Applied Mechanics and Materials Vols. 157-158 (2012) pp 960-963
Online available since 2012/Feb/27 at www.scientific.net

doi:10.4028/www.scientific.net/AMM.157-158.960

Wear and tribotermal effects of nanostructured nickel chemical coatings

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Keywords: tribology, wear, coatings, nanotribology, nickel, thermography

Abstract. The abrasive wear and the wear resistance of composite nickel + SiC coatings are investigated. The coatings are deposited by the method for electroless nickel plating EFTTOM-NICKEL developed in TU-Sofia. Nanosized particles of SiC are used as a strengthened material. The size of the particles is 35-40 [nm]. The thickness of the coatings is 50 [µm]. The investigation of the coatings deposited on the different roughness surfaces is performed. Some of the samples are thermal processed at 300ºC, 6 hours after deposition process. The methods for wear resistance testing is developed and the experimental results for the dependence of the massive wear, wear speed, intensity of wear and wear resistance on the friction road and the time of a contact interaction are obtained.

Introduction

The calendaring is a process of a material pressing with shafts (calendars) to obtain a sheet material – paper, card board, leader, foil etc. The calendars work at different temperatures and dynamic's conditions in production and as a result of complicated contact interactions under friction they are being wearied out. In the practice the extension of the calendars work life is achieved by the deposition of thin wear resistance hard chrome coatings.

The research group from The Institute of Information and Communication Technologies at the Bulgarian Academy of Sciences and Technical University in Bulgaria are developing a Project for replacement of toxic chrome with nickel coatings strengthened with micro and naosized particles. The improving of the wear resistance of composite nickel coatings is observed using nanosized diamond particles (nanodiamond) and microsized BN particles as a strengthened material. The thermal processing of the coatings improves their wear resistance behavior [1, 2].

In the present work the investigation of the abrasive wear and the wear resistance of composite nickel coatings with nanosized SiC particles are performed in a laboratory.

Exposition

Description of the coatings

Nanostructured composite coatings are obtained by electroless nickel plating method EFTTOM-NICKEL developed at Technical University in Sofia [1, 2]. SiC nanoparticles average size of 35÷40 [nm] is used as a strengthened phase. The density of the SiC nanoparticles in the coating is between 5÷7 v.%. Five different types of coatings are tested: electroless nickel coating (Ni), composite nickel coating with nanoparticles (Ni-SiC). The coatings are deposited on the different roughness surfaces R_a=0.3[µm] and R_a=2.1[µm]. Some of the samples with the composite coatings are put to the thermal processing at 300^{o}C , 6 hours to improve the microhardness and the adhesion of the coating to the padding. The microhardnes is measured by Knoop Method under load of 0,5[N]. The coatings are deposited on the steel samples and their thickness is 50[µm]. The thickness is measured by the device "Pocket LEPTOSKOP 2021 Fe" on 10 surface points and the average velue is struk. The data for the tested samples are presented in Table1.

Table 1: *Coatings data: nanoparticles content, thermal processing, microhardness and roughness*

№	Content	Thermal processing	HK0.02	R_a[μm]
1.	Ni	300[^{o}C],6[h]	860	0.3
2.	Ni+SiC	-	473	0.3
3.	Ni+SiC	300[^{o}C],6[h]	980	0,3
4.	Ni+SiC	-	485	2.1
5.	Ni+SiC	300[^{o}C],6[h]	940	2.1

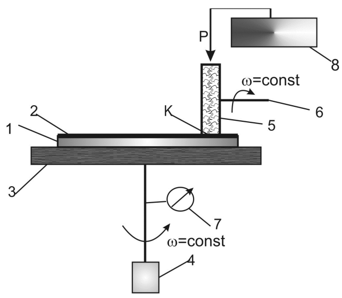


Fig. 1: *Functional design of the device for the wear testing under friction upon fixed abrasive*

Wear: Methods of testing and Experimental results

The experimental tests are performed in the Tribology center at the Technical University in Sofia. The methods for abrasive wear test of nickel coatings is developed using a device working on a cinematic scheme back to back disc. The functional scheme of the device is shown on Fig. 1.
The antibody is a disc from a special abrasive material *CS10*. Upon the constant angular speed ω=*const* of the sample 1 and upon constant nominal contact pressure $p_a=P/A_a=47.15$[N/sm^2]=*const* the friction in the contact surface *K* keeps constant rotation speed of the antibody 5.

The test method consists of the operations: Preparation of the samples with the same ring shape and size before coating deposition. Mechanical treatment, namely grinding and polishing to ensure an equal surface roughness R_a=0.3[μm] and R_a=2.1[μm]. The weight of the sample is weighed before and after a determinate number of the disc rotation by an analytical balance WPS 180/C/2 précised to 0.1[mg]. The samples are treated with a special solution to neutralize the static electricity before the weighting. Sample 1 is fixed on a horizontal disc 3 and by the lever system in the device 8 the desire normal load *P* is set. The friction road *S* is determined by the number of cycles N, accounted with a cyclometer 7. Test basic parameters are: absolute massive wear *m*[mg]; speed of massive wear $\dot{m}$ [mg/min]. Intensity of wear *i* - this is the lost coating thickness for one friction road.

$$i = m/\rho A_a S \tag{1}$$

where: ρ is the coating density; A_a is the nominal interaction contact surface: A_a=26.10$^-$6[m^2]; *S* is the friction road, estimated by the number of cycles N: $S=2\pi RN$[m], , where *R* is the distance between the rotation axis of the bearing disc and the mass center of the contact place between the sample 1 and the contra body 5. Absolute wear resistance is:

$$I = 1/i \tag{2}$$

Specific wear intensity is:

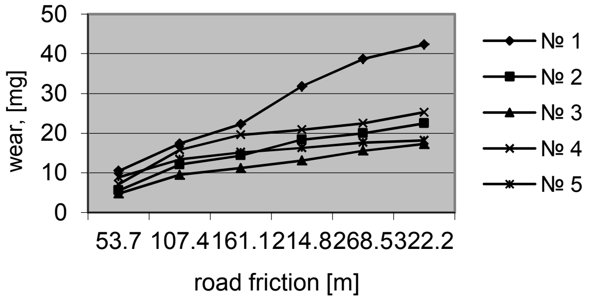
$$I_s = m/SA_a\text{[mg/m.mm}^2\text{]} \tag{3}$$

Specific wear-resistance is:

$$I_s = 1/i_s \tag{4}$$

The specific wear-resistance I_s indicates the sliding way *S* covered by the contact area 1[mm^2], in order that a mass 1[mg] of it will be destroyed.

Experimental results for the massive wear m and the intensity of wear $\dot{m}$ of all type of coatings are presented in Fig. 2 and Fig. 3. The results for the intensity of wear and the wear resistance of all type of coatings are presented in Fig. 4 and Fig.5.



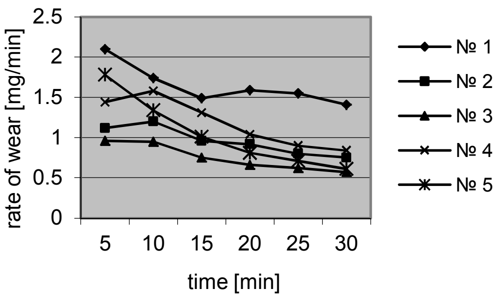
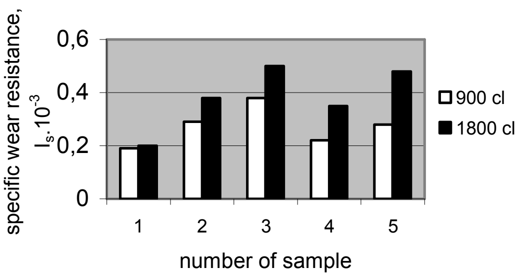


Fig. 2: *Dependence of the massive wear* m **Fig.3:** *Dependence of the intensity of*
wear $\dot{m}$ *on the rotation road time* *on the time*



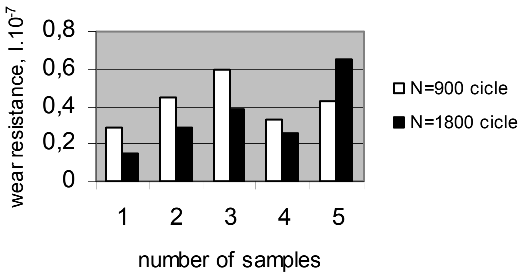


Fig. 4: *Table gram of the specific wear-resistance* I_s **Fig.5:** *Table gram of the wear resistance* I

Tribothermal effects: approach and results

An experimental set up has been developed for determination of temperature rise at the contact surface by infrared camera ThermoCam SC640. It is employed a thermographic technique to capture a real-time images of the surface temperature distribution during the abrasive wear test of nickel coatings [3].

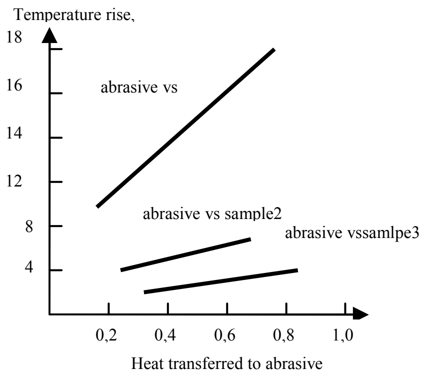


Fig.6: *Temperature rise plotted against the heat dissipation*

By this technique has been assessed the magnitude and distortion of near-surface temperature within a fretting contact. The steady-state heat generation due to friction depends directly proportional on the coefficient of friction, the velocity and the normal load. The result of the experiments for the samples 1, 2 and 3 show that there is a linear relationship between temperature rise at interface and the heat transferred to the disc of an abrasive material CS10. This material has got high emissivity that was measured before the test and used for emissivity map creation. Fig. 6 shows the result of temperature rise plotted against the heat dissipation. The linearity between the temperature rise and temperature of the abrasive disk can be expressed as $\Delta T = \alpha . T_1$,where α is the slope of the line. The relation for wear coefficients K_1 and K_2 of two examined samples is

$$\frac{K_1}{K_2} = \left(\frac{\eta_1 \mu_1 H_1 \alpha_1}{\eta_2 \mu_2 H_2 \alpha_2} \right) \frac{\dot{m}_1 \Delta T_2}{\dot{m}_2 \Delta T_1} \tag{5}$$

where H is the hardness, A is the area of the contact, $\dot{m}$ is the wear rate, η is the heat partitioning factor and μ is the characteristic factor of the material [3]. The indices respond to the numbers of tested samples.

The last equation is the base of the methodology for evaluation of the wear coefficient merely by measuring the contact temperature. This method provides a simple and effective technique to quantitatively characterize the wear behavior of a friction system.

Regarding image subtraction as an image conversion function might seem strange, but that is really what this type of work is all about. It is possible by using ThermaCam Researcher 2.9 to get another sequence containing difference images as the result. We have been compared images of the same (or similar) object(s), taken at different times, in order to detect changes in temperature, position or shape. When the subtraction is over, and the output images are displayed, it is may notice that the measurement units have changed. This is because there are no longer any absolute temperatures in the real sense. On Fig. 7 are shown some of used thermal images used in the proposed approach. In result can be concluded that the ratio K_1/K_3 is about two times bigger than the ratio K_1/K_2.

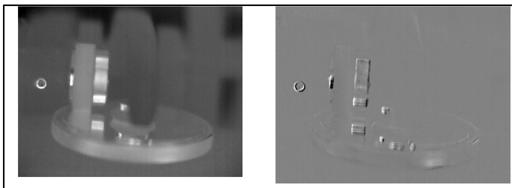


Fig.7. *Thermal image for surface temperature measurement - a); negative subtracted image – b)*

Analysis of the results and conclusions

The variation in the massive wear value during the process of contact interaction under friction upon an abrasive surface is linear after a time of friction, corresponding to the contact system recast. The recast process is with a different duration: the higher value is achieved for the pure nickel coating: (№1) – S=268.5[m], the lower – for the thermal processed composite coatings (№3 and №5) – S=107.4[m] (Fig. 2). The maximum wear is observed for pure nickel coating (№1). The thermal processed composite coatings have less wear than the coatings without thermal processing. The minimum wear is observed for the coatings with smallest roughness (sample № 3 - R_a =0.3[μm] – Fig. 2).The massive wear speed and the intensity of wear have a pointedly nonlinear character over the time (Fig.3). This is in confirmation of the thesis for the nonstationary character of the contact interactions, irrespective of constant value of the external dynamic factors – speed of sliding and nominal contact pressure. The contribution is of a contact surface and more of the roughness.

The analysis of the wear Tablegram (Fig. 4) shows the significant influence of the roughness value at different stages of the contact interaction. It is seem that the different resistance to abrasion is observed for the same coatings at different duration (cycles) of interaction. It can be argued that the higher wear resistance is achieved for the thermal processed composite nickel coatings (№ 3 and № 5). But at different cycles the wear resistance depends on the difference in the degree of the roughness. At N=900 cycles the coating (№3) with less roughness (Ra=0.3[μm]) has 1.6 times higher wear resistance than the rough coating - №5 (Ra=2.1[μm]). With twice as many cycles (N=1800 cycles) contrariwise I_s observed – the rougher coating has 1.5 times higher wear resistance.

The effect of load, velocity, environmental conditions, etc., on the wear rate can be accounted for by considering frictional energy dissipation within a contact. The investigation of the coatings properties during the overtime process, in stationary conditions, as well as the dependence on the roughness, microstructure and etc. are the subject to further author's research.

The presented investigations are carried out and financed under the Projects NSFB Grants No D*002-13/2009, and No ID002-262/2008*

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Mechatronics and Applied Mechanics
10.4028/www.scientific.net/AMM.157-158

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