To	µo	µ	Δµ
0^+	9,8	0,22	0,19	0,03	6,5	0,14	0,12	0,02
20^+	11,4	0,25	0,23	0,02	9,3	0,21	0,17	0,04
100^+	12,6	0,28	0,25	0,03	10,4	0,23	0,21	0,02
150^+	14,2	0,31	0,28	0,03	10,8	0,24	0,19	0,05
300^+	15,3	0,34	0,30	0,04	13,0	0,29	0,26	0,03
700^+	16,6	0,37	0,32	0,05	14,2	0,31	0,27	0,04

Figure 6 presents diagrams of the starting friction force, and Figure 7 - of the jump of the friction coefficient for both tribosystems from Table 4.

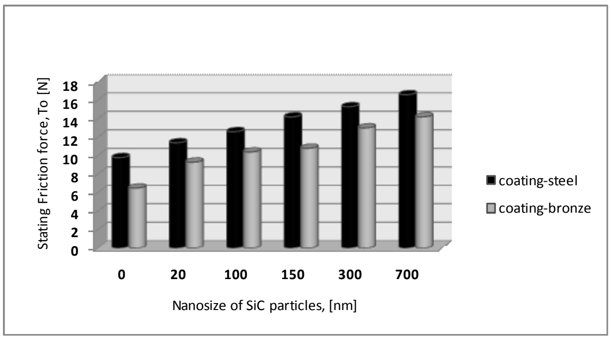

Figure 6 Starting friction force for coatings with SiC particles

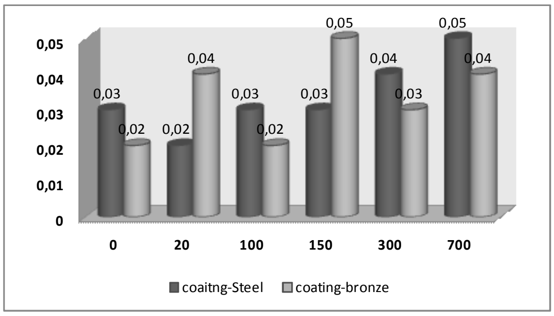

Figure 7 Friction coefficient jump

The analysis of above results allows the following conclusions to be drawn:

- the starting friction force in the tribosystem „coating-steel" is higher than that in the tribosystem „coating-bronze" for all studied coatings (Fig.6);
- the starting friction force grows linearly with the increment of nanoparticles size for both studied tribosystems (Fig.6);
- there is not any obvious dependence in the variation of the friction coefficient jump. Highest is the jump for the tribosystem „coating-bronze" when the coating contains nanoparticles of the size 150 nm; this jump is almost twice higher than that of the same coating in contact with steel (Fig. 7).
- the friction coefficient jump varies almost linearly with the size of the nanoparticles for the tribosystem „coating-steel", while in the tribosystem „coating-bronze" two maximums are observed – for particles with sizes 20 nm and 150 nm (Fig. 7).

5.Conclusions

The paper presents the developed procedures and the obtained experimental results and relationships for the characteristics of the abrasive wear and the starting friction of nickel chemical coatings containing SiC nanoparticles of various sizes.

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