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A STUDY ON EROSIVE WEAR RESISTANCE OF DIFFERENT MULTILAYER COATINGS TYPES Cr/CrN/(CrN-Me_1Me_2N)$_{\mathrm{MULTINANO}}$/(Me_1Me_2N-VN)$_{\mathrm{MULTINANO}}$

Key words: multilayer coatings, erosive wear resistance.

Abstract: In the article, the authors present the results of erosion tests of five different material solutions of surface engineering, i.e. multilayer coatings type Cr/CrN/(CrN-Me_1Me_2N)$_{\mathrm{multinano}}$/(Me_1Me_2N-VN)$_{\mathrm{multinano}}$, where metals Me_1 and Me_2 were chosen from Al, Cr, Ti, Zr and Si. Multilayer coatings used for testing were deposited by the Arc Evaporation method. The research methods presented in the article focused on the analysis of surface topography of the multilayer coatings after erosion test. The erosive wear resistance of tested coatings was carried out by the modern research equipment designed and produced by Łukasiewicz Research Network- Institute for Sustainable Technologies in Radom. The erosive craters were analysed by using the interference microscope Talysurf CCI by Taylor Hobson. The chemical composition of the craters were analysed by using a Scanning Electron Microscope – SEM (Hitachi TM3000).

Badanie odporności na zużycie erozyjne różnych powłok wielowarstwowych typu Cr/CrN/(CrN-Me_1Me_2N)$_{\mathrm{multinano}}$/(Me_1Me_2N-VN)$_{\mathrm{multinano}}$

Słowa kluczowe: powłoki wielowarstwowe, odporność na zużycie erozyjne.

Streszczenie: W artykule autorzy zaprezentowali wyniki badań odporności na zużycie erozyjne dla pięciu różnych rozwiązań materiałowych typu powłoka wielowarstwowa Cr/CrN/(CrN-Me_1Me_2N)$_{\mathrm{multinano}}$/(Me_1Me_2N-VN)$_{\mathrm{multinano}}$, gdzie metale Me_1 and Me_2 wybrano spośród Al, Cr, Ti, Zr i Si. Powłoki wielowarstwowe wykorzystane do badań wykonano metodą Arc Evaporation. Metody badawcze przedstawione w artykule koncentrowały się na analizie topografii powierzchni powłok wielowarstwowych po testach erozyjnych. Badanie odporności na zużycie erozyjne wykonano przy zastosowaniu nowoczesnego urządzenia do badania erozji zaprojektowanego przez Sieć Badawczą Łukasiewicz – Instytut Technologii Eksploatacji w Radomiu. Kratery erozyjne zbadano przy zastosowaniu mikroskopu interferometrycznego Talysurf CCI firmy Taylor Hobson. Skład chemiczny powstałych kraterów zbadano przy zastosowaniu Skaningowego Mikroskopu Elektronowego – SEM (Hitachi TM3000).

Introduction

Multilayer coating create many possibilities for shaping the functional properties of machine elements and tools in many industries area. Their complex structure allows one to give several functional properties at the same time. These coatings, through the possibility of shaping the properties of individual component layers, are characterized by good resistance to complex mechanisms of destruction including the simultaneous action of several destructive factors. Erosion wear is this type of a complex mechanism of destruction. It is known from the literature that erosive wear is caused by the impact of solid or liquid particles on the surface of the object causing the following wear mechanisms [1-4]: micro-cutting, grooving, cracking and chipping of the material, fatigue wear, chemical and electrochemical reactions causing creating products of these reactions and their mechanical removal. Due to the complex mechanism of destruction, multilayer coatings seem to be the best material solution that can counteract these phenomena.

The authors proposed a certain material solution to improve erosive wear resistance. The proposed PVD coating includes three zones [5], where each zone has different properties (Fig. 1). Zone 1 is the Cr/CrN complex located directly on the tool surface, providing the required adhesion to the substrate. Zone 2 is a nano-multilayered coating CrN-$Me_1Me_2N_{multinano}$, which is a transition zone between the "adhesive complex," and Zone 3 is responsible for cooperation with the external material. In the coating CrN-$Me_1Me_2N_{multinano}$, where Me_1 and Me_2 are metals which are components of the nano-multilayer coating in Zone 3. In the case of the designed multilayer coating, Zone 3 consists of alternately applied layers of Me_1Me_2N and VN, with nanometric thicknesses, where Me_1, Me_2 ≈ Al, Cr, Ti, Zr, Si.

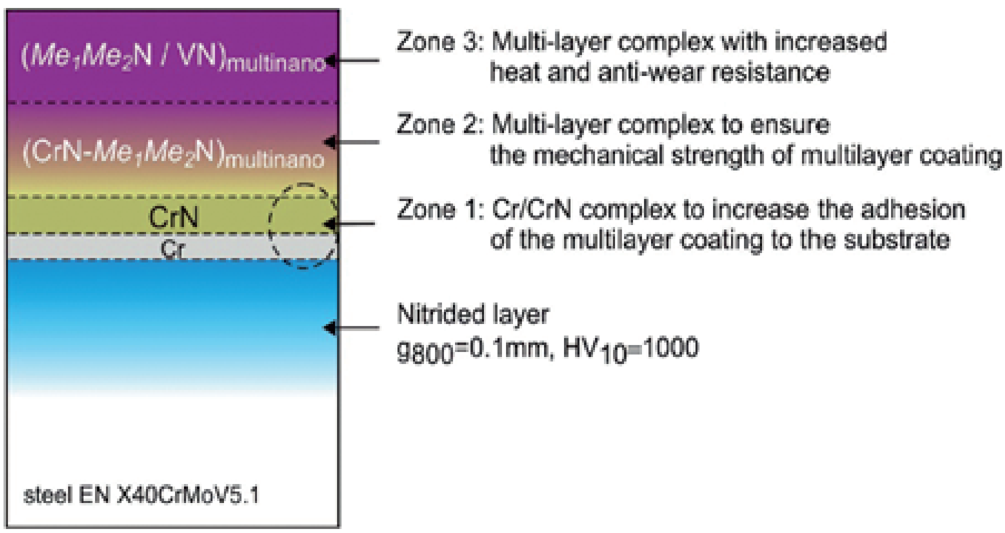

Fig.1. Scheme of multilayer coatings selected for testing [5]

The authors developed an extensive methodology of testing the properties of erosive wear resistance and conducted an analysis of how the chemical composition of the component layers in a multilayer coating can influence wear resistance.

A detailed description about composition of the multilayer coatings and their preparation method was presented in the publication [5].

1. Methodology

The samples were prepared for the research on nitrided steel ENX40CrMoV5.1 (nitride layer: HV10=1000-1100 HV, gHV800 ≈0.07mm), according to the Fig. 1. Multilayer coatings for testing were deposited by the Arc Evaporation method using the a MZ383 technological device produced by Metaplas Ionon in accordance with the parameters shown in Table 1.

Table 1. Parameters of PVD treatment

Component layer of multilayer coatings	Pressure in the chamber p_k [mbar]	U_{BIAS} [V]	I_z [A]	Temperature T [^oC]	Time t [min.]
Cr- CrN / $(CrN\text{-}CrAlN)_{multinano}$ / $(CrAlN\text{-}VN)_{multinano}$	$5.0x10^{-3}$ $3.5x10^{-2}$ $3.5x10^{-2}$ $3.5x10^{-2}$	-50 -150 -150 -150	3x55 (Cr) 3x55 (Cr) 2x55 (Cr) 2x55 (CrAl) 2x55 (CrAl) 2x55 (V)	T_k=400	10 22 30 54
Cr- CrN / $(CrN\text{-}TiAlN)_{multinano}$ / $(TiAlN\text{-}VN)_{multinano}$	$5.0x10^{-3}$ $3.5x10^{-2}$ $4.0x10^{-2}$ $4.0x10^{-2}$	-50 -150 -150 -100	3x55 (Cr) 3x55 (Cr) 2x55 (Cr) 2x55 (TiAl) 2x55 (TiAl) 2x55 (V)	T_k=400	10 22 35 57

Cr -CrN / $(CrN\text{-}TiZrN)_{multinano}$ / $(TiZrN\text{-}VN)_{multinano}$	$5.0x10^{-3}$ $3.5x10^{-2}$ $3.5x10^{-2}$ $3.5x10^{-2}$	50 -150 -150 -150	3x55 (Cr) 3x55 (Cr) 2x55 (Cr) 2x55 (TiZr) 2x55 (TiZr) 2x55 (V)	T_k=400	10 22 35 47
Cr -CrN / $(CrN\text{-}CrSiN)_{multinano}$ / $(CrSiN\text{-}VN)_{multinano}$	$5.0x10^{-3}$ $3.5x10^{-2}$ $3.5x10^{-2}$ 3.5x10	50 -150 -150 -150	3x55 (Cr) 3x55 (Cr) 2x55 (Cr) 2x55 (CrSi) 2x55 (CrSi) 2x55 (V)	T_k=400	10 22 24 40
Cr -CrN / $(CrN\text{-}VN)_{multinano}$	$5.0x10^{-3}$ $3.5x10^{-2}$ $3.5x10^{-2}$	-50 -150 -150	3x55 (Cr) 3x55 (Cr) 2x55 (Cr) 2x55 (V)	Tk=400	10 63 51

In all cases, the total thicknesses of the deposited coatings were similar and were in the range of 3.1 to 3.7 µm (Table 2). The basic mechanical properties of the obtained multilayer coatings are presented in Table 2 [5].

Table 2. The basic mechanical properties of five multilayer coatings selected for erosion tests [5]

Multilayer coatings	Thickness of coating [µm]	Hardness of the coating H [GPa]	Young Modulus E [GPa]	Resistance to elastic deformation H/E	Resistance to plastic deformation H^3/E^2
Cr-CrN / $(CrN\text{-}CrAlN)_{multinano}$ / $(CrAlN\text{-}VN)_{multinano}$ (P1.5)	3.5	25.4 ± 1.2	373 ± 28	0.068	0.117
Cr-CrN / $(CrN\text{-}TiAlN)_{multinano}$ / $(TiAlN\text{-}VN)_{multinano}$ (P2.5)	3.4	25.6 ± 1.4	400 ± 37	0.064	0.105
Cr-CrN / $(CrN\text{-}TiZrN)_{multinano}$ / $(TiZrN\text{-}VN)_{multinano}$ (P3.5)	3.7	24.9 ± 1.7	353 ± 16	0.071	0.124
Cr-CrN / $(CrN\text{-}CrSiN)_{multinano}$ / $(CrSiN\text{-}VN)_{multinano}$ (P4.5)	3.1	23.2 ± 1.5	333 ± 20	0.070	0.113
Cr-CrN / $(CrN\text{-}VN)_{multinano}$ (P5.5)	3.7	21.8 ± 1.6	327 ± 21	0.067	0.097

The erosive wear resistance tests were carried out in dust erosion conditions using a technological device designed and manufactured by Łukasiewicz Research Network – National Research Institute in Radom presented in Fig. 2. The authors described the precise construction and methodology of the device in the publication [6].

The detailed parameters were selected in accordance with the procedure described in standard ASTM G76-07, which is applicable to the study of erosion. Three steps of preparation were necessary to obtain repeatability and were carried out before proceeding with erosion tests. They are as follows:

1. Heating the abrasive particles Al_2O_3.
2. Heating of channels, that are responsible for mobilising the abrasive materials. (Stabilization of temperature in laboratory room).
3. Test of the repeatability the flow of abrasive flow.

Table 3 presents the parameters of the erosion test for five multilayer coatings.

Table 3. Parameters of erosion tests.

Parameters of erosion tests	Unit	Value
Velocity of the abrasive particles Al_2O_3	[m/s]	70
The angle of incidence of abrasive particles	[°]	40
The flow of abrasive particles	[g/min]	2
Time of the singe test	[min]	10
Temperature of test	[°C]	22

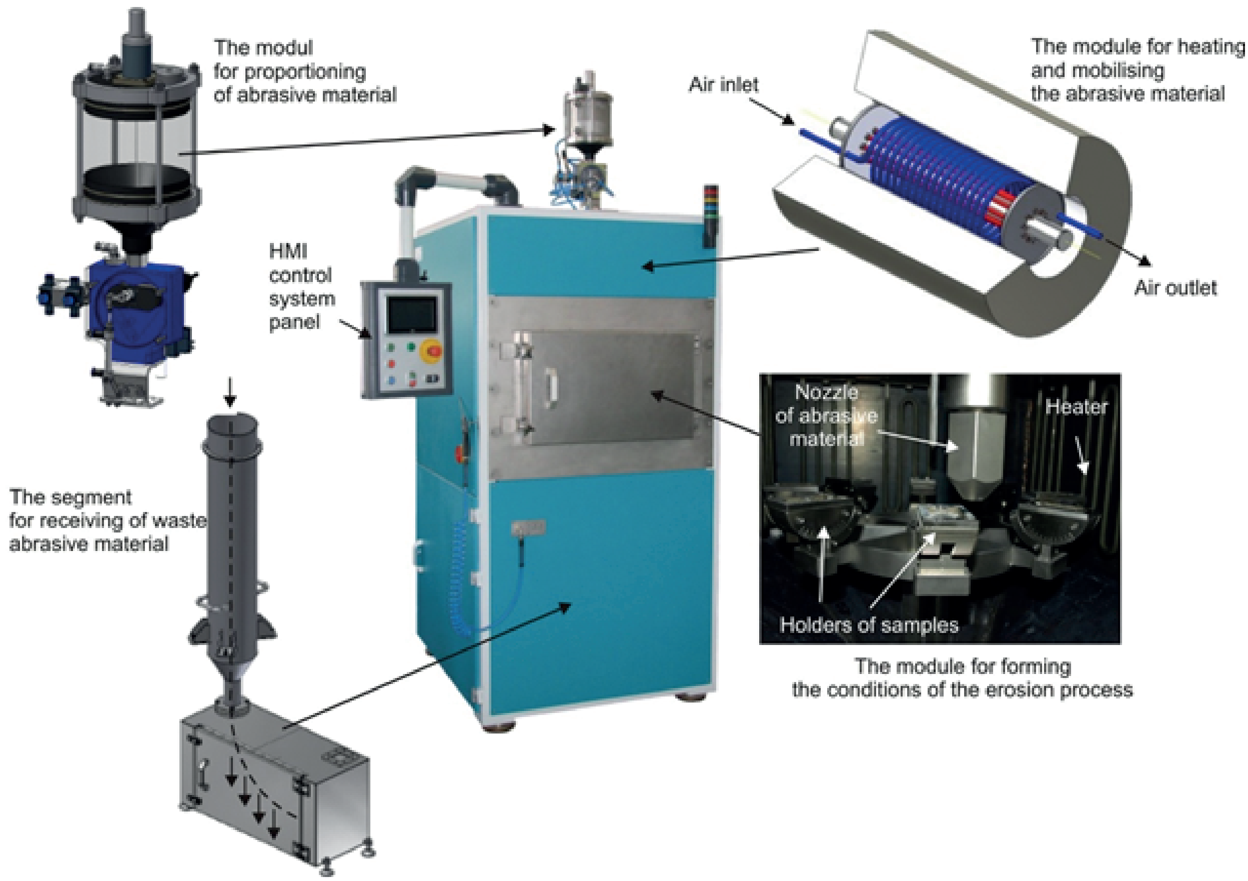

Fig. 2. The universal test equipment to carry out erosion tests

For each of the five multilayer coatings, three erosion tests were carried out. Before the next test cycle, the flow of abrasive particles was checked. The images of samples with marked craters formed after erosion tests and the direction of the abrasive particles are shown in Figure 3.

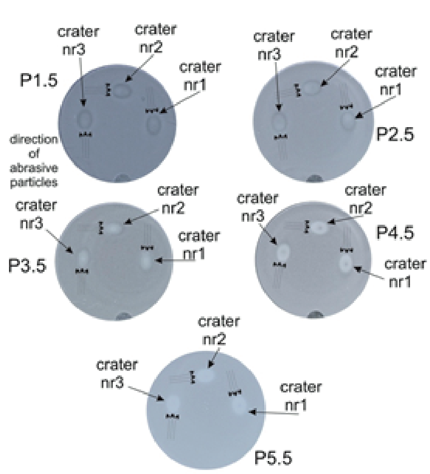

Fig. 3. Samples with craters which were formed after erosion tests

The obtained erosive craters were scanned using an interference microscope Talysurf CCI made by Taylor Hobson, which allows one to shape measurements by optical method with magnification 2.5 The craters analyses were performed by Mountains Map Universal 7.4.8737 program with possibility of 2D (profile) and 3D (topography) images. Based on the received results, the authors calculated the maximum depth and volume of the craters.

The analyses of the erosive mechanisms in tested multilayer coatings were made using the Scanning Electron Microscope – SEM (Hitachi TM3000) with the accelerating voltage of 15 kV. The quantitative analysis of the chemical composition and surface analysis of the chemical composition were performed in 3 selected places: on the surface outside the erosive crater, within ¼ of the resulting erosive crater, and within ½ of the resulting erosive crater as shown in Fig. 4.

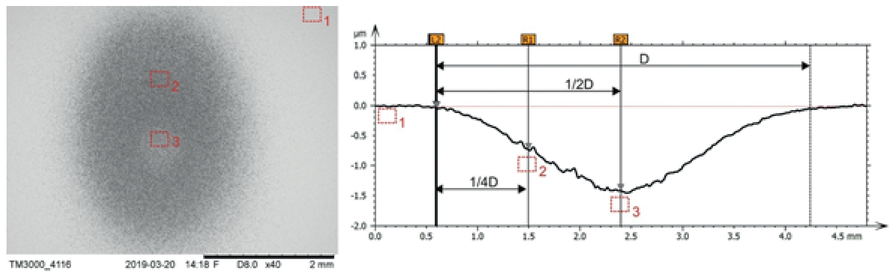

Fig. 4. Scheme of selected crater formed after erosion tests

2. Results and discussion

The results of erosive tests are presented in Figures 5 and 6. Figure 5 presents an analysis of erosive craters to assess their depth and surface. In the case of the two tested coatings, i.e., Cr-CrN/(CrN-CrSiN)$_{multinano}$/(CrSiN-VN)$_{multinano}$ (P 4.5) and Cr-CrN/(CrN-VN)$_{multinano}$ (P5.5), one can observe the formation of craters with much greater depth (approx. 1.5 µm) compared to other coatings. Within these craters is also visible a rough and heterogeneous surface, which indicates damage to the coating due to material chipping during erosion test. The craters formed on the remaining samples were characterized by a much smoother surface and much smaller depth (in the range of 0.5 to 1 µm), which proves their better resistance to abrasive particles.

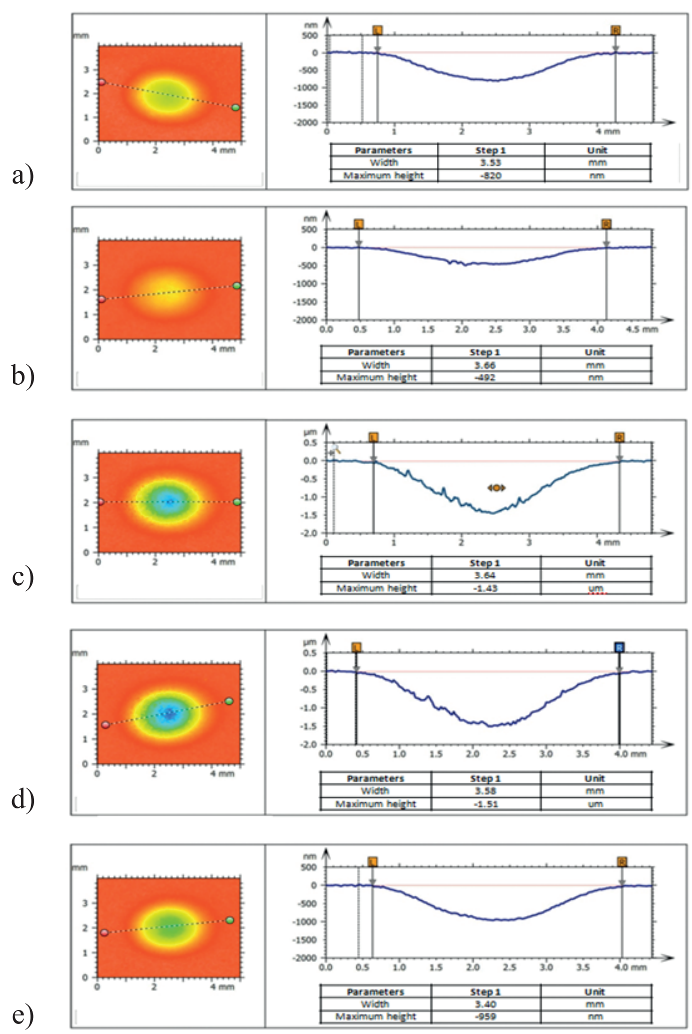

Fig. 5. Profile formed from the intersection of the erosive craters as a result of the erosive wear resistance test for coatings: a) Cr-CrN/(CrN-CrAlN)$_{multinano}$/(CrAlN-VN)$_{multinano}$ (P1.5), b)Cr-CrN/(CrN-TiAlN)$_{multinano}$/(TiAlN-VN)$_{multinano}$ (P2.5); c) Cr-CrN/(CrN-TiZrN)$_{multinano}$/(TiZrN-VN)$_{multinano}$ (P3.5); d) Cr-CrN/(CrN-CrSiN)$_{multiano}$/(CrSiN-VN)$_{multinano}$ (P4.5); e) Cr-CrN/(CrN-VN)$_{multiano}$(P5.5)

Analysis of the chemical composition of the erosive craters surface showed the presence of Al_2O_3 particles originating from the erosive stream, in all tested coatings. The presence of these particles indicates the fatigue wear of the material and its plastic deformation. In the case of coatings Cr-CrN/(CrN-CrSiN)$_{multinano}$/(CrSiN-VN)$_{multinano}$ (P 4.5) and Cr-CrN/(CrN-VN)$_{multinano}$ (P 5.5), one can observe a much higher density of these particles in the crater area. This indicates a lower fatigue resistance of these materials compared to other coatings. Similar results were also shown by the analysis of the volume of formed craters. In the case of two coatings i.e., Cr-CrN/(CrN-CrSiN)$_{multinano}$/(CrSiN-VN)$_{multinano}$ (P 4.5) and Cr-CrN/(CrN-VN)$_{multinano}$ (P5.5), a significantly larger volume of removed material (4.06E -03 ± 4.90E-04 mm^3) in comparison with other coatings was noted. The coating Cr-CrN/(CrN-TiZrN)$_{multinano}$/(TiZrN-VN)$_{multinano}$ (P3.5) was characterized by the smallest volume of formed craters (1.27E-03 ± 9.09E-05 mm^3) and the best erosion resistance.

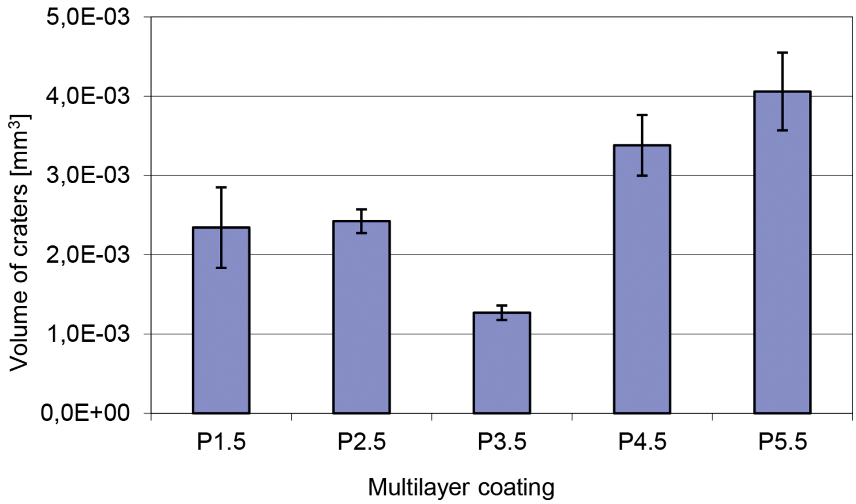

Fig. 6. The results of volume of erosive craters for the tested multilayer coatings

Conclusion

The analysis of the performed tests clearly showed that the coating Cr-CrN/(CrN-TiZrN)$_{multinano}$/(TiZrN-VN)$_{multinano}$ (P 3.5) was characterized by the best resistance to plastic deformation ($H^3/E^2 = 0.124$) and also exhibits the best erosive wear resistance. The research showed that the coatings characterized by the worst erosive wear resistance among the analysed samples were Cr-CrN/(CrN-CrSiN)$_{multinano}$/(CrSiN-VN)$_{multinano}$(P 4.5) and Cr-CrN/(CrN-VN)$_{multinano}$ (P 5.5). The craters formed as a result of the erosion tests of these coatings were characterized by the greatest depth, rough surface and the presence of a large amount of abrasive particles. It was confirmed that the dominant mechanism of wear material in the erosion process was intensive plastic deformation and fatigue wear. The low fatigue resistance of these coatings is associated with the low hardness (H4.5 = 23.2 ± 1.5 H5.5 = 21.8 ± 1.6) and the Young's modulus (E4.5 = 333 ± 20, E5.5 = 327 ± 21) of these materials.

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