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INFLUENCE OF COUNTERBODY MATERIAL ON SLIDING WEAR BEHAVIOUR OF NiCrSiB-TiB_2 PLASMA SPRAYED MATERIAL

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Wear behavior of NiCrSiB-20wt.%TiB_2 plasma sprayed coatings against NiCrSiB, Al_2O_3 and Cr_2O_3 counter bodies is studied under dry sliding conditions at sliding speed of 0.5 m/s and at constant load applied to the pin of 0.8 N. Running against the NiCrSiB plasma-sprayed NiCrSiB-20wt.%TiB_2 coating exhibits wear rate of 14 µm/km. The specific wear rate of NiCrSiB-20wt.%TiB_2 coatings against Cr_2O_3 is equal 12 µm/km and against Al_2O_3 is 10 µm/km. The investigation of worn surfaces shows that oxidative wear mechanism is proved to be dominant for friction couples. In all cases protective oxide layer is formed on the on the contact surfaces and protects the coating against any pronounced damages.

Key words: nickel - based self-fluxing alloy, titanium diboride, plasma-sprayed coating, wear.

Introduction

The wear resistance of functional surfaces is the critical factor for many machine parts in industrial applications. Wear-resistant coatings are employed to prevent severe wear of components whose surface is submitted to wear and corrosion at operation.

Nickel-based self-fluxing alloys are widely used as protective coatings for various engineering components [1-3]. As a rule, Ni-based alloys contain addition of boron, chromium, silicon and carbon in various amount. Chromium increases hardness of the coating by formation of hard phases such as chromium borides and carbides. Boron reduces melting point and contributes the formation of hard phases. Silicon is added to improve self-fluxing properties of alloy. Carbon produces hard carbides that results in increasing wear-resistance of coating.

However, their wear-resistance can be substantially improved by reinforcement with hard refractory compounds [4-8]. Titanium diboride with high hardness (33 GPa), low density (4.52 g/cm^3) and high melting point (2900 ^{o}C) has received considerable interests [9]. In this work, titanium diboride additives have been introduced in Ni-based self-fluxing alloy in order to enhance wear-resistance of plasma sprayed coatings.

In general case, the wear performance of protective coatings depends on their microstructure and properties as well as on the characteristics of tribological system, such as counter body material, loading conditions and sliding speed. Therefore, the investigation of wear behavior under various working conditions is essential for the designing wear-resistant coatings for any tribological applications.

The aim of this study is to understand the wear behavior of the NiCrBSi-20wt.%TiB_2 plasma sprayed coating in dry sliding conditions against different counter bodies. In this work the NiCrBSi, Al_2O_3 and Cr_2O_3 plasma sprayed coatings have been chosen as counter bodies because these materials have been widely used as wear-resistance coatings in surface engineering.

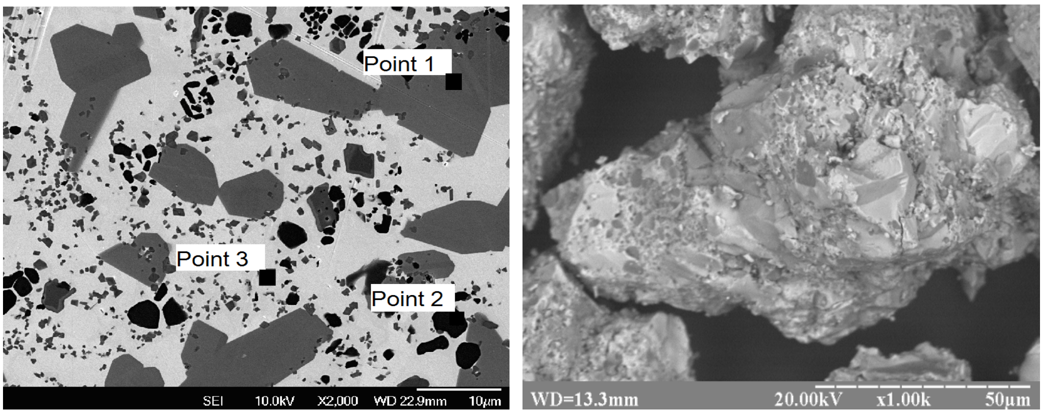
Methods and materials

In our experiment we have fabricated composite powder NTB20 (NiCrSiB-20wt.%TiB_2) for plasma-sprayed coating deposition. The commercially available powder of NiCrSiB alloy (Ni - base, Cr - 16 %, Si - 3.2%, C - 0.72%, B - 2.7%, Fe < 5%; 30-32 µm in size) was mixed with 20 wt.% of TiB_2 particles (98.7% purity; 2-3 µm in size). The powders mixture was cold compacted in a bulk under pressure of 50 MPa and subsequently sintered in vacuum at 1200 ^{o}C for 30 min.

The microstructure of NTB20 bulk materials, powder and coatings was investigated using the scanning electron microscope (SEM) equipped with an energy dispersive X-ray detector. One can see in fig.1a the images of the cross-sectional picture of sintered NTB20 bulk material. The developed composite material of (NiCrSiB-20wt.%TiB_2) system has the heterogeneous structure consisting of the matrix, the latter being reinforced with the borides inclusions. It has been found that sintering process induces chemical reactions between components of NiCrSiB-20wt.%TiB_2 system that leads to the active formation of CrB grains (Fig. 1, a, Point 1). The chromium boride inclusions have a size of 10-20 µm in size, the microhardness value being 22-26 GPa. The black phase (Fig. 2, a, Point 4) is the titanium boride grains with the 33.6 GPa microhardness value. The metal matrix represents itself Ni-based solid solution with microhardness of 6 - 7 GPa.

The sintered composite material of NiCrSiB-TiB_2 system was crushed and classified into a powder of size range (+ 60 to −100) μm (Fig. 1, b). The morphology of sieved and classified powder is shown Fig. 1, b. The powder is seen to be angular as result of crushing process. Each particles of obtained powder is a conglomerate, comprising both the metal-matrix and reinforcement grains.

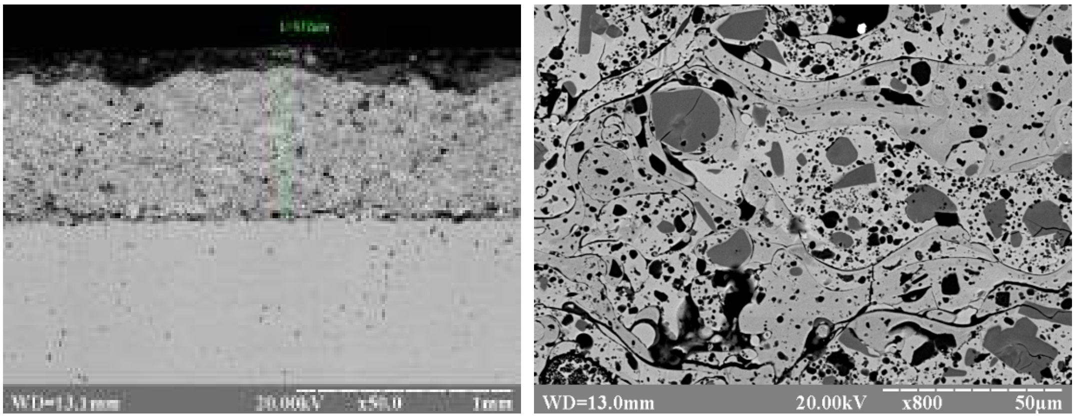
The composite powder NTB20 was deposited by plasma spraying using УПУ-3Д-М installation. The spraying parameters were: spray distance – 150 - 160 mm, spray current – 450 - 500 A, plasma gas flow rate - 2.6-3.2 m^3/h. Cylindrical steel pins with dimensions of 15mm × 5mm were used as the substrates. Prior to spraying the specimens were cleaned and grid blasted.



a b

Fig. 1 – Structure of NTB20 composite material (a) and morphology of NTB20 powder (b)

Fig. 2a shows the NTB20 coating approximately 500 μm thick which appears to be well bonded to the steel substrate (Fig. 2, a). The heterogeneous structure of plasma sprayed NTB20 coating conforms to the structure of bulk materials and powder: titanium diboride and chromium boride grains are distributed in nickel-rich metal matrix (Fig 2, b).



a b

Fig. 2 – SEM image of plasma-sprayed NTB20 coating

The surface of deposited NTB20 coatings were polished using 240/280, 400/800 and 2400 grit paper. Due to the brittle failure during polishing process some grains of chromium boride have been pulled out form matrix that leads to the formation of pits on the coating surface.

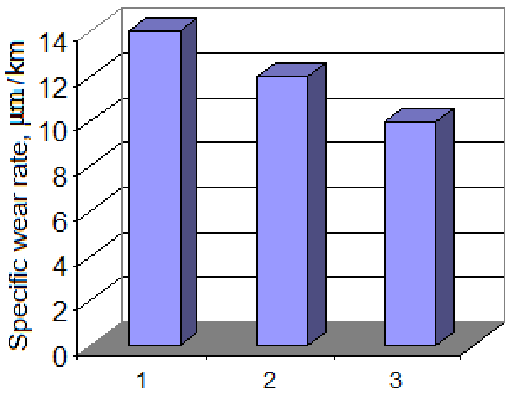
Sliding wear behavior of NiCrSiB-20wt.%TiB_2 coating was examined using CETR-UMT-2 tribometer in pin-on-disk configuration. Wear tests were carried out under dry sling conditions at constant sliding speed of 0.5 m/s and normal load applied to the pin of 0.8 N. NTB20-coated cylindrical pins were used as test samples. Wear tests were performed using different counter bodies: NiCrSiB, Al_2O_3 and Cr_2O_3 coatings deposited on steel discs by plasma spraying. Wear track diameters in our experiments were 10 mm. Wear rates of friction couples were calculated for 1 km sliding distance. The friction coefficients were detected automatically during the test.

Before each test the working surfaces of the pins were preliminary run-in against SiC abrasive sheets, fixed on the flat surface of disc. After run-in tests both the specimen and counter body disc were cleaned with alcohol to remove any possible contaminants.

The worn surfaces were observed using optical and scanning electron microscopy to determine the wear mechanisms of NTB20 plasma-sprayed coatings against NiCrSiB, Al_2O_3 and Cr_2O_3 coatings under dry sliding conditions.

Experimental results and discussion

The wear rates and friction coefficients of NTB20 running against different counter bodies are presented in fig. 3. Under the tribological conditions employed in this study the wear-resistance of NTB20 (NiCrSiB-20wt.%TiB_2) coating against Al_2O_3 and Cr_2O_3 is better than against NiCrSiB (14 μm/km). The specific wear rate of NiCrSiB-20wt.%TiB_2 coatings against Cr_2O_3 is equal 12 μm/km, friction coefficient is equal 0.6. Running against Al_2O_3, the NTB20 plasma-sprayed coating exhibits the lowest wear rate of 10 μm/km and friction coefficient of 0.5.



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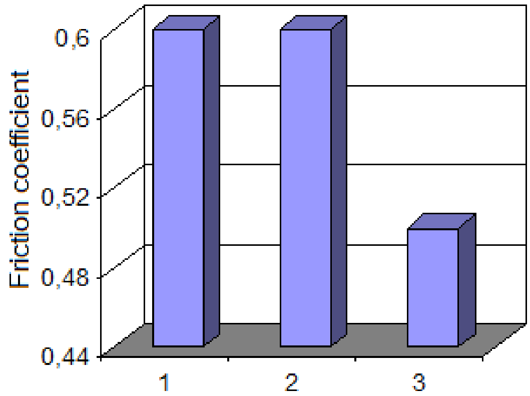


b

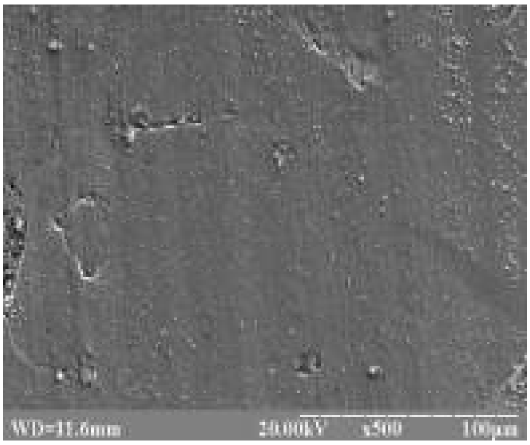
Fig. 3 – Wear rate (a) and friction coefficient (b) of tribocouple:
1- NTB20-NiCrSiB;
2- NTB20-Cr_2O_3;
3 - NTB20-Al_2O_3

The morphology and microstructure of NTB20-coated pins and NiCrSiB, Al_2O_3, Cr_2O_3-coated discs after wear tests are shown in fig. 4 - 6. After wear test the NTB20 pin, having been in sliding contact with NiCrSiB disc, has smooth surface and any signs of adhesion interaction or brittle failures have not been observed (Fig. 4, a - b). The worn surfaces of NiCrSiB-coated counter body contains only some signs of damages (Fig.4c-d). The worn surfaces of NTB20 plasma-sprayed coatings, having been tested against Cr_2O_3 and Al_2O_3 counterfaces, are smooth, without any sings of cracks and adhesive seizure. The worn surfaces of Cr_2O_3 and Al_2O_3-coated disks also does not contain any pronounced damages (Fig. 5, Fig 6).

The wear mechanism of NTB20-NiCrSiB tribocouple has been studied using optical microscopy, scanning electron microscopy and Auger electron spectroscopy [10, 11]. It was determined that the insertion of TiB_2 particles into NiCrSiB self-fluxing alloy leads to the increase of coating hardness and promotes formation of protective oxide films on the mating surfaces, that prevent adhesive interaction between NTB20 and NiCrSiB coatings under dry sliding conditions [10]. Oxidative wear mechanism is proved to be dominant when NTB20 coating slides against NiCrSiB coating. It has been shown that formation of a stable oxide layer containing various oxides (TiO_2, B_2O_3, NiO, Cr_2O_3) are responsible for wear process of NTB20-NiCrSiB tribocouple [11]. In this case oxide films are formed on the sliding surfaces and prevent severe damages of contact surfaces.

Energy Dispersive X-Ray Analysis (EDX), performed on the worn surface of NTB20 plasma-sprayed coating having been in sliding contact with Al_2O_3-coated disk, has indicated large amount of aluminium and oxygen (Fig. 5, b, Table 2). One can see, that particles of Al_2O_3 have filled into the pits on the NTB20 coating surface and serve as separating layer between mating surfaces. On the other hand, nickel has been observed on the majority of wear track area of Al_2O_3 disk (Fig. 4, Table 2), suggesting the intensive transferring of NTB coating material on the surface of counter body. It seems as oxidized nickel is smeared on the sliding surface of counter body that promotes formation of uniform protective layer between sliding surfaces.

The wear mechanism of NTB20-Cr_2O_3 tribocouple appears to be very similar to that of NTB20-Al_2O_3 tribocouple. However, the particularity of tribological behavior of NTB20 coating against Cr_2O_3 counter body is the active generation of wear debris during wear test. EDX analysis has detected that wear debris on the worn surface of NTB20-coated pin mainly contains chromium, oxygen and nickel (Fig.6, Table 3). This debris fills up cavities on the NTB20 coating surface, smoothing it. It should be noted that large amount of wear particles is scattered all over the contact surface of Cr_2O_3-coated disk and can be easily removed by air flow (Fig. 6). Transferring layer of NTB20 coating material has not been determined on the Cr_2O_3 sliding surface. Taking into consideration the results of wear tests and worn surfaces observation it is reasonable to assume that formation and further removing of wear debris is the cause of a little higher wear rate of NTB20-Cr_2O_3 tribocouple as compare with NTB20-Al_2O_3 tribocouple.



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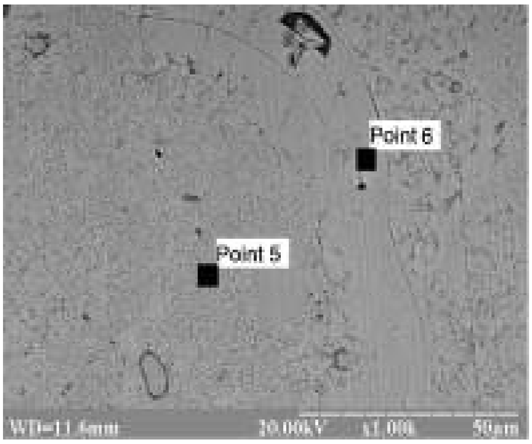

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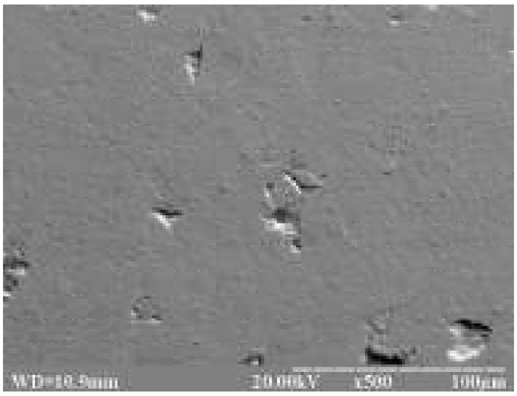

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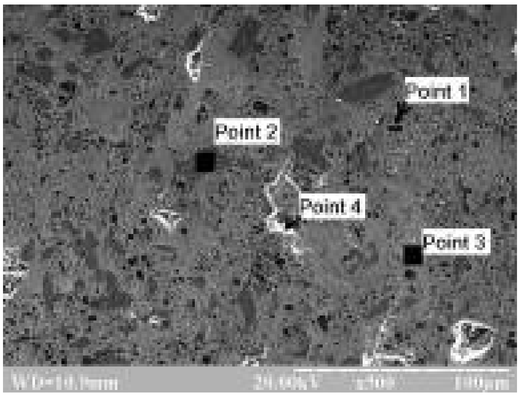


d

Fig. 4 – Morphology and microstructure of worn surfaces of NTB20-NiCrSiB tribocouple:
a, b – worn surface of NTB20-coated pin;
c, d – worn surface of NiCrSiB-coated disc

Table 1

Results of chemical analysis of worn surfaces of NTB20 - NiCrSiB tribocouple

Sample	Point	Phase composition [wt. %]						Phase
		O	Cr	Ni	Ti	Fe	Si	
NTB20 - coated pin	№1	17.13	2.27	2.90	77.42	0.28	-	Titanium diboride
	№2	5.93	89.35	2.15	1.6	0.53	0.44	Chromium boride
	№3	1.16	7.08	79.83	4.28	4.82	2.83	Ni-based matrix
	№4	10.56	24.31	54.32	5.69	2.37	2.75	Wear debris
NiCrSiB - coated disk	№5	4.05	10.56	80.22	-	2.57	2.6	Ni-based matrix
	№6	5.31	17.14	72.64	-	3.05	1.86	Ni-based matrix

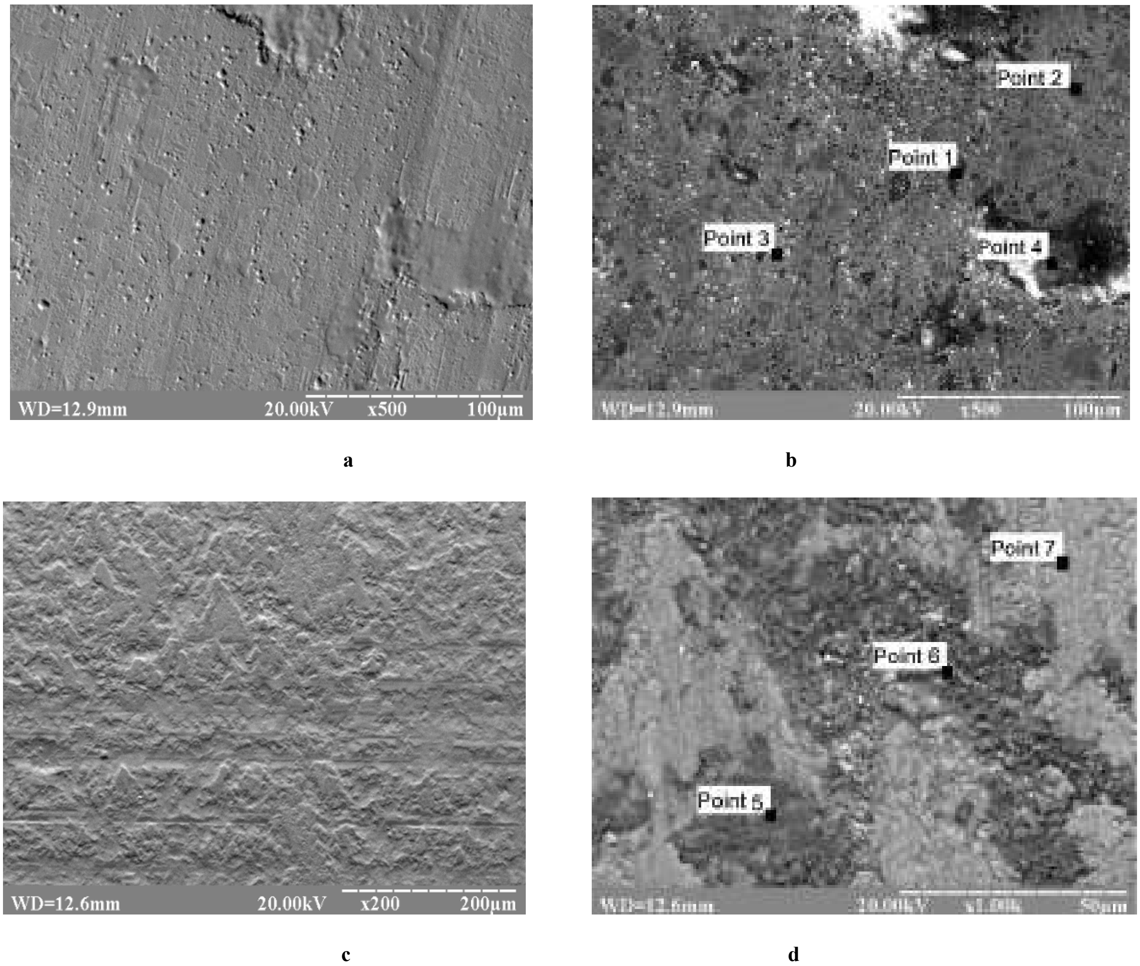
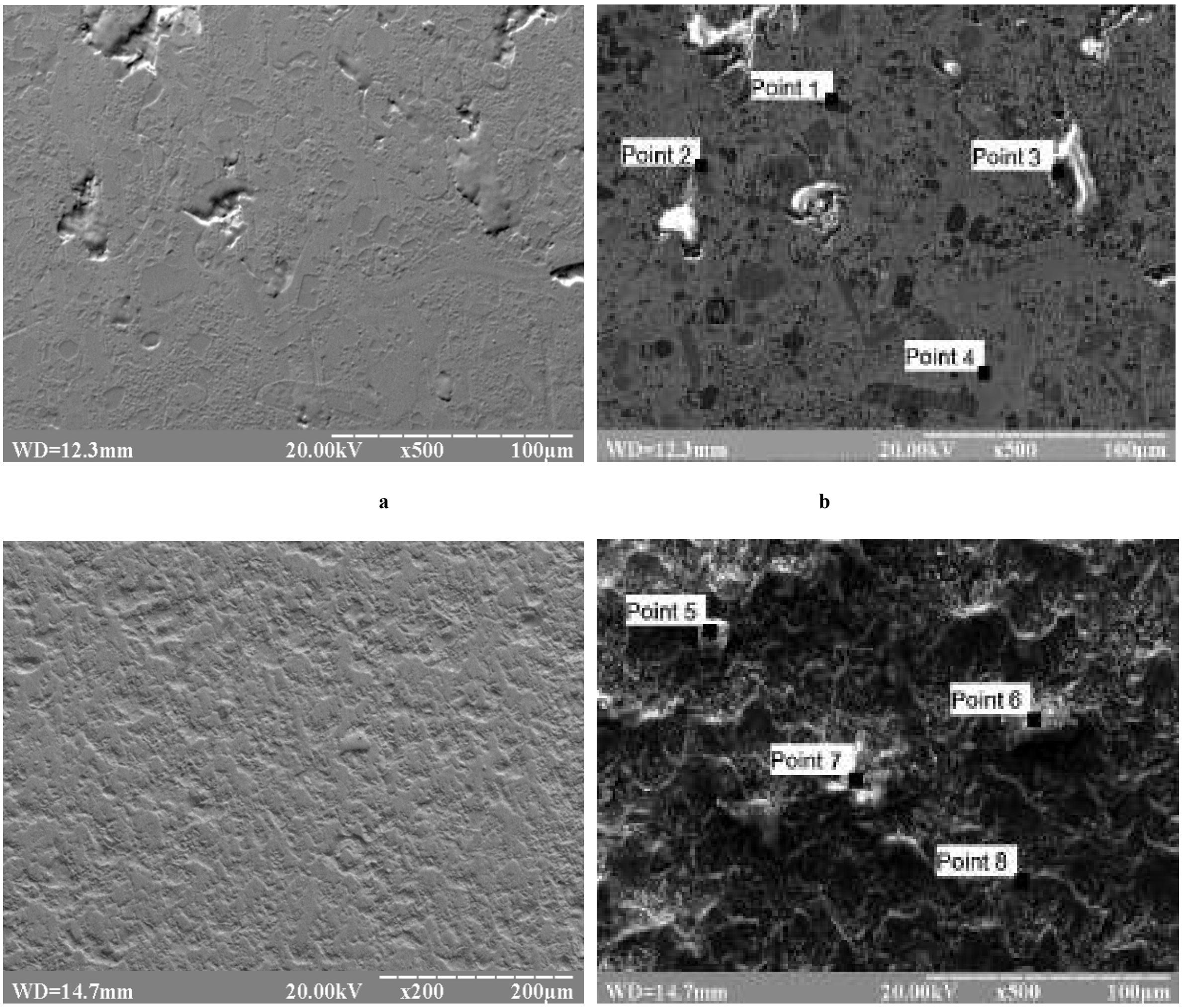


Fig. 5 – Morphology and microstructure of worn surfaces of NTB20-Al_2O_3 tribocouple:
a, b – worn surface of NTB20-coated pin;
c, d – worn surface of Al_2O_3-coated disc

Table 2

Results of chemical analysis of worn surfaces of NTB20 - Al_2O_3 tribocouple

Sample	Point	Phase composition [wt. %]							Phase
		O	Cr	Ni	Ti	Fe	Si	Al	
NTB20-coated pin	№1	16.51	2.22	3.90	76.56	0.35	-	-	Titanium diboride
	№2	5.18	89.05	2.17	1.95	1.18	0.48	-	Chromium boride
	№3	1.17	6.03	80.51	4.12	2.19	2.83	3.15	Ni-based matrix
	№4	39.65	5.11	25.25	6.33	1.93	2.22	19.52	Wear debris
Al_2O_3-coated disk	№5	34.45	5.24	21.71	6.41	1.76	2.39	28.05	Al_2O_3 with tribofilm
	№6	35.08	0.51	3.18	2.51	0.14	1.37	56.58	Al_2O_3
	№7	38.84	4.31	17.48	5.49	1.11	2.35	30.42.	Al_2O_3 with tribofilm



a b

c d

Fig. 6 – Morphology and microstructure of worn surfaces of NTB20-Cr$_2$O$_3$ tribocouple:
a, b – worn surface of NTB20-coated pin;
c, d – worn surface of Cr$_2$O$_3$-coated disc

Table 3

Results of chemical analysis of worn surfaces of NTB20-Cr$_2$O$_3$ tribocouple

Sample	Point	Phase composition [wt. %]						Phase
		O	Cr	Ni	Ti	Fe	Si	
NTB20-coated pin	№1	13.51	0.68	2.96	82.95	0.35	-	Titanium diboride
	№2	4.72	91.11	2.56	1.23	0.23	0.15	Chromium boride
	№3	40.54	17.35	30.64	6.91	2.41	2.15	Wear debris
	№4	0.95	8.63	76.51	7.14	3.99	2.79	Ni-based matrix
Cr_2O_3-coated disc	№5	37.48	28.79	24.19	4.78	2.85	1.91	Wear debris
	№6	33.53	45.77	10.01	4.18	5.22	1.29	Wear debris
	№7	31.07	51.52	13.04	3.11	0.43	0.82.	Wear debris
	№8	31.7	56.52	7.80	1.88	1.34	0.75.	Cr_2O_3

Conclusions

Tribological studies have been carried out on NTB20 plasma-sprayed coating against NiCrSiB, Al_2O_3 and Cr_2O_3 counter bodies under dry sliding conditions. It was determined that oxidative wear mechanism is dominant for the NTB20-NiCrSiB tribocouple. The formation of complex oxide film that is proved to be a mechanical mixture of B_2O_3, TiO_2 and NiO, Cr_2O_3 oxides is responsible for high wear resistance of NTB20 coating in this case. The NTB20 coating has shown good wear-resistance having been in sliding contact with Al_2O_3 and Cr_2O_3. This is also caused by active formation of oxide layer on the NTB20 coating surface: wear debris, has been generated mainly from oxide ceramics counter bodies, are filled in the pits on NTB20 coating surface. It provides formation of tribofilm which further prevents severe damages of NTB20 contact surface.

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Стороженко М.С., Уманский А.П., Терентьев А.Е., Костенко А.Д. **Влияние материала контртела на износостойкость и механизмы изнашивания плазменного покрытия системы NiCrSiB-TiB$_2$.**

Исследованы износостойкость и механизмы изнашивания плазменного покрытия системы NiCrSiB-20мас.%TiB$_2$ в паре трения с плазменными покрытиями NiCrSiB, Al_2O_3 и Cr_2O_3 в условиях трения скольжения без смазки при скорости скольжения 0,5 м/с и при постоянной нагрузке 0,8 Н. Структура плазменного покрытия НХТБ20 состоит из матрицы на основе никеля, в которой равномерно распределены упрочняющие зерна диборида титана и боридов хрома. Установлено, что износ покрытия NiCrSiB-20мас.%TiB$_2$ в паре трения с плазменным покрытием NiCrSiB составляет 14 мкм/км, в паре трения с покрытиями Al_2O_3 и Cr_2O_3 - 12 мкм/км и 8 мкм/км соответственно. В результате исследования поверхностей трения установлено, что основным механизмом изнашивания исследуемых пар трения является окислительный: в процессе трения на сопряженных поверхностях формируются защитные оксидные пленки, которые эффективно предотвращают повреждение покрытий.

Ключевые слова: самофлюсующийся сплав, диборид титана, плазменные покрытия, изнашивание**.**