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STUDY OF THE STRUCTURE AND PROPERTIES OF DEPOSITED LAYERS OF NiCrBSi ALLOY, MODIFIED WITH COMPOSITE MATERIAL

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The structure and properties of deposited layers with a self-fluxing PG-10N-01 alloy of the NiCrBSi system, which is modified with composite material obtained by self-propagating high-temperature synthesis, were studied. Powders of titanium, technical carbon, refractory clay, aluminum, iron oxide, and PT-NA-01 thermosetting powder are used as the initial components of the modifying composite material. The powders were mechanically activated in a ball mill, pressed into a cylindrical sample, and then subjected to the process of self-propagating high-temperature synthesis. The deposition of the samples was carried out with a non-fusible graphite electrode with a diameter of 9.5 mm, at a current of 110 A, using an inverter power source SV-290NK. It was established that the structure of the layer deposited with the PG-10N-01 alloy consists of a solid solution based on nickel (γ-Ni) and a eutectic formed on its basis with Ni_3B boride. Single inclusions of carbides of chromium Cr_3C_2 and boron B_4C were also detected in the deposited layer. When adding a modifying composite material to the PG-10N-01 alloy, the structure of the deposited layer consists of γ-hard solution and eutectics, strengthened by carbides of titanium TiC and silicon SiC, which increase the microhardness and wear resistance of the layer. The microhardness of the layer deposited with the composite material, which contained 10% of the modifying component, is 660 HV, which exceeds the microhardness of the layer deposited with the PG-10N-01 alloy, which is equal to 510 HV. Based on the results of the research, operational tests of the set of duckfoot blades of the KPP-8 semi-trailer cultivator, aggregated with the New Holland T 6090 tractor, were carried out in the conditions of the Kamianuvatka farm (Novoukrainka district, Kirovohrad region). Based on the tests, it was proved that the relative wear resistance of duckfoot blades made of 65G steel, strengthened on the reverse side according to the "toe-working blade" scheme by depositing a layer of composite material is 1.7 times greater compared to the wear resistance of blades made by standard technology logic.

***Keywords**: self-propagating high-temperature synthesis, charge, composite material, deposition, deposited layer, carbide, structure, hardness, abrasive, wear resistance, machine parts.*

Problem statement

One of the methods that allows to increase the resource of the parts of tillage machines is the deposition of self-fluxing alloys of the NiCrBSi system on their working surfaces, which make it possible to create a protective layer of a given thickness on the surface of the part, which differs from the main metal of the part in terms of its physical and mechanical properties. The practice of using self-fluxing alloys of the NiCrBSi system indicates the need, and most importantly, the technological possibility of their strengthening due to the introduction of additional compounds of metal carbides, borides and nitrides, which improve the properties of the deposited material.

Analysis of known developments

The main phases of the layers of self-fluxing alloys of the PG-10N-01, PG-12N-01 brands of NiCrBSi system are a solid solution based on nickel (γ-Ni) and eutectic, which consists of γ-Ni and the boride phase Ni_3B [1–3]. Addition of the modifying impurities to NiCrBSi allows to control the phase composition of the material and obtain new compounds (phases) in the nickel matrix. Such layers, as a rule, have a composite structure.

Thus, the modification of NiCrBSi alloy with silicon carbide SiC particles is considered in [4]. The combination of the technology of plasma spraying of NiCrBSi alloy with the addition of titanium nitrides TiN and their subsequent induction remelting was carried out by the authors of the paper [5]. The paper [6] was devoted to the development of composite material of the NiCrBSi-TiB_2 type for coatings with a high level of wear resistance, and the paper [7] studied the modification of NiCrBSi alloys by introducing a rare-earth metal - yttrium oxide Y_2O_3.

A promising direction of NiCrBSi-alloys ыегвн is the addition of materials obtained by self-propagating high-temperature synthesis (SHS process) to them. The use of the SHS process makes it possible to obtain cheaper materials, which, in comparison with WC and VC, are not inferior in terms of their physical and mechanical properties, in particular, hardness and wear resistance [8]. Thus, the synthesized silicon carbide SiC from rice hulls, obtained with the use of the SHS process, is described in [9]. The high-temperature synthesis of the Cu–Ti–B_4C system is considered in the paper [10]. The paper [11] is devoted to the production of synthesized titanium carbide TiC using a special reactor made of wood.

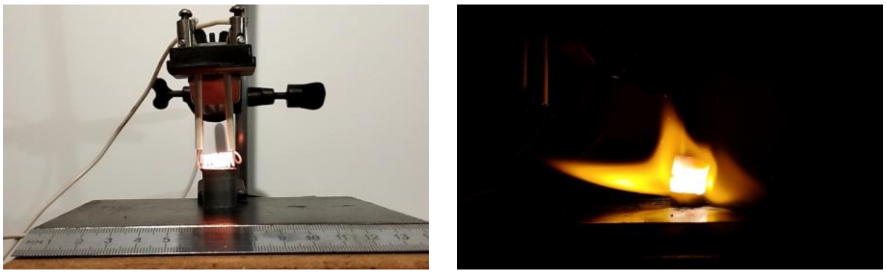
The research on the structures and properties of coatings depending on the method of their application is of great importance in the study of NiCrBSi alloys with the addition of various modifying impurities. According to the type of energy used during coating, coating methods are divided into six main groups: mechanical, thermomechanical, thermal, chemical-thermal, electrochemical, and physical ones [12]. Various methods can be used to obtain a certain surface layer with the required parameters. In [13], the structure and properties of sprayed plasma coatings (thermomechanical group) with a self-fluxing NiCrBSi alloy of the PG-10N-01 brand with the addition of carbides of titanium TiC and silicon SiC, obtained by the SHS process, were studied. Along with the plasma spraying method, one of the promising methods is the arc depositing method (thermal group).

The aim of the paper

Study of the structure and properties of the layers deposited with a self-fluxing NiCrBSi system alloy of PG-10N-01 brand, which is modified with composite material obtained by self-propagating high-temperature synthesis.

Research materials and methodology

Self-fluxing NiCrBSi system alloy of PG-10N-01 brand was used for deposition, as well as a composite material obtained on its basis using the SHS process. The composite material was obtained in two stages. At the first stage, mixing of PTM-1 titanium Ti powder, P-803 technical carbon, silicon SiO_2 and aluminum Al_2O_3 oxides (which were added in the form of PGOSA-0 thermosetting powder), PAP-1 aluminum AI powder, iron oxide Fe_2O_3 and of PT-NA-01 thermosetting powder was performed. The ratio of the components in the charge 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. The particle size index of all initial components did not exceed the size of 100 μm. Mixing and mechanical activation of the charge was carried out in a BM-1 ball mill for 15 minutes at 130 rpm and a 1:40 ratio of the mass of the charge to the mass of the grinding bodies (steel balls with a diameter of 6 mm). After mechanical activation, the maximum particle size of the charge did not exceed 40 μm [14]. 10% of Metylan glue was added to the resulting charge, mixed to a paste-like state, and a cylindrical sample with a diameter of 16 mm and a height of 20 mm, which was dried for 72 hours, was obtained using a special mold and a manual screw press. Initiation of the SHS process (Fig. 1) of the obtained sample was carried out in an environment of argon Ar with a purity of 98% using a special device from a heated nichrome spiral with a diameter of 0.8 mm. The initial temperature of the sample at the beginning of the reaction was 25 °C. After the start of the SHS process, the nichrome spiral was moved aside [15].



a b

Fig. 1. Self-propagating high-temperature synthesis of the modifying composite material:
a – initiation of the SHS process; b – SHS process

At the second stage, the modifying composite material (MCM) obtained in the form of spike was crushed to a powdery state, after which an amount of 10% to 30% of MCM was added to the self-fluxing PG-10N-01 alloy and mixed in a ball mill for 15 minutes.

The resulting mixtures in the form of powder were applied to the surface of the 65G steel sample with a 3 mm thick layer, after which arc depositing was carried out with a graphite electrode with a diameter of 9.5 mm, at a current of 100–110 A, with direct polarity. The SV-290 NK DC welding inverter was used as a power source.

The microstructure and phase composition of the deposited layers were studied by methods of metallographic analysis (Neophot-32 microscope equipped with a digital imaging attachment), electron microscopy (Tescan Mira 3LMU scanning electron microscope with an installed energy dispersive spectrometer Oxford X-max) and X-ray structural analysis (X-ray diffractometer Rigaku Ultima- IV). The microhardness of the deposited layers was measured using a PMT-3 microhardness tester using the Vickers method at a load of 0.1 kg [16].

The study of abrasive wear with unfixed abrasive was carried out in accordance with the information of the paper [17]. Dried quartz sand, the particle size of which did not exceed 200 μm, was continuously fed into the contact zone of the rubber disk and the sample. The rotation speed of the disk was 60 rpm, the sample pressure force was 25 N. The mass of the samples was measured using VLR-200 scales.

Research results

The microstructure of the layer deposited with the PG-10N-01 alloy has a dendritic structure (Fig. 2, a). The microstructure of the layer deposited with a composite material with a composition of 10% MCM + 90% PG-10N-01 has the structure of the matrix material of the self-fluxing PG-10N-01 alloy with distributed inclusions of different sizes and morphologies (Fig. 2, b).

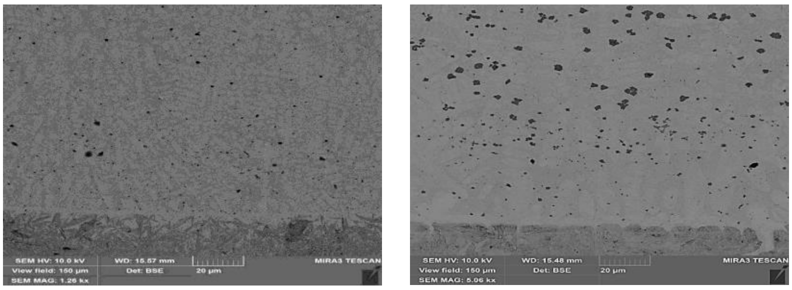


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Fig. 2. Microstructure of the deposited layers:
a – PG-10N-01; b – 10% MCM + 90% PG-10N-01

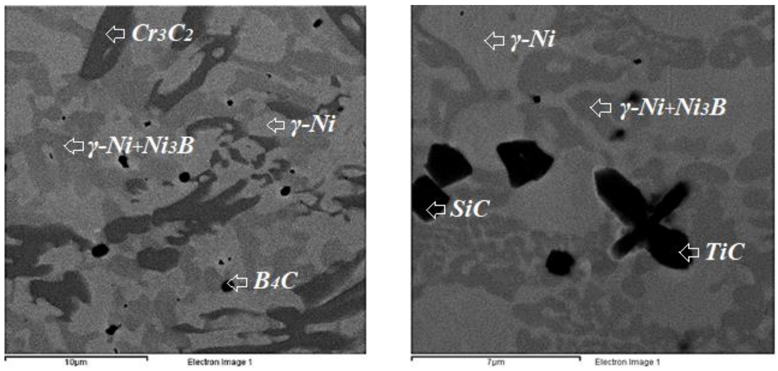

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Fig. 3. Microstructure and phase composition of deposited layers:
a – PG-10N-01; b – 10% MCM + 90% PG-10N-01

According to the results of scanning electron microscopy, it was established that the layer deposited with self-fluxing PG-10N-01 alloy consists of a solid solution based on nickel (γ-Ni) and a eutectic formed on its basis with the boride phase Ni_3B. The eutectic formation occurs as a result of the interaction between the original Ni and B during heating and cooling in the deposition process. In addition, both in the detected dendrites of the solid solution and in the eutectic, single inclusions of chromium carbides Cr_3C_2 and boron carbides B_4C are found (Fig. 3, a).

In the layer deposited with a composite material with a composition of 10% MCM + 90% PG-10N-01,inclusions of titanium TiC and silicon SiC carbides were found in the dendrites of the γ-Ni solid solution and the eutectic (Fig. 3, b). Addition of the MCM to the PG-10N-01 alloy allows to get a deposited layer that has a composite structure.

The X-ray structural phase analysis of the deposited layers proved their phase non-uniformity at the macro- and micro-levels with identified phases of γ-Ni, Ni_3B, Cr_3C_2, B_4C, TiC, SiC (Fig. 4).

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

When measuring the microhardness, it was found that the average microhardness of the layer deposited with the PG-10N-01 alloy is 510 HV (Fig. 7, a). The microhardness of the layer deposited with a composite material with a composition of 10% MCM + 90% PG-10N-01, is 660 HV (Fig. 4, b). When increasing the amount of MCM added to the PG-10N-01 alloy, the microhardness of the deposited layers increases and is 720 HV at 20% MCM and 760 HV at 30% MCM. The stable distribution of the microhardness values of the layer deposited with the composite material (Fig. 7, b) indicates the uniform distribution of TiC and SiC carbide inclusions in the matrix material [16].

The results of tests of wear resistance in the conditions of friction with an unfixed abrasive are shown in Fig. 8. Layers deposited with compo-

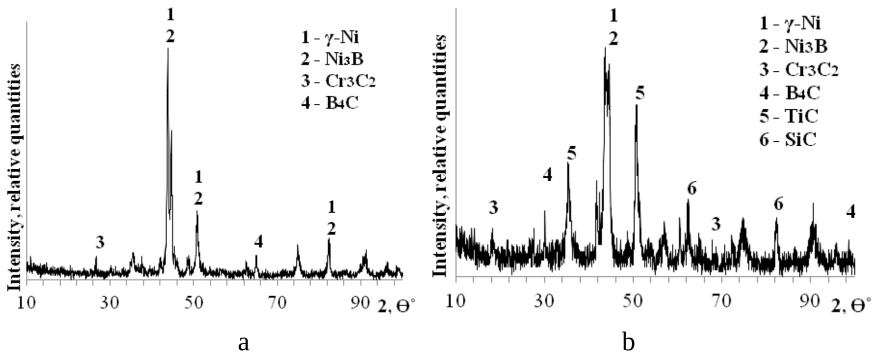
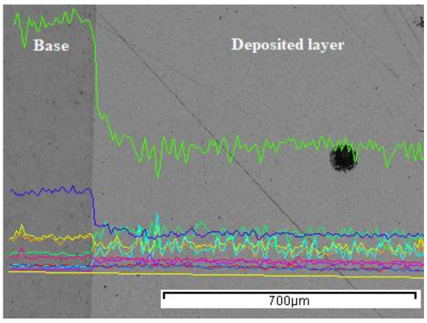


Fig. 4. Diffractograms of deposited layers:
a – PG-10N-01; b – 10% MCM + 90% PG-10N-01



Analysis section

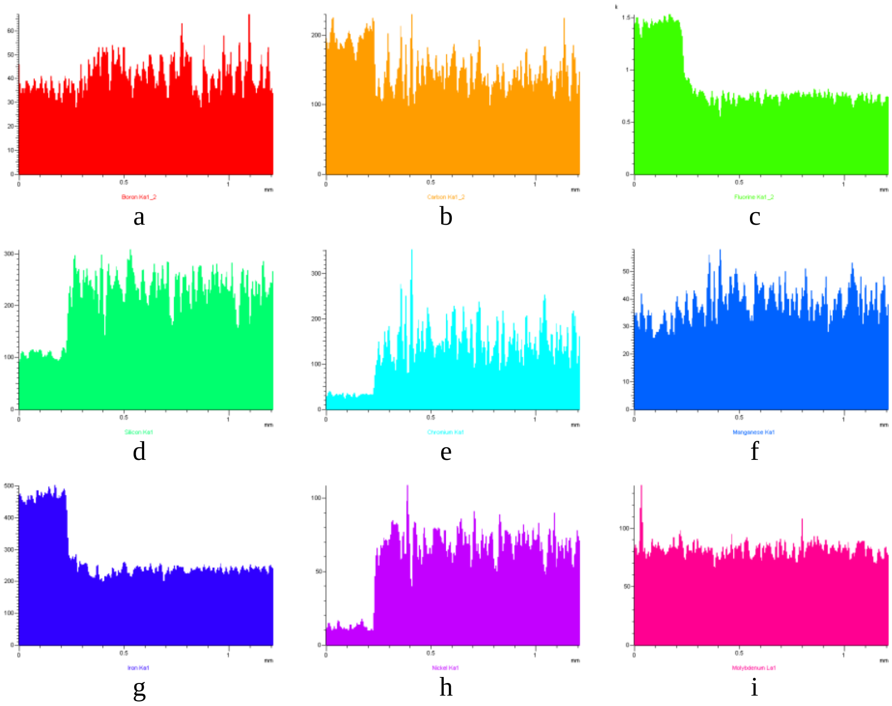


Fig. 5. Distribution of elements of the layer deposited with the PG-10N-01 alloy:
a – B; b – C; c – F; d – Si; e – Cr; f – Mn; g – Fe; h – Ni; i – Mo

site material have increased wear resistance compared to layers deposited with PG-10N-01 alloy. The layer deposited with the composite material with the composition of 10% MCM + 90% PG-10N-01 has 1.6 times greater wear resistance compared to the wear resistance of the layer deposited with the PG-10N-01 alloy. Increasing the amount of added MCM helps to increase the wear resistance of the layer. Thus, with 20% MCM content, the wear resistance of the layer is 1.9 times greater, and with 30% MCM – 2.1 times. This increase is due to the addition of TiC and SiC, which strengthen the solid solution of nickel γ-Ni and the eutectic γ-Ni-Ni_3B. The dependence of the indicator of the relative wear resistance of the deposited layers on the amount of MCM added to the PG-10N-01 alloy is shown in Fig. 9.

The morphology of the friction surfaces in the conditions of abrasive wear with an unfixed abrasive of the deposited layers is shown in Fig. 10. The friction surface of the layer deposited with the PG-10N-01 alloy has lines up to 12 µm deep (Fig. 10, a). The friction surface of the layer deposited with a composite material with a composition of 10% MCM + 90% PG-10N-01 has lines up to 7 µm (Fig. 10, b).

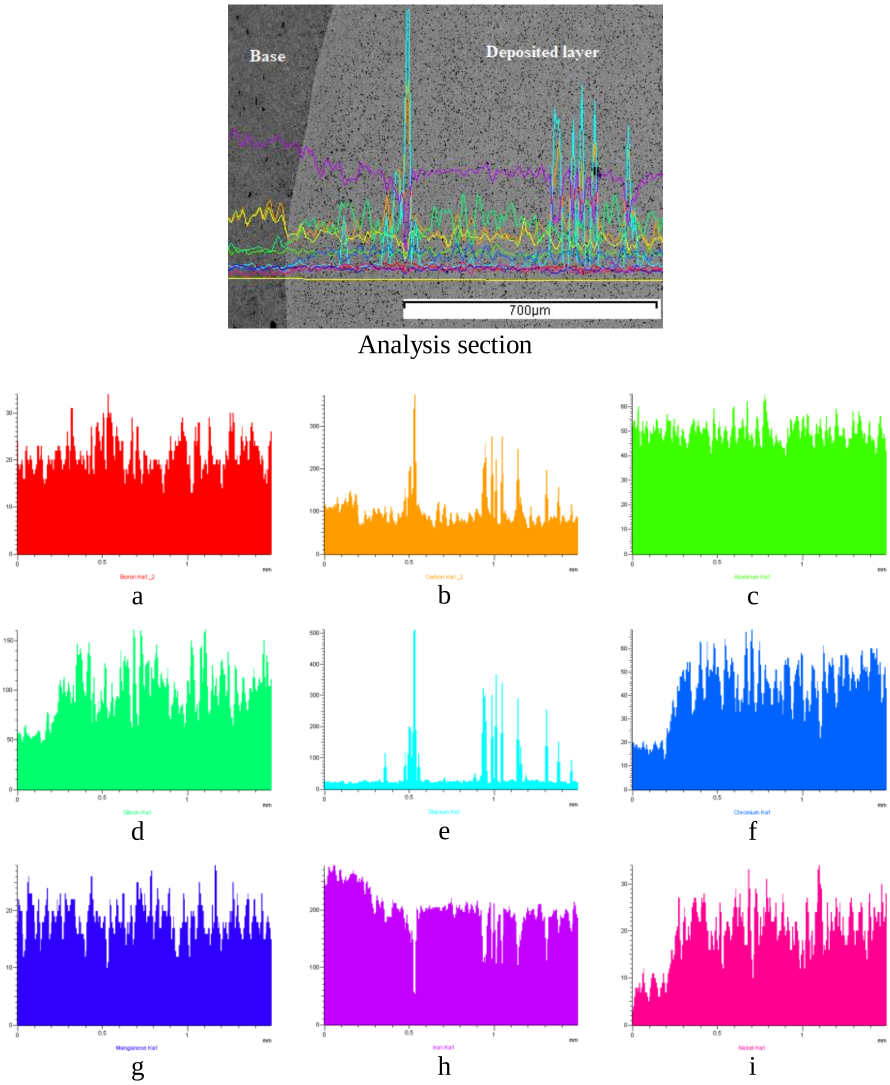


Fig. 6. Distribution of elements according to the thickness of the layer deposited with a composite material with the composition of 10% MCM + 90% PG-10N-01:
a – B; b – C; c – Al; d – Si; e – Ti; f – Cr; g – Mn; h – Fe; i – Ni

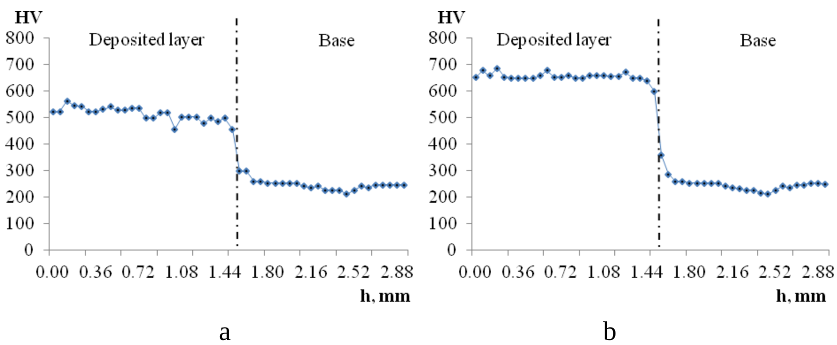


Fig. 7. Change in microhardness depending on the depth of the deposited layer:
a – PG-10N-01; b – 10% MCM + 90% PG-10N-01

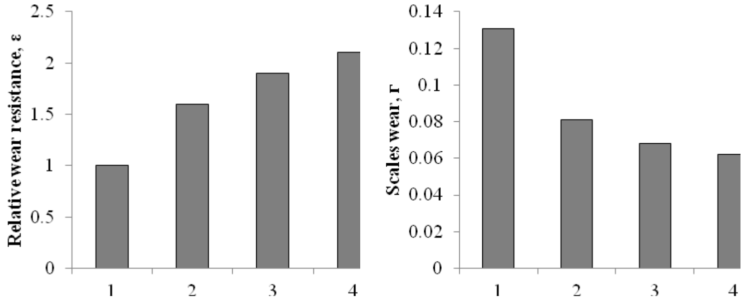


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Fig. 8. Wear resistance of deposited layers in the process of abrasive wear with unfixed abrasive:
a – relative wear resistance; b – wear of deposited layers;
1 – PG-10N-01; 2 – 10% MCM + 90% PG-10N-01;
3 – 20% MCM + 80% PG-10N-01; 4 – 30% MCM + 70% PG-10N-01

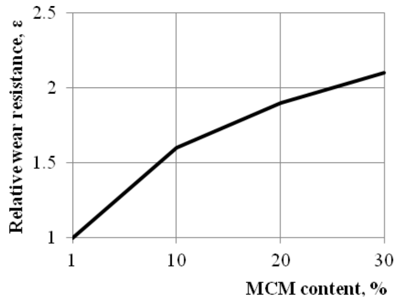

Fig. 9. Relative wear resistance of layers deposited with composite material, depending on the MCM content

Fig. 11 shows the results of scanning electron microscopy of the friction surface of the layer deposited with the PG-10N-01 alloy. It was established that the wear of the layer occurs by the mechanism of activation of softer phases: solid solution of nickel and eutectics formed on its basis (Fig. 11, a). The friction surface of the layer deposited by the composite material of the composition of 10% MCM + 90% PG-10N-01, has a more dispersed solid solution structure and eutectic with solid inclusions, which increase the resistance of such a layer to abrasive wear (Fig. 11, b).

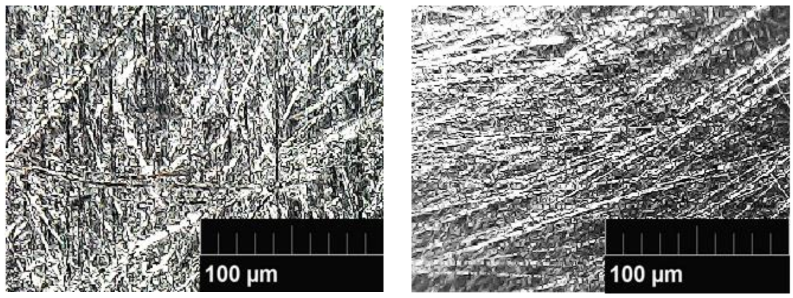

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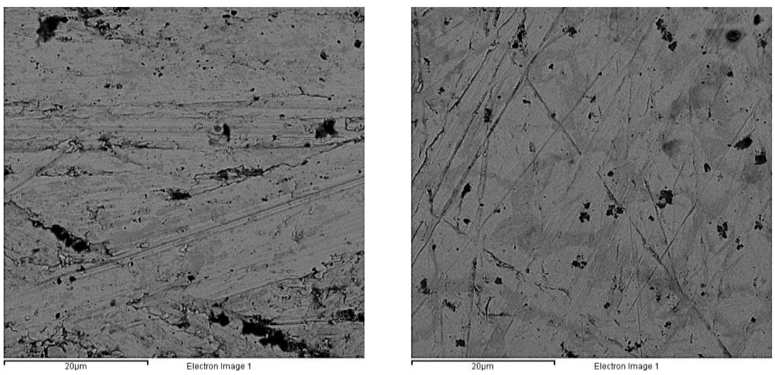
Fig. 10. Morphology of friction surfaces:
a – PG-10N-01; b – 10% MCM + 90% PG-10N-01



a b

Fig. 11. Microstructure of friction surfaces:
a – PG-10N-01; b – 10% MCM + 90% PG-10N-01

Operational tests of the composite material were carried out in the conditions of the Kamianuvatka farm (Novoukrainka district, Kirovohrad region) [18]. For the tests, a set of duckfoot blades was used, on the toe and working blades of which a layer of composite material with a composition of 10% MCM + 90% PG-10N-01 was deposited on the reverse side. Deposition was carried out with a non-fusible graphite electrode with a diameter of 9.5 mm at a current of 110 A in direct polarity using an inverter power source SV-290NK. The experimental set of parts was installed to the KPP-8 semi-trailer cultivator, aggregated with the New Holland T6090 tractor, when processing ordinary black soil to a depth of 100–110 mm with a working speed of the cultivator of 7 km/h.

The conducted tests showed that after processing an area of 5 ha, the linear wear of the toe of the non-strengthened duckfoot blade amounted to 4.2 mm, which is 1.7 mm more compared to the wear of the toe of the blade strengthened with composite material from the reverse side. The wear of the working surfaces of the blades of standard duckfoot blades was 2.1 mm and 1.2 mm in strengthened ones. The relative wear resistance of duckfoot blades made of 65G steel, strengthened on the reverse side by depositing a layer of composite material obtained using the SHS process, is 1.7 times higher compared to the wear resistance of duckfoot blades made by standard technology.

Conclusions

The structure, phase composition and properties of the layers deposited with a self-fluxing alloy of the NiCrBSi system with the addition of a modifying composite material (MCM) obtained by self-propagating high-temperature synthesis were studied.

The structure of the layer deposited with the PG-10N-01 alloy consists of a solid solution of nickel (γ-Ni) and the eutectic formed on its basis with the Ni_3B boride phase. The structure of the layer deposited with a composite material of 10% MCM + 90% PG-10N-01 consists of a solid solution of nickel and eutectics, which are additionally strengthened with TiC and SiC carbides. With an increase in the MCM content, the amount of TiC and SiC carbides increases, which contributes to an increase in microhardness and wear resistance.

The microhardness of the layer deposited with the composite material of the composition of 10% MCM + 90% PG-10N-01 is 660 HV, which exceeds the microhardness of the layer deposited with the PG-10N-01 alloy, which is 510 HV.

Abrasive wear resistance of a layer deposited with a composite material with a composition of 10% MCM + 90% PG-10N-01 under conditions of wear by unfixed abrasive particles is 1.6 times greater than the wear resistance of a layer deposited with a PG-10N-01 alloy.

The operational tests carried out in the conditions of the Kamianuvatka Farm proved that the relative wear resistance of duckfoot blades strengthened with the obtained composite material is 1.7 times greater in comparison with the wear resistance of blades manufactured according to standard technology.

References

1. Mrdak, M. R. (2012). Microstructure and mechanical properties of nickel-chrome-bor-silicon layers produced by the atmospheric plasma spray process. *Vojnotehnicki glasnik – Military Technical Courier*, vol. LX, iss. 1, pp. 183–200. https://doi.org/10.5937/vojtehg1201183M.
2. Röttger, A., Kuepferle, J., Brust, S., Mohr, A., & Theisen, W. (2015). Abrasion in tunneling and mining. *International Conference on Stone and Concrete Machining (ICSCM)*, vol. 3, pp. 246–261. https://doi.org/10.13154/icscm.3.2015.246-261.
3. Bergant, Z., Batic, B., Felde, I., Sturm, R., & Sedlacek, M. (2022). Tribological properties of solid solution strengthened laser cladded NiCrBSi/WC-12Co metal matrix composite coatings. *Materials*, vol. 15, iss. 1, paper 342. https://doi.org/10.3390/ma15010342.
4. Buytoz, S., Ulutan, M., Islak, S., Kurt, B., & Nuri, Ç. (2013). Microstructural and wear characteristics of high velocity oxygen fuel (HVOF) sprayed NiCrBSi–SiC composite coating on SAE 1030 steel. *Arabian Journal for Science and Engineering*, vol. 38, iss. 6, pp. 1481–1491. https://doi.org/10.1007/s13369-013-0536-y.
5. Chen, J., Dong, Y., Wan, L., Yang, Y., Chu, Z., Zhang, J., He, J., & Li, D. (2018). Effect of induction remelting on the microstructure and properties of in situ TiN-reinforced NiCrBSi composite coatings. *Surface and Coatings Technology*, vol. 340, pp. 159–166. https://doi.org/10.1016/j.surfcoat.2018.02.024.
6. Storozhenko, M. S. (2013). *Mekhanizmy znoshuvannia plazmovykh pokryttiv systemy NiCrBSi-TiB2 v umovakh tertia ta kovzannia bez mastyla* [Wear mechanisms of NiCrSiB-TiB2 plasma-sprayed coatings under dry sliding conditions]. *Problemy trybolohii – Problems of Tribology*, vol. 70, no. 4, pp. 121–128 (in Ukrainian).
7. Cai, B., Tan, Y., Tan, H., Jing, Q., & Zhang, Z. (2013). Tribological behavior and mechanism of NiCrBSi−Y_2O_3 composite coatings *Transactions of Nonferrous Metals Society of China*, vol. 23, iss. 7, pp. 2002−2010. https://doi.org/10.1016/S1003-6326(13)62689-8.
8. Luzan, S. O. & Sytnykov, P. A. (2022). *Retrospektyvnyi analiz formuvannia ta rozvytku samoposhyriuvanoho vysokotemperaturnoho syntezu* [Retrospective analysis of the formation and development of self-propagating high-temperature synthesis]. *Visnyk Kremenchutskoho natsionalnoho universytetu imeni Mykhaila Ostrohradskoho – Transactions of Kremenchuk Mykhailo Ostrohradskyi National University*, iss. 4 (135), pp. 88–96 (in Ukrainian). https://doi.org/10.32782/1995-0519.2022.4.12.
9. Niyomwas, S. (2009). Synthesis and characterization of silicon-silicon carbide composites from rice husk ash via self-propagating high temperature synthesis. *Journal of Metals, Materials and Minerals*, vol. 19, no. 2, pp. 21–25.

10. Liang, Y. H., Wang, H. Y., Yang, Y. F., Zhao, R. Y., & Jiang, Q. C. (2008). Effect of Cu content on the reaction behaviors of self-propagating high-temperature synthesis in Cu–Ti–B_4C system. *Journal of Alloys and Compounds*, vol. 462, iss. 1–2, pp. 113–118. https://doi.org/10.1016/j.jallcom.2007.08.033.
11. Warner, T. E., Clausen, A. K., & Poulsen, M. G. (2019). Self-propagating high-temperature synthesis of titanium carbide: An educational module using a wooden block reactor. *International Journal of Self-Propagating High-Temperature Synthesis*, vol. 28, iss. 1, pp. 56–63. https://doi.org/10.3103/S106138621901014X.
12. Iushchenko, K. A., Borysov, Yu. S., Kuznetsov, V. D., & Korzh, V. M. (2007). *Inzheneriia poverkhni* [Surface engineering]. Kyiv: Naukova dumka, 553 p. (in Ukrainian).
13. Sytnykov, P. A. (2023). Plasma coatings based on self-fluxing NiCrBSi alloy with improved wear resistance properties. *Journal of Mechanical Engineering – Problemy Mashynobuduvannia*, vol. 26, no. 3, pp. 54–64. https://doi.org/10.15407/pmach2023.03.054.
14. Luzan, S. O. & Sytnykov, P. A. (2023). *Doslidzhennia vplyvu parametriv mekhanichnoi aktyvatsii shykhty Ti–C–Al–SiO_2–Al_2O_3–Fe_2O_3–PT-NA-01 na tryvalist syntezu kompozytsiinoho materialu, shcho modyfikuie* [Study of the influence of the parameters of mechanical activation of the charge Ti–C–Al–SiO_2–Al_2O_3–Fe_2O_3–PT-NA-01 on the duration of the synthesis of the modifying composite material]. *Visnyk KhNADU – Bulletin of Kharkiv National Automobile and Highway University*, iss. 100, pp. 42–47 (in Ukrainian). https://doi.org/10.30977/BUL.2219-5548.2023.100.0.42.
15. Luzan, S. O. & Sytnykov, P. A. (2023). *Doslidzhennia osoblyvostei initsiiuvannia protsesu samoposhyriuvanoho vysokotemperaturnoho syntezu modyfikuiuchoho kompozytsiinoho material* [Study of the peculiarities of initiating the process of self-propagating high-temperature synthesis of a modifying composite material]. *Visnyk Kremenchutskoho natsionalnoho universytetu imeni Mykhaila Ostrohradskoho – Transactions of Kremenchuk Mykhailo Ostrohradskyi National University*, iss. 2 (139), pp. 102–109 (in Ukrainian). https://doi.org/10.32782/1995-0519.2023.2.13.
16. Luzan, S. O. & Sytnykov, P. A. (2023). *Struktura ta vlastyvosti naplavlenykh shariv kompozytsiinym materialom, yakyi oderzhano z vykorystanniam SVS-protsesu* [Structure and properties of deposited coatings of composite material obtained using the shs process]. *Visnyk Khmelnytskoho natsionalnoho universytetu. Seriia: Tekhnichni nauky – Herald of Khmelnytskyi national university. Series: Technical sciences*, vol. 323, iss. 4, pp. 194–201. (in Ukrainian). https://doi.org/10.31891/2307-5732-2023-323-4-194-201.
17. Student, M. M., Voytovych, A. A., Sirak, Ya. Ya., & Gvozdetskyi, V. M. (2020). Development of new electrode materials, methods of restoration and protection of thin-walled parts of equipment, which are operated under the conditions of abrasive and gas-abrasive wear. *The Paton Welding Journal*, iss. 10, pp. 31–34. https://doi.org/10.37434/tpwj2020.10.06.
18. Sytnykov, P. A. & Luzan, S. O. (2023). *Dosvid elektroduhovoho naplavlennia zmitsniuiuchykh shariv detalei gruntoobrobnykh mashyn* [Experience of electric arc surfacing of reinforcing layers of parts of tillage machines]. *Teoretychni ta praktychni doslidzhennia molodykh vchenykh – Theoretical and practical research of young*: Scientists collection of abstracts of reports of the 17th International Scientific and Practical Conference of Master's and Postgraduate Students, Kharkiv, NTU "KhPI", November 28-30, 2023. Kharkiv: NTU "KhPI", pp. 469 (in Ukrainian).

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Дослідження структури й властивостей наплавлених шарів NiCrBSi-сплаву, модифікованого композиційним матеріалом

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Досліджено структуру й властивості шарів, наплавлених самофлюсівним сплавом системи NiCrBSi марки ПГ-10Н-01, модифікованим композиційним матеріалом, отриманим самопоширюваним високотемпературним синтезом. Як вихідні компоненти модифікуючого композиційного матеріалу використано порошки титану, технічного вуглецю, вогнетривкої глини, алюмінію, оксиду заліза й термореагуючого порошку ПТ-НА-01. Порошки були механічно активовані в кульовому млині, спресовані в циліндричний зразок, після чого піддані процесу самопоширюваного високотемпературного синтезу. Наплавлення зразків здійснювали неплавким графітовим електродом діаметром 9,5 мм, при струмі 110 А із застосуванням інверторного джерела живлення СВ-290НК. Встановлено, що структура шару, наплавленого сплавом ПГ-10Н-01, складається з твердого розчину *на основі нікелю (γ-Ni) й евтектики, утвореної на його основі з боридом Ni_3B. Також в наплавленому шарі виявлені поодинокі включення карбідів хрому Cr_3C_2 і бору B_4C. При додаванні до сплаву ПГ-10Н-01 модифікуючого композиційного матеріалу структура наплавленого шару складається з γ-твердого розчину й евтектики, зміцнених карбідами титану TiC і кремнію SiC, які підвищують мікротвердість і зносостійкість шару. Мікротвердість шару, наплавленого композиційним матеріалом, який містив 10% модифікуючої складової, становить 660 HV, що перевищує мікротвердість шару, наплавленого сплавом ПГ-10Н-01, яка дорівнює 510 HV. За результатами досліджень проведені експлуатаційні випробування в умовах Фермерського господарства «Кам'януватка» (Новоукраїнський район, Кіровоградська область) комплекту стрілчастих лап напівпричіпного культиватору КПП-8, агрегованого з трактором New Holland T 6090. На основі проведених випробувань доведено, що відносна зносостійкість стрілчастих лап, виготовлених зі сталі 65Г, зміцнених зі зворотного боку за схемою «носок-робочі леза» шляхом наплавлення шару композиційного матеріалу, в 1,7 рази більша порівняно з зносостійкістю лап, виготовлених за стандартною технологією.*

***Ключові слова:** самопоширюваний високотемпературний синтез, шихта, композиційний матеріал, наплавлення, наплавлений шар, карбід, структура, твердість, абразив, зносостійкість, деталі машин.*

Література

1. Mrdak M. R. Microstructure and mechanical properties of nickel-chrome-bor-silicon layers produced by the atmospheric plasma spray process. *Vojnotehnicki glasnik – Military Technical Courier*. 2012. Vol. LX. Iss. 1. P. 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. Vol. 3. P. 246–261. https://doi.org/10.13154/icscm.3.2015.246-261.
3. Bergant Z., Batic B., Felde I., Šturm R., Sedlacek M. Tribological properties of solid solution strengthened laser cladded NiCrBSi/WC-12Co metal matrix composite coatings. *Materials*. 2022. Vol. 15. Iss. 1. Paper 342. https://doi.org/10.3390/ma15010342.
4. Buytoz S., Ulutan M., Islak S., Kurt B., Nuri, Ç. Microstructural and wear characteristics of high velocity oxygen fuel (HVOF) sprayed NiCrBSi–SiC composite coating on SAE 1030 steel. *Arabian Journal for Science and Engineering*. 2013. Vol. 38. Iss. 6. P. 1481–1491. https://doi.org/10.1007/s13369-013-0536-y.
5. Chen J., Dong Y., Wan L., Yang Y., Chu Z., Zhang J., He J., Li D. Effect of induction remelting on the microstructure and properties of in situ TiN-reinforced NiCrBSi composite coatings. *Surface and Coatings Technology*. 2018. Vol. 340. P. 159–166. https://doi.org/10.1016/j.surfcoat.2018.02.024.
6. Стороженко М. С. Механізми зношування плазмових покриттів системи NiCrBSi-TiB_2 в умовах тертя та ковзання без мастила. *Проблеми трибології*. 2013. Т. 70. № 4. С. 121–128.
7. Cai B., Tan Y., Tan H., Jing Q., Zhang Z. Tribological behavior and mechanism of NiCrBSi−Y_2O_3 composite coatings *Transactions of Nonferrous Metals Society of China*. 2013. Vol. 23. Iss. 7. P. 2002−2010. https://doi.org/10.1016/S1003-6326(13)62689-8.
8. Лузан С. О., Ситников П. А. Ретроспективний аналіз формування та розвитку самопоширюваного високотемпературного синтезу. *Вісник Кременчуцького національного університету імені Михайла Остроградського*. 2022. Вип. 4 (135). С. 88–96. https://doi.org/10.32782/1995-0519.2022.4.12.
9. Niyomwas S. Synthesis and characterization of silicon-silicon carbide composites from rice husk ash via self-propagating high temperature synthesis. *Journal of Metals, Materials and Minerals*. 2009. Vol. 19. No. 2. P. 21–25.
10. Liang Y. H., Wang H. Y., Yang Y. F., Zhao R. Y., Jiang Q. C. Effect of Cu content on the reaction behaviors of self-propagating high-temperature synthesis in Cu–Ti–B_4C system. *Journal of Alloys and Compounds*. 2008. Vol. 462. Iss. 1–2. P. 113–118. https://doi.org/10.1016/j.jallcom.2007.08.033.
11. Warner T. E., Clausen A. K., Poulsen M. G. Self-propagating high-temperature synthesis of titanium carbide: An educational module using a wooden block reactor. *International Journal of Self-Propagating High-Temperature Synthesis*. 2019. Vol. 28. Iss. 1. P. 56–63. https://doi.org/10.3103/S106138621901014X.
12. Ющенко К. А., Борисов Ю. С., Кузнецов В. Д., Корж В. М. Інженерія поверхні. Київ: Наукова думка, 2007. 553 с.
13. 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. P. 54–64. https://doi.org/10.15407/pmach2023.03.054.
14. Лузан С. О., Ситников П. А. Дослідження впливу параметрів механічної активації шихти Ti–C–Al–SiO_2–Al_2O_3–Fe_2O_3–ПТ-НА-01 на тривалість синтезу композиційного матеріалу, що модифікує. *Вісник ХНАДУ*. 2023. Вип. 100. С. 42–47. https://doi.org/10.30977/BUL.2219-5548.2023.100.0.42.

15. Лузан С. О., Ситников П. А. Дослідження особливостей ініціювання процесу самопоширюваного високотемпературного синтезу модифікуючого композиційного матеріалу. *Вісник Кременчуцького національного університету імені Михайла Остроградського*. 2023. Вип. 2 (139). С. 102–109. https://doi.org/10.32782/1995-0519.2023.2.13.
16. Лузан С. О., Ситников П. А. Структура та властивості наплавлених шарів композиційним матеріалом, який одержано з використанням СВС-процесу. *Вісник Хмельницького національного університету. Серія: Технічні науки.* 2023. Т. 323. № 4. С. 194–201. https://doi.org/10.31891/2307-5732-2023-323-4-194-201.
17. Студент М. М., Войтович А. А., Сірак Я. Я., Гвоздецький В. М. Розробка нових електродних матеріалів, методів відновлення і захисту тонкостінних деталей обладнання, які експлуатуються в умовах абразивного та газоабразивного зношування. *Автоматичне зварювання.* 2020. № 10. С. 34–37. https://doi.org/10.37434/as2020.10.06.
18. Ситников П. А., Лузан С. О. Досвід електродугового наплавлення зміцнюючих шарів деталей ґрунтообробних машин. Теоретичні та практичні дослідження молодих вчених: зб. тез доп. 17-ї Міжнар. наук.-практ. конф. магістрантів та аспірантів, Харків, НТУ «ХПІ», 28–30 листопада 2023 р. Харків: НТУ «ХПІ», 2023. С. 469.