TECHNICAL SCIENCES

STRUCTURAL-PHASE STATE AND PROPERTIES OF SPRAYED PLASMA COATINGS BASED ON SELF-FLUXING ALLOY OF NiCrBSi SYSTEM WITH THE ADDITION OF SHS COMPOSITES

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https://doi.org/10.5281/zenodo.10246932

Abstract
The structural-phase state and mechanical properties of plasma coatings sprayed with a composite material based on a self-fluxing alloy of the PG-10N-01 NiCrBSi system modified with a composite material obtained using self-propagating high-temperature synthesis were studied.

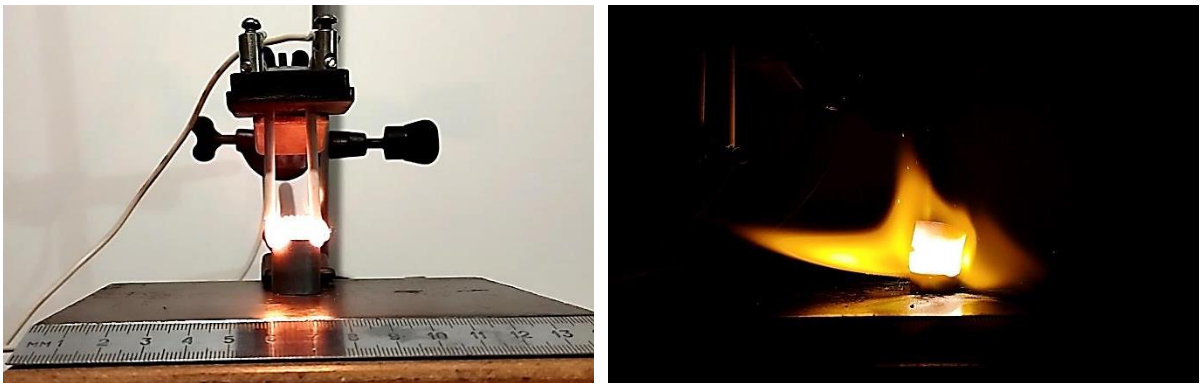
Keywords: Spraying, plasma coating, self-propagating high-temperature synthesis, composite material, structure, phase composition, microhardness, wear resistance.

Relevance of the research topic. Plasma spraying of self-fluxing alloys of the NiCrBSi system of PG-10N-01, PG-10N-04, PG-12N-02 brands is one of the effective technological methods used to increase the resource of the tillage machines parts. The main phases of plasma coatings of such alloys are a solid solution of nickel (γ-Ni), as well as a eutectic formed on its basis with a Ni_3B boride phase [1–3]. Inclusion of modifying additives, which are obtained by self-propagating high-temperature synthesis (SHS), to NiCrBSi allows to control the phase composition of the coating and obtain new compounds (phases) in the solid solution and eutectic. Those new compounds provide a higher level of physical and mechanical properties of the coating, which in many cases has composite structure.

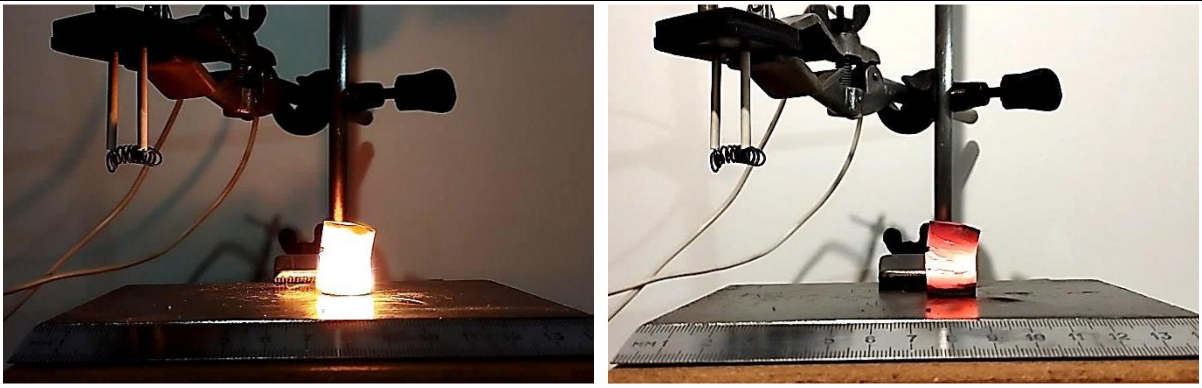
The aim of the paper – study of the structural-phase composition and mechanical properties of plasma coatings of the self-fluxing NiCrBSi alloy and the composite material obtained on its basis due to the addition of SHS composites.

Research materials and methodology. Spraying of plasma coatings was carried out with two experimental compounds: a self-fluxing alloy of the PG-10N-01 brand, as well as a composite material based on it, which was obtained using self-propagating high-temperature synthesis. The composite material was obtained in two stages. At the first stage, PTM-1 powders of titanium Ti, P-803 technical carbon C and PGOSA-0 refractory clay were used to obtain the modifying composite material (MCM). In order to enhance the thermal effect of the reaction, aluminum Al in the form of PAP-1 powder, iron oxide Fe_2O_3 and PT-NA-01 thermosetting powder were added to the initial charge. The particle size of the initial powders did not exceed 100 μm. The ratio of powders was equimolar, so that during the further passage of the SHS process, the synthesis of carbides of titanium TiC and silicon SiC of stoichiometric composition took place.

Mixing and mechanical activation of the charge was carried out in a BM-1 ball mill for 15 min at 130 rpm and a ratio of 1:40 of the mass of the charge to the mass of the falling bodies (steel balls with a diameter of 6 mm). After mechanical activation, the maximum particle size of the charge did not exceed 40 μm [4]. 10% of "Metylan" glue was added to the processed charge, after which a cylindrical sample with a diameter of 16 mm and a height of 20 mm was pressed. The sample was dried for 72 hours. Initiation of the SHS process of the sample was carried out with a heated nichrome spiral with a diameter of 0.8 mm (Fig. 1) using a specially developed device [5]. The SHS process was carried out in an argon medium with pure Ar 98 %.



a) *b)*



c) *d)*

Figure 1 – Stages of initiation and the SHS process of the sample: a – the beginning of the SHS process; b – SHS process; c – the end of the SHS process; d – cooling of the obtained spike.

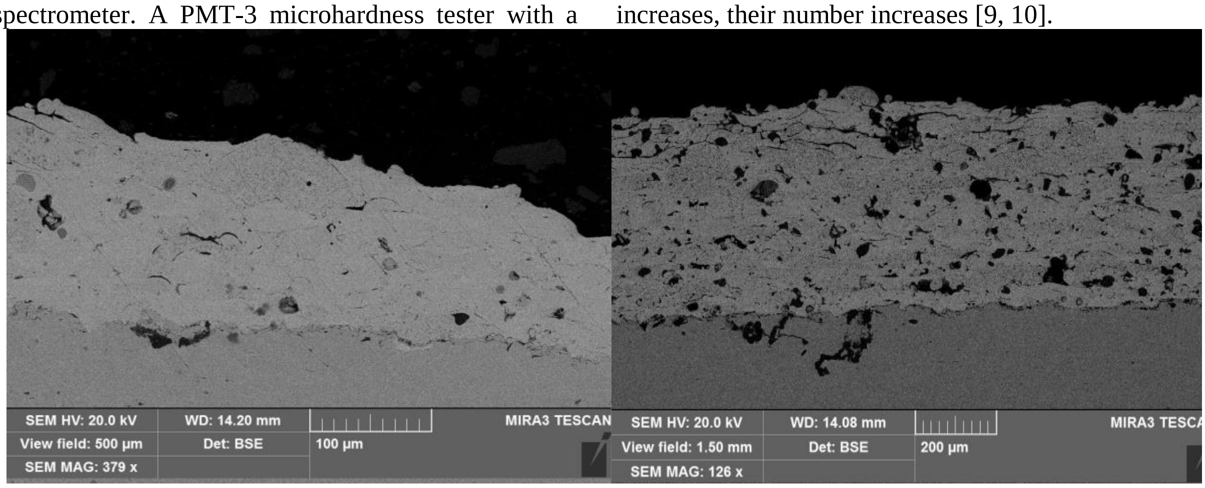
At the second stage, the MCM obtained in the form of a spike was crushed to a powdery state, after which an amount of 10% to 30% of MCM was added to the matrix material – self-fluxing PG-10N-01 alloy and mechanical activation was carried out for 15 minutes.

The application of plasma coatings was carried out using the MPN-004 with plasmatron MP-04 unit at E.O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine [6, 7]. Spraying process parameters are: electric current I = 45 A, voltage U = 30 V, consumption of plasma-forming gas Q_{pl} = 70 l/h, consumption of protective gas Q_{pg} = 280 l/h, spraying distance L = 100 mm. Spraying was carried out on samples made of 65G steel with a thickness of 3 mm. Previously, the samples were subjected to jet-abrasive treatment and ultrasonic cleaning was carried out on the surface with isopropyl alcohol for 15 minutes.

The microstructure and phase composition of the coatings were studied using a Neophot-32 optical microscope and a Tescan Mira 3LMU scanning electron microscope with an Oxford X-max energy dispersive spectrometer. A PMT-3 microhardness tester with a load of 0.1 kg was used to measure the microhardness of sprayed coatings.

The methodology described in [8] was used to determine the abrasive wear resistance of sprayed plasma coatings under the conditions of wear with an unfixed abrasive. The disk rotation speed was 60 rpm, the sample pressure force was 25 N, the abrasive size (dried quartz sand) did not exceed 200 μm. The relative wear resistance of sprayed coatings containing MCM was compared with the amount of wear of the coating sprayed with the PG-10N-01 alloy. The amount of wear was determined by the weight method using the VLR-200 analytical scales.

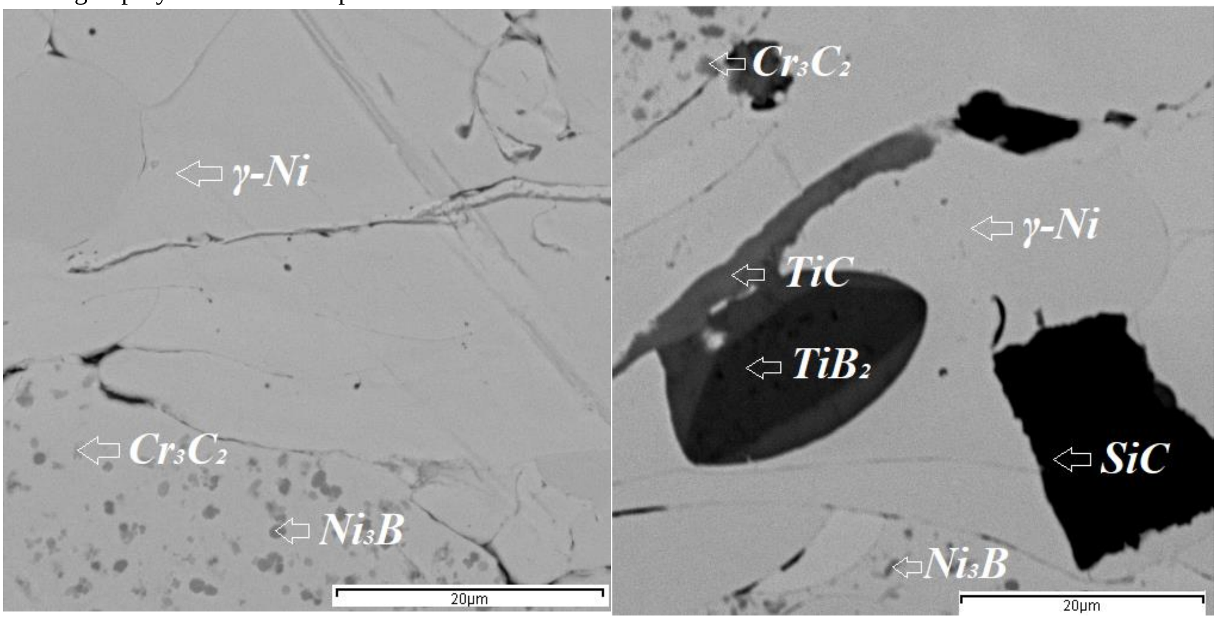
The main research material. When spraying both with the PG-10N-01 alloy and the composite material with a composition of 10% MCM + 90% PG-10N-01, dense, uniform in thickness coatings with a lamellar structure are formed (Fig. 2, a). The microstructure of the 10% MCM + 90% PG-10N-01 coating consists of the matrix material of the self-fluxing alloy PG-10N-01, in the lamellae of which there are inclusions of different sizes (Fig. 2, b). When the content of MCM increases, their number increases [9, 10].



a) *b)*

Figure 2 – Microstructure of sprayed plasma coatings: a – PG-10N-01; b – 10% MCM + 90% PG-10N-01.

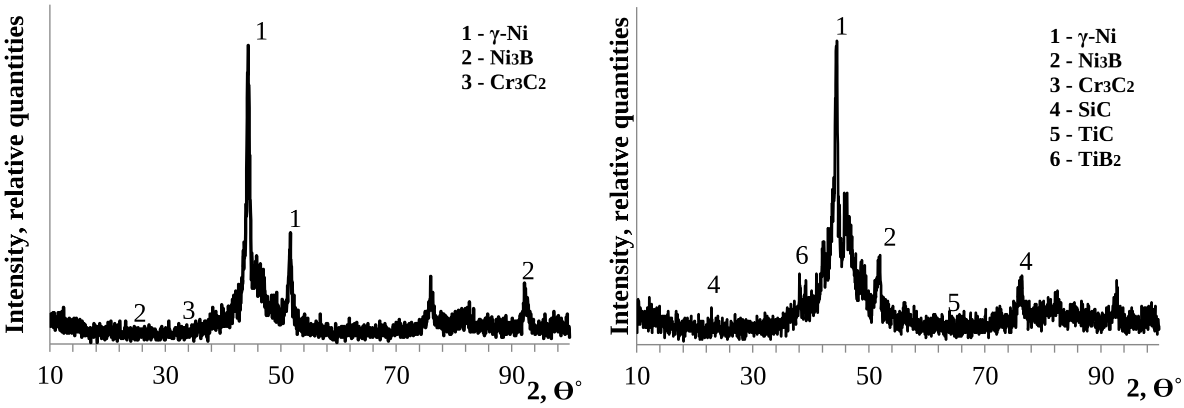
With the help of scanning electron microscopy with energy dispersive analysis, it was established that the basis of the sprayed PG-10N-01 coating is a solid solution of nickel (γ-Ni) with inclusions of nickel borides Ni_3B and chromium carbides Cr_3C_2 (Fig. 3, a). Coatings sprayed with a composite material with a composition of 10% MCM + 90% PG-10N-01, in addition to the solid solution based on nickel γ-Ni and the Ni_3B and Cr_3C_2 indicated above, contains phases of carbides of titanium TiC and silicon SiC, as well as titanium diborides TiB_2 (Fig. 3, b).



a) b)

Figure 3 – Microstructure and phase composition of sprayed plasma coatings:
a – PG-10N-01; b – 10% MCM + 90% PG-10N-01.

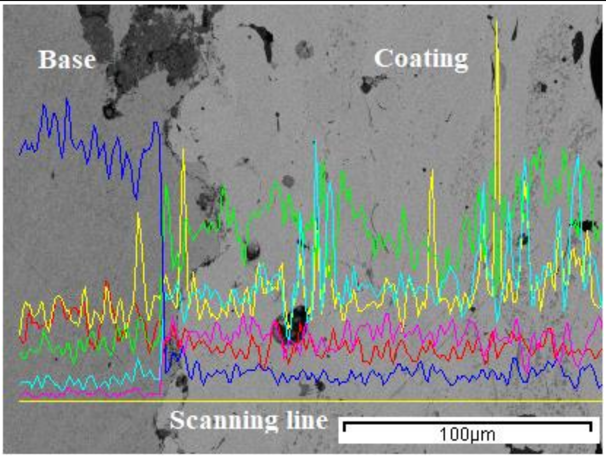
The conducted X-ray structural phase analysis confirmed the phase non-uniformity of the sprayed plasma coatings at the macro- and micro-levels with detected γ-Ni, Ni_3B, Cr_3C_2, TiC, SiC, TiB_2 phases (Fig. 4).

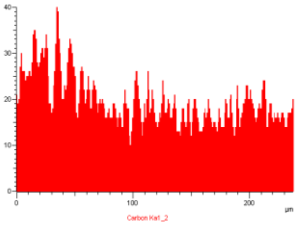
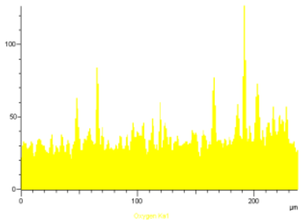
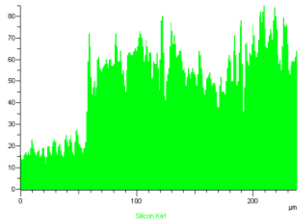


a) b)

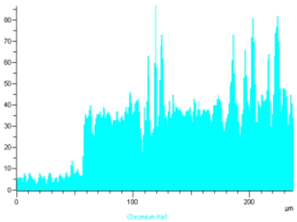
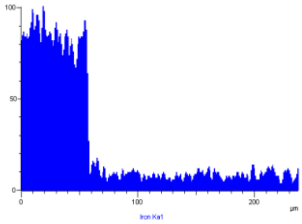
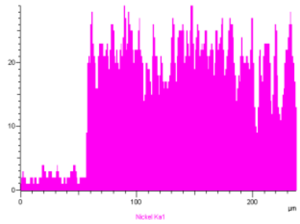
Figure 4 – Diffractograms of sprayed plasma coatings: a – PG-10N-01; b – 10% MCM + 90% PG-10N-01

The distribution of elements in sprayed plasma coatings with PG-10N-01 alloy (Fig. 5) and composite material with a composition of 10% MCM + 90% PG-10N-01 is determined with the method of scanning electron microscopy with energy dispersive analysis along the scanning line (Fig. 6).



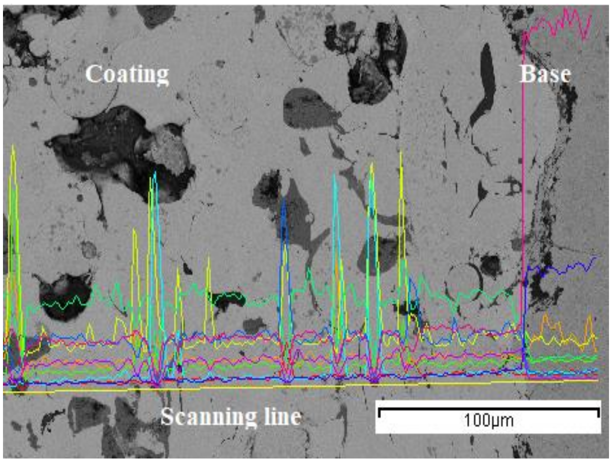




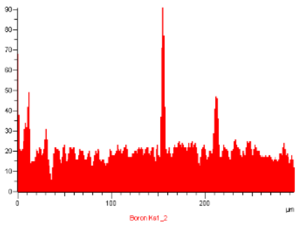
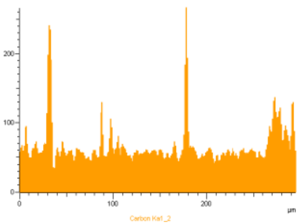
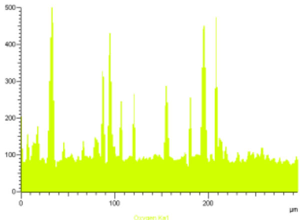
a) *b)* *c)*

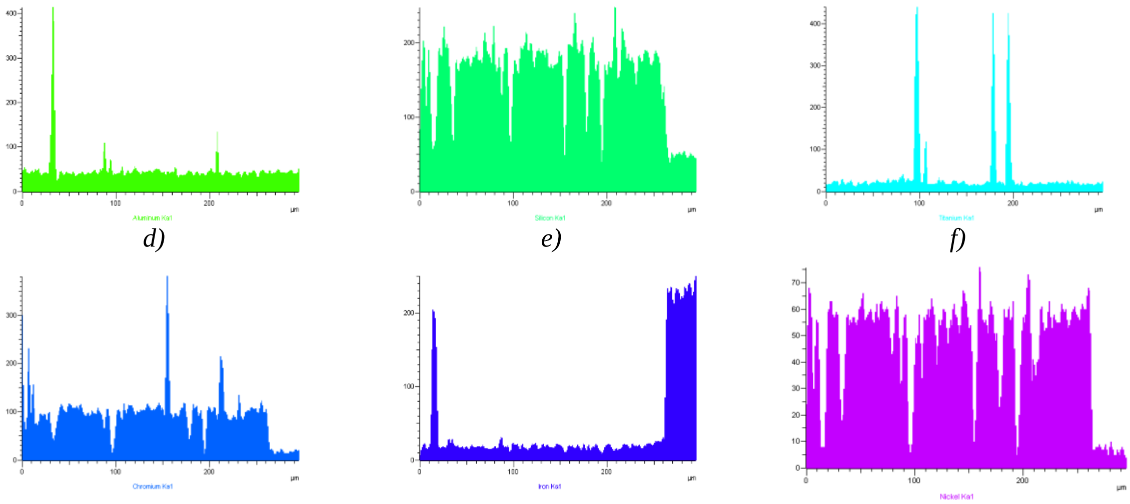
d) *e)* *f)*

Figure 5 – Distribution of elements of sprayed plasma coating of the PG-10N-01 alloy:
a – C; b – O; c – Si; d – Cr; e – Fe; f – Ni.



a) *b)* *c)*

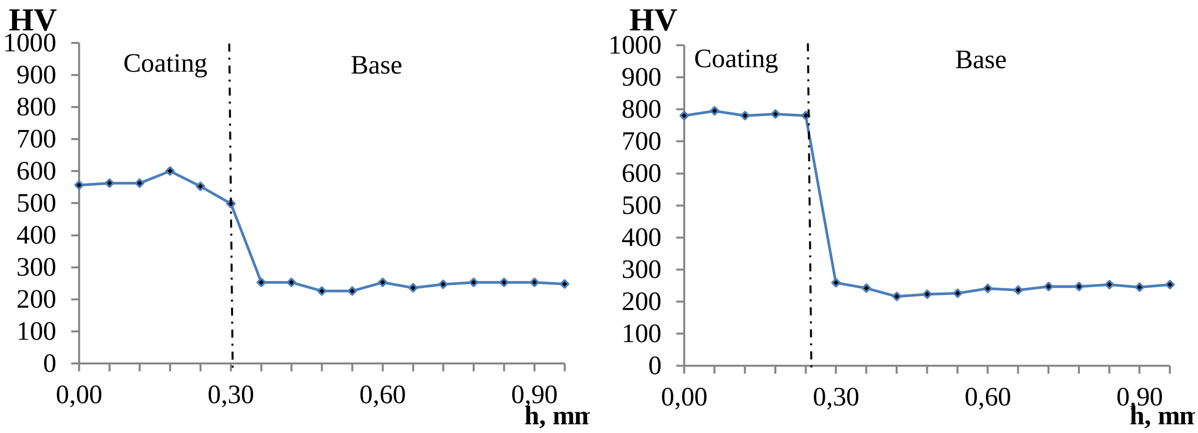


d) e) f)

g) h) i)

Figure 6 – Distribution of elements of sprayed plasma coating of composite material with a composition of 10% MCM + 90% PG-10N-01: a – B; b – C; c – O; d – Al; e – Si; f – Ti; g – Cr; h – Fe; i – Ni

The microhardness of sprayed plasma coatings, measured in the direction from the surface of the coating to the surface of the base, is shown in Fig. 7.



a) b)

Figure 7 – Variation of microhardness (HV) of sprayed coatings in the direction from the surface of the coating to the surface of the base: a – PG-10N-01; b – 10% MCM + 90% PG-10N-01.

When measuring microhardness, it was found that the average microhardness of a sprayed plasma coating of a composite material with a composition of 10% MCM + 90% PG-10N-01 is 780 HV, with 20% MCM + 80% PG-10N-01 it is 835 HV, and with 30% MCM + 70% PG-10N-01 – 880 HV, which exceeds the average microhardness of the sprayed coating with the PG-10N-01 alloy, which is equal to 555 HV (Fig. 8). The stable nature of the microhardness distribution in the sprayed coatings of the composite material indicates the uniform distribution of TiC and SiC carbides, as well as diborides TiB_2, in the matrix material [9, 10].

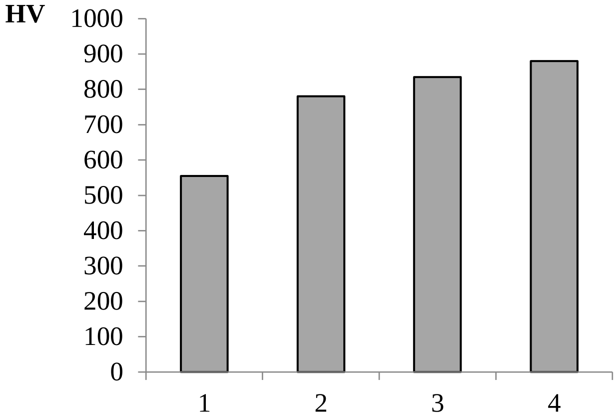
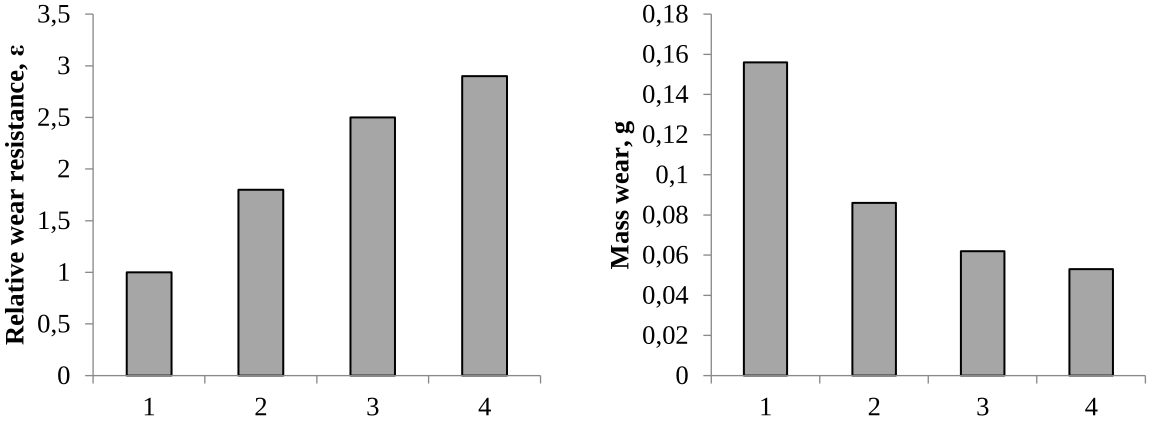


Figure 8 – Average microhardness (HV) of deposited plasma coatings (measured in the direction from the surface of the deposited coating to the surface of the base): 1 – PG-10N-01; 2 – 10% MCM + 90% PG-10N-01; 3 – 20% MCM + 80% PG-10N-01; 4 – 30% MCM + 70% PG-10N-01.

The results of studies of the coatings wear resistance under the conditions of abrasive wear with an unfixed abrasive are shown in Fig. 9.



a) *b)*

Figure 9 – Wear resistance of sprayed plasma coatings in the process of abrasive wear with an unfixed abrasive: a – relative wear resistance; b – wear of sprayed coatings; 1 – PG-10N-01; 2 – 10% MCM + 90% PG-10N-01; 3 – 20% MCM + 80% PG-10N-01; 4 – 30% MCM + 70% PG-10N-01.

When analyzing the results of measurements of the sprayed plasma coatings abrasive wear resistance, it was found that the coatings of the composite material have a higher abrasive wear resistance compared to the coating of the self-fluxing PG-10N-01 alloy. This is explained by the fact that in the structure of the sprayed coating with the composite material, along with the solid solution of nickel γ-Ni and $Ni_3B–Cr_3C_2$ inclusions, there are particles of carbides of titanium TiC and silicon SiC, as well as titanium diborides TiB_2. With an increase in the content of MCM, the number of these carbides and borides increases, accordingly, the wear resistance of the coating in the process of abrasive wear increases (Fig. 10).

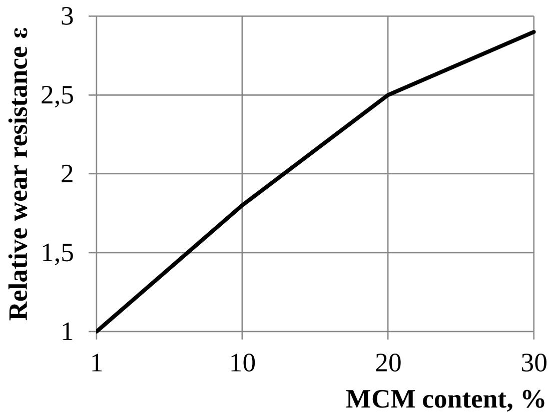
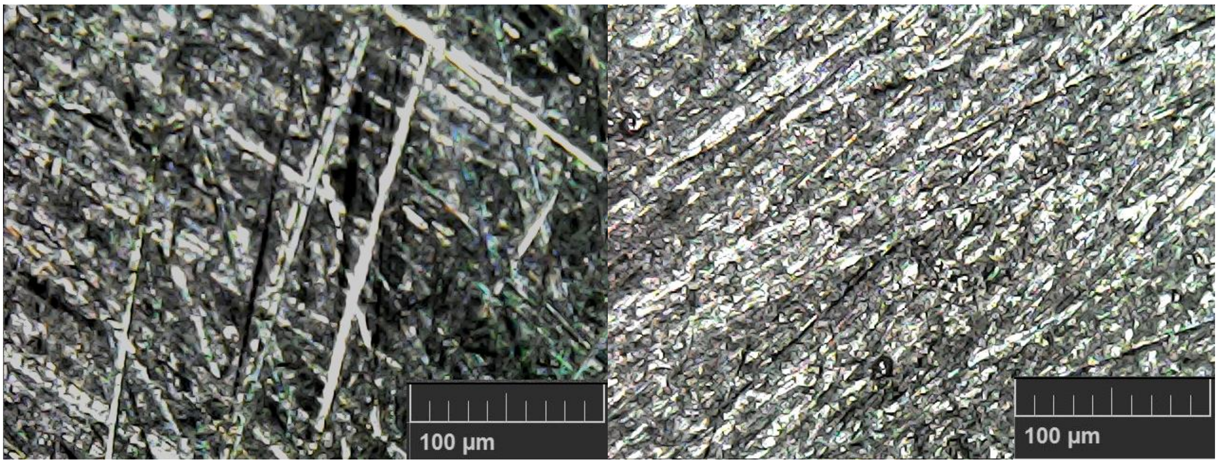


Figure 10 – Relative wear resistance of sprayed plasma coatings depending on the MCM content.

The morphology of the friction surfaces is shown in Fig. 11. On the friction surface of the plasma coating sprayed with the PG-10N-01 alloy, lines with a depth of up to 12 μm were detected (Fig. 11, a), the friction surface of the coating of the composite material of 10% MCM + 90% PG-10N-01 has lines with a depth of up to 7...9 μm (Fig. 11, b). When the MCM content increases, the depth of the lines decreases.



a) b)

Figure 11 – Morphology of friction surfaces of sprayed plasma coatings:
a – PG-10N-01, b – 10% MCM + 90% PG-10N-01.

The analysis of the obtained results shows that plasma coatings based on the self-fluxing alloy PG-10N-01, modified with a composite material obtained by self-propagating high-temperature synthesis, have a structure of a solid solution based on nickel (γ-Ni) and $Ni_3B–Cr_3C_2$ inclusions, as well as strengthening phases of carbides of titanium TiC and silicon SiC and diborides TiB_2. Added TiC, SiC, TiB_2 strengthen the solid solution based on nickel, which increases the microhardness and wear resistance of the coating [10].

Conclusions

A composite material based on the self-fluxing PG-10N-01alloy, modified with a composite material (MCM), obtained by self-propagating high-temperature synthesis (SHS) was obtained. To obtain MCM with the application of the SHS process, PTM-1 powders of titanium, P-803 technical carbon, iron oxide, PAP-1 aluminum, PT-NA-01 thermosetting powder and PGOSA-0 refractory clay were used.

It was established that the structure of the plasma coating sprayed with a composite material with a composition of 10% MCM + 90% PG-10N-01 consists of a solid solution based on nickel (γ-Ni) with Ni_3B-Cr_3C_2 inclusions and contains solid reinforcing phases in the form of carbides of titanium TiC and silicon SiC, as well as titanium diborides TiB_2. When the MCM content in the composite material increases, the amount of TiC, SiC, and TiB_2 increases as well, which increases the microhardness of the coating and increases its wear resistance.

The microhardness of the sprayed coating of the composite material with a composition of 10% MCM + 90% PG-10N-01 is 780 HV, with 20% MCM + 80% PG-10N-01 it is 835 HV, with 30% MCM + 70% of PG-10N-01 it is 880 HV, which exceeds the microhardness of the plasma coating sprayed with self-fluxing PG-10N-01 alloy, which is equal to 555 HV.

Under test conditions with unfixed abrasive, abrasive wear resistance of sprayed plasma coating of 10% MCM + 90% PG-10N-01 is by 1.8 times higher compared to the wear resistance of the plasma coating of the PG-10N-01 alloy. For the coating of 20% MCM + 80% PG-10N-01 it is by 2.5 times higher and for the coating of 30% MCM + 90% PG-10N-01 – by 2.9.

References:

1. Mrdak, M. R. Microstructure and mechanical properties of nickel-chrome-bor-silicon layers produced by the atmospheric plasma spray process. Vojnotehnicki glasnik. 2012. No. 60 (1). pp. 183–200. https://doi.org/10.5937/vojtehg1201183M

2. Röttger, A., Kuepferle, J., Brust, S., Mohr, A., & Theisen, W. Abrasion in Tunneling and Mining. International Conference on Stone and Concrete Machining (ICSCM). 2015. pp. 246–261. https://doi.org/10.13154/icscm.3.2015.246-261

3. Bergant, Z., Batic, B., Felde, I., Sturm, R., & Sedlacek, M. Tribological Properties of Solid Solution Strengthened Laser Cladded NiCrBSi/WC-12Co Metal Matrix Composite Coatings. Materials. 2022. No. 15 (1), p. 342. https://doi.org/10.3390/ma15010342

4. Luzan, S. O., & Sytnykov P. A. Study of the influence of the parameters of mechanical activation of the Ti–C–Al–SiO_2–Al_2O_3–Fe_2O_3–PT-NA-01 charge stock on the duration of the synthesis of the modifying composites. Bulletin of the Kharkiv Automobile and Road University. 2023. No. 100. pp. 42–47. https://doi.org/10.30977/BUL.2219-5548.2023.100.0.42 (in Ukrainian)

5. Luzan S. O., & Sytnykov, P. A. Study of the peculiarities of initiating the process of self-propagating high-temperature synthesis of a modifying composite material. Bulletin of Mykhailo Ostrogradsky National University of Kremenchug. 2023. No. 2 (139). pp. 102–109. https://doi.org/10.32782/1995-0519.2023.2.13 (in Ukrainian)

6. Borisov, Yu. S., Kyslytsa, O. N., Voinarovych, S. G., Kuzmych-Ianchuk, Ie. K. & Kaliuzhnyi, S. M. Investigation of plasmatron electric and energy

characteristics in microplasma spraying with wire materials. The Paton Welding Journal. 2018. No. 9. pp. 18–22. http://dx.doi.org/10.15407/tpwj2018.09.04

7. Borisov, Yu. S., Voinarovych, S. G., Fomakin, O. O., & Yushchenko, K. A. (2002) Plasmatron for spraying of coatings. Pat. Ukraine No. 2002076032, Int. Cl. B23K10/00. (in Ukrainian).

8. Student M. M., Voytovych A. A., Sirak Ya. Ya., Gvozdetskyi V. M., Karpenko G. V. Development of new electrode materials, methods of restoration and protection of thin-walled parts of equipment, which are operated in the conditions of gas abrasive wear. Automatic welding. 2020. No. 10. pp. 34–37. https://doi.org/10.37434/as2020.10.06 (in Ukrainian)

9. Luzan S. O., & Sytnykov P. A. Structure and properties of plasma coatings when sputtered with a composite material obtained using the SHS process. Visnyk of Kherson National Technical University. 2023. No. 2 (85). pp. 49–57. https://doi.org/10.35546/kntu2078-4481.2023.2.6 (in Ukrainian)

10. Sytnykov P. A. Plasma Coatings Based on Self-Fluxing NiCrBSi Alloy with Improved Wear Resistance Properties. Journal of Mechanical Engineering – Problemy Mashynobuduvannia, 2023. Vol. 26, No. 3, pp. 54–64. https://doi.org/10.15407/pmach2023.03.054