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Coatings

WEAR RESISTANT CHROMIUM COATING WITH DIAMOND NANOPARTICLES UPON AN ARC DEPOSITED LAYER

V. PETKOV[a], P. TASHEV[a], N. GIDIKOVA[a], M. KANDEVA[b]*, R. VALOV[a]

[a] *Institute of Metal Science, Equipment and Technologies, Bulgarian Academy of Sciences, 67 Shipchensky prohod Blvd, 1574 Sofia, Bulgaria*
[b] *Tribology Centre, Faculty of Industrial Engineering, Technical University – Sofia, Sofia, Bulgaria*
E-mail: *kandevam@gmail.com*

ABSTRACT

A method for applying a thin chromium coating containing nanodiamonds upon an arc deposited layer on steel is developed. The wear resistance of the binary coating is studied. A comparative analysis is performed between the chromium coating containing nanodiamonds and the pure arc deposited layer on steel. The wear resistance of the chromium coating containing nanodiamonds is increased with more than 450% compared to the pure arc deposited layer. The hardness of the binary coating on steel is increased, too.

Keywords: nanodiamonds, galvanic coatings, wear resistant coatings, chromium coatings**.**

AIMS AND BACKGROUND

The economic crisis of the recent 5–6 years made us consider seriously the decreasing natural resources of the Earth. The metals are used in all fields of industry. Their protection with different surface protective coatings like polymers, ceramic and metallic contribute to their long-term usage in modern industry. In this paper we pay special attention to one new binary coating. The first layer is surfaced arc deposited material and the second layer is composite chromium coating with nanodiamond particles (ND). The nanodiamonds are nanosized diamond particles obtained by detonation synthesis. Their grain size is less than 50 nm with average value of 4 nm. Thus we deem to increase significantly the exploitation properties of the products exposed to wear, erosion, corrosion, etc. This is

* For correspondence.

one of the most important issues of the modern material science. The development of efficient wear resistant coatings is a complicated task since the coatings has to combine high hardness and toughness with low inner tensions, good adhesion to the substrate material and low coefficient of friction.

EXPERIMENTAL PROCEDURE AND RESULTS

The compositions and their respective electrochemical parameters were selected as a result of previous investigations[1].

Low carbon construction steel S235 as per EN 10025 with pearlite-ferrite structure was used. An arc deposited wear resistant layer was surfaced with basic electrode IZA – E 300. The content of the surfaced layer is presented in Table 1.

Table 1. The content of the surface layer

C (%)	Mn (%)	Si (%)	Cr (%)
0.1–0.15	1.6–1.8	0.4–0.8	0.8–1.2

Standard electrolyte was used to prepare the chromium layer with nanodiamond particles. The ratio of the chromium anhydrate to the sulphuric acid was 100:1. This ratio produced the highest yield in relation to the current density. The composition of the chromating electrolyte was CrO_3 – 220 g/l and H_2SO_4 – 2.2 g/l. The used current density was within the range 45 80 A/dm^2, the duration of the process – 50 min, the temperature of the electrolyte – 50–55°C and the anode was lead. The nanodiamond particles (ND) were added to the electrolyte as a water suspension and their concentrations in the chromating solution were different: 0.25 and 42 g/l. According to some authors, the best wear resistance is achieved when the chromium coatings with nanodiamonds are obtained at a temperature of 55±1°C, current density of 40 A/dm^2 and nanodiamond concentration of 5.0 g/l (Ref. 2).

The surfacing was done on rectangular plates with thickness 25 mm out of the chosen steel (Fig. 1) and then the samples for wear resistance tests were prepared by water abrasive cutting machine (Fig. 2). The samples represented cyl-

Fig. 1. Surfaced layer on steel with 25 mm thickness

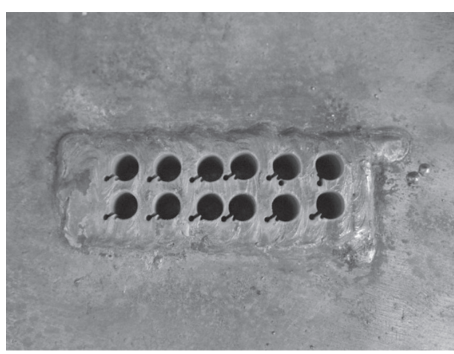


Fig. 2. Surfaced cylindrical samples cut with diameter of 8 mm

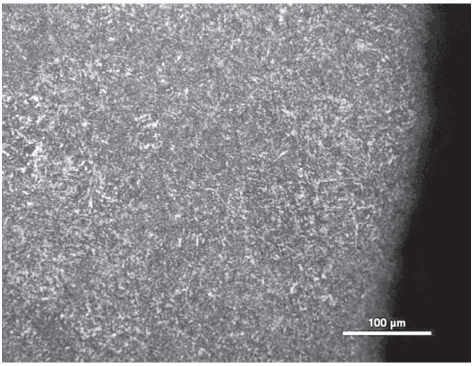


Fig. 3. Microstructure of surfaced layer martensite type without coating, ×200

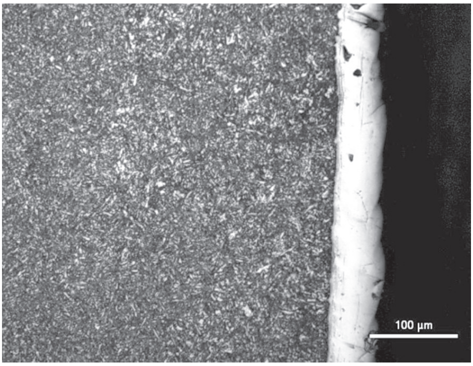


Fig. 4. Microstructure of chromium coating with nanodiamonds, ×200

inders with their axis along the thickness of the plate. Their dimensions were diameter d – 8 mm and length h – 25 mm. The surfaced part was about 10 mm along the length of the sample.

Microstructure of electric arc surfaced layer on steel is shown in Fig. 3 and chromium coating with nanodiamonds with thickness of about 50 µm deposited on the steel – in Fig. 4.

A procedure for accelerated testing has been developed in the Laboratory of Tribology at the Technical University – Sofia and a pin-on-disk tribotester (Fig. 5) device has been used for the experimental study of coatings wear. The procedure matches the operative standards[3,4].

The studied cylindrical specimen *1* with the chromium coating is placed in a holder *2* of the loading box *8*, so that the coating stays in contact with the abrasive surface *3*, fixed on horizontal disk *4*. The disk is driven by the motor *6* and is rotating around its vertical central axis with rotational speed ω = const.

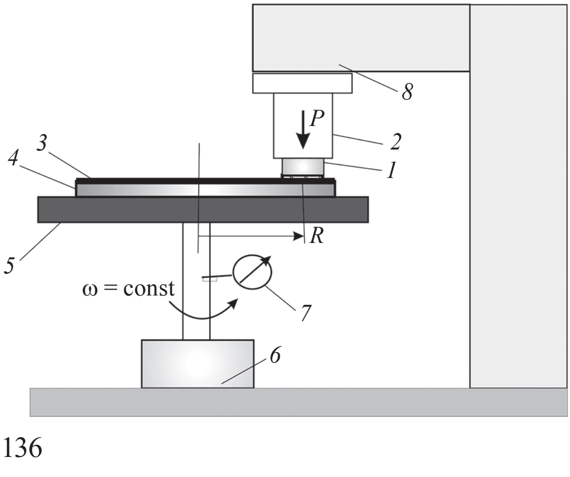


Fig. 5. Scheme of the tribotester for fixed abrasive wear study of coatings

The sliding distance was measured by the number of revolutions read on the revolution counter *7*. The device allows sliding speed variation by changing the disk rotational speed through the control unit and/or by changing the distance *R* between disk axis and specimen axis.

The abrasive surface *3* is built of impregnated corundum of average grain size 320 μm and 9.0 Mohs hardness, which meets the standard requirement for over 60% higher hardness than the hardness of the tested coatings.

The procedure included determining the mass wear of the coatings by measuring the specimen mass before and after the preset number of cycles read by the revolution counter *7* (friction duration *t*) using electronic balance of 0.1 mg accuracy. In order to avoid static electricity, the specimens were cleaned with appropriate solution before each measurement. A normal central load *P* was performed by a leverage system in the loading box *8*. All coatings were tested at one and the same load $P = 3.92$ N and in this way nominal contact pressure $P_a = 7.84$ N/cm^2 was realised. The wear parameters were determined at a different number of cycles $N = 100$, 150, 250 and 400. The wear resistance *I* was determined as non-dimensional value by the measured mass wear by the formula:

$$I = \frac{\rho A_a S}{m} \quad (1)$$

where ρ is the density of the coating; *S* – the friction distance; A_a – the nominal contact surface.

The wear of the samples after different number of cycles is presented in Table 2, and the wear resistance of the samples obtained at the same galvanisation conditions – in Table 3.

The relations of the mass wear to the number of cycles of coatings without nanodiamonds and with concentration of the nanodiamonds 25 and 42 g/l obtained at different current density are graphically presented in Figs 6 (45 A/dm^2), 7 (60 A/dm^2) and 8 (80 A/dm^2).

Table 2. Wear of samples after different number of cycles (mg)

Sample No	Concentration of ND (g/l)	Current density (A/dm^2)	Number of cycles				
			50	100	150	250	400
			wear (mg)				
1	0	0	1.5	4	5.6	9.3	11.7
2	25	45	1.3	2.6	4	4.3	4.8
3	25	60	1.5	2.8	4.3	5.9	6.6
4	25	80	1.8	3.1	5.2	7	7.4
5	42	45	1	1.8	2.1	2.7	3
6	42	60	1	1.5	2	3	3.5
7	42	80	1	1.4	1.9	3.2	3.8

Table 3. Wear resistance of samples after different number of cycles ×10^{-6}

Sample No	Concentration of ND (g/l)	Current density (A/dm^2)	Number of cycles				
			50	100	150	250	400
			wear resistance, 10^{-6}				
1	0	0	2.71	2.03	2.18	1.75	1.75
2	25	45	3.13	3.13	3.05	3.78	4.23
3	25	60	2.71	2.9	2.84	2.75	3.08
4	25	80	2.26	2.62	2.35	2.23	3.33
5	42	45	4.06	4.52	5.81	5.81	8.13
6	42	60	4.06	5.42	6.1	5.42	5.8
7	42	80	4.05	5.62	6.21	5.32	5.5

From Figs 6, 7 and 8 one may see that the biggest mass wear is in samples without chromium coating, and the least mass wear is in samples with chromium coating with 42 g/l nanodiamonds. The least mass wear is achieved in samples prepared at current density 45 A/dm^2 which is almost 4 times less than the pure arc deposited layer. Similar relation is observed at current densities 60 and 80 A/dm^2.

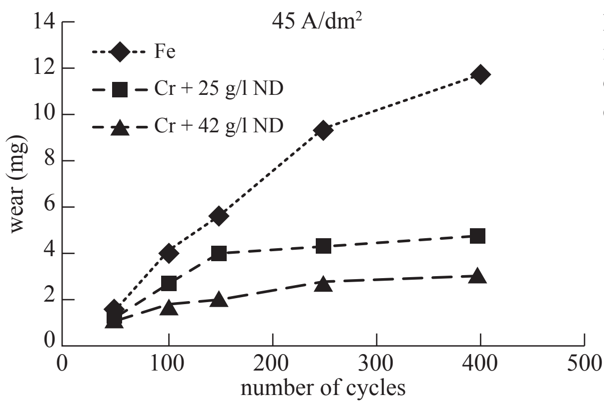


Fig. 6. Relation of the wear of coatings with different content of nanodiamonds to the cycles number at constant current density 45 A/dm^2

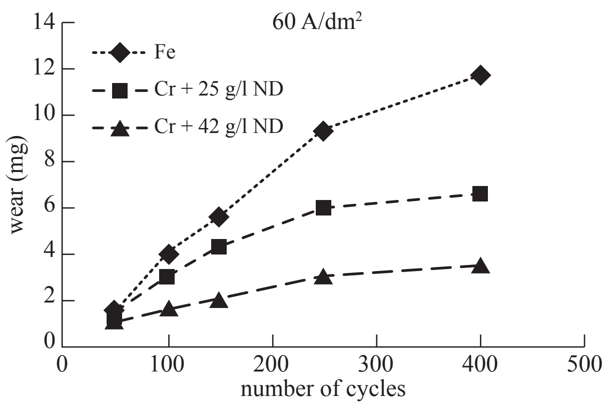
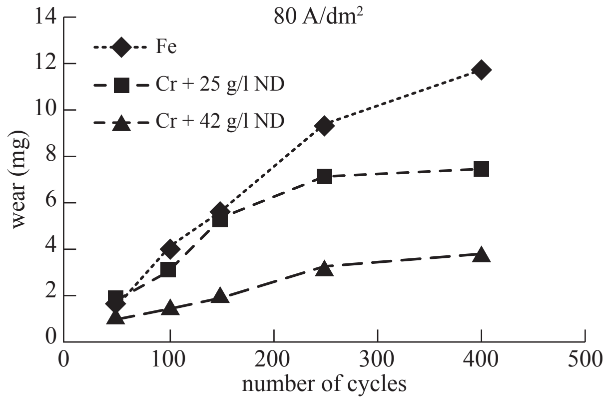


Fig. 7. Relation of the wear of coatings with different content of nanodiamonds to the cycles number at constant current density 60 A/dm^2

Fig. 8. Relation of the wear of coatings with different content of nanodiamonds to the cycles number at constant current density 80 A/dm²



Diagrams of the wear resistance of coatings without and with different nanodiamonds content and at different current density – 45, 60 and 80 A/dm² for 400 cycles of friction are presented in Figs 9, 10 and 11.

The least wear resistance is observed in samples without chromium coating (Figs 9–11). The biggest wear resistance is achieved in samples with chromium coating with 42 g/l ND and current density 45 A/dm². It is almost 5 times bigger

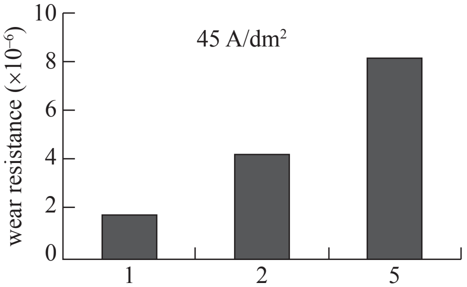


Fig. 9. Diagram of the wear resistance of coatings with different nanodiamonds content (1 – 0, 2 – 25, 5 – 42 g/l) at current density 45 A/dm² for number of cycles $N = 400$

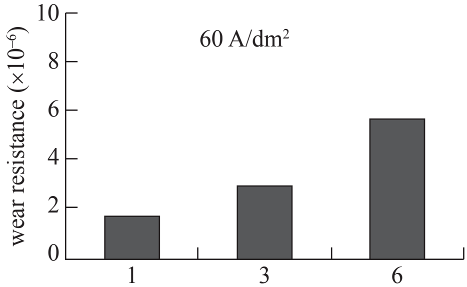


Fig. 10. Diagram of the wear resistance of coatings with different nanodiamonds content (1 – 0, 3 – 25, 6 – 42 g/l) at current density 60 A/dm² for number of cycles $N = 400$

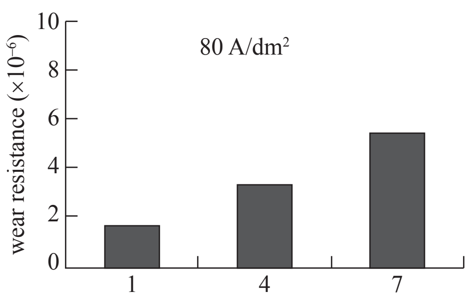


Fig. 11. Diagram of the wear resistance of coatings with different nanodiamonds content (1 – 0, 4 – 25, 7 – 42 g/l) at current density 60 A/dm² for number of cycles $N = 400$

than the pure arc deposited layer. The similar phenomenon is observed at current density 60 and 80 A/dm^2.

CONCLUSIONS

- A method for preparation of wear resistant chromium coating with nanodiamonds on surfaced arc deposited layer is developed.
- A comparative analysis between pure arc deposited layer and one with chromium coating with ND is performed.
- With increasing the ND concentration to 42 g/l the wear resistance is increased.
- The biggest wear resistance is achieved in samples with chromium coating with 42 g/l ND and current density 45 A/dm^2. It is almost 5 times bigger than the one without chromium. At current densities 60 and 80 A/dm^2 the wear resistance is a little lower.

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