

PACS numbers: 62.20.Qp, 68.55.J-, 81.05.Je, 81.20.Ev, 81.20.Ka, 81.40.Pq, 82.33.Vx

Application of the Process of Self-Propagating High-Temperature Synthesis for the Fabrication of Modifying Composite Ceramic–Metal Powders

S. O. Luzan

*National Technical University ‘Kharkiv Polytechnic Institute’,
2 Kyrpychova Str.,
UA-61002 Kharkiv, Ukraine*

The processes based on self-propagating high-temperature synthesis (SHS) for the fabrication of two types of modifying composite materials (MCM) of a charge containing boron: Ti, B, C, Fe₂O₃, Al, PT-NA-01, and a charge, in which silicon (SiO₂) and aluminium (Al₂O₃) oxides in the form of refractory clay of the PGOSA-0 brand are included instead of expensive boron (B). The thermodynamic evaluation of the possibility of interplay between the components is carried out using the Gibbs energy. The phase compositions of the deposited coatings with composite materials (CM) based on PG-10N-01 alloy and their microhardness are presented. The results of studies of the wear resistance of CM during the friction against fixed abrasive particles show 1.5–2.4 times higher wear resistance compared to the PG-10N-01 alloy. As established, the deposited CM modified by the MCM, which contains silicon (SiO₂) and aluminium (Al₂O₃) oxides instead of boron (B), has higher wear resistance, when it works in an abrasive environment. This is due to the content of chromium, titanium, silicon, and boron carbides in its structure. The morphology of the friction surfaces is also in a good agreement with the results of friction tests upon fixed particles of the deposited coatings PG-10N-01 and CM.

Key words: composite material, boride, SHS process, surfacing, wear resistance.

Corresponding author: Serhiy Oleksiyovych Luzan
E-mail: khadi.luzan@gmail.ua

Citation: S. A. Luzan, Application of the Process of Self-Propagating High-Temperature Synthesis for the Fabrication of Modifying Composite Ceramic–Metal Powders, *Metallofiz. Noveishie Tekhnol.*, **48**, No. 7: 703–714 (2026). DOI: [10.15407/mfint.48.07.0703](https://doi.org/10.15407/mfint.48.07.0703)

© Publisher PH “Akadempriodyka” of the NAS of Ukraine, 2026. This is an open access article under the CC BY-ND license (<https://creativecommons.org/licenses/by-nd/4.0>)

Досліджено процеси саморозповсюджуваної високотемпературної синтези для одержання двох типів модифікувальних композиційних матеріалів (МКМ) з шихти, що містить бор: Ti, B, C, Fe_2O_3 , Al, ПТ-НА-01, і шихти, в якій замість дорогого бору (B) включено оксиди Силіцію (SiO_2) й Алюмінію (Al_2O_3) у вигляді вогнетривкої глини марки ПГОСА-0. Термодинамічну оцінку можливості перебігу взаємочину між компонентами проводили з використанням Гіббсової енергії. Наведено фазові склади нагрітих покриттів композиційними матеріалами (КМ) на основі стопу ПГ-10Н-01 та їхню мікротвердість. Результати досліджень зносостійкості КМ під час тертя об закріплені абразивні частинки показали у 1,5–2,4 рази більшу зносостійкість порівняно зі стопом ПГ-10Н-01. Встановлено, що нагрітий КМ, модифікований МКМ, який містить оксиди Силіцію (SiO_2) й Алюмінію (Al_2O_3) замість бору (B), має вищу зносостійкість під час роботи в умовах абразивного середовища. Це зумовлено вмістом у його структурі карбідів Хрому, Титану, Силіцію та Бору. Морфологія поверхонь тертя також добре узгоджується з результатами випробувань на тертя об закріплені частки нагрітих покриттів ПГ-10Н-01 і КМ.

Ключові слова: композиційний матеріал, борид, саморозповсюджувана високотемпературна синтеза, нагрівання, зносостійкість.

(Received 14 July, 2025; in final version, 10 March, 2026)

1. INTRODUCTION

To strengthen and restore machine parts, various methods of surfacing have become the most widespread, including arc surfacing with consumable and non-consumable electrodes, as it has a number of advantages: low cost of the equipment used, insignificant penetration of the surfacing surface, which ensures stable properties of the surfacing layer throughout its thickness.

Currently, there are many materials available for surfacing machine parts represented by flux-cored and composite wires, coated electrodes, and surfacing tapes, but the amount of research into the development of materials, which work under abrasive wear conditions, is relatively small.

The resistance of materials to abrasive wear depends significantly on their structural and phase composition, which is determined not only by their chemical composition, but also depends on the surfacing method and mode, weld pool crystallization conditions, and heat treatment modes of the welded products.

The basis of the structure of wear-resistant alloys is the matrix, in which there are strengthening phases (carbides, nitrides, borides, etc.). The alloy matrix performs two functions: it serves as a structural element, on which wear resistance depends, and it contributes to the reliable retention of the hardening phases to prevent their crumbling under the influence of abrasives and impacts. The type of matrix, its con-

dition and properties determine the likelihood of crack initiation, growth and consolidation in the metal under the influence of various factors and the environment, which affects the wear rate of the alloy.

To achieve high wear resistance of parts operating under abrasive wear conditions, there are two options for creating wear-resistant alloys. The first is to create materials with a metastable structure. Such materials are capable of absorbing energy introduced from the outside and dissipating it through structural and phase transformations, primarily through the $\gamma \rightarrow \alpha$ transformation. However, such alloys have little resistance to abrasive wear at temperatures up to 550°C, which is associated with thermal weakening of the alloy matrix [1]. The second option is to develop materials that have a thermally stable structure reinforced with a large amount of solid phase [2]. Materials with such a structure are the most promising for resisting abrasive wear at elevated temperatures.

In addition, the wear resistance of surfacing materials depends significantly on the type and amount of the carbide phase in the alloys. Most often, the hardening phase should contain the following carbides: Fe_3C , Mn_3C , Cr_7C_3 , W_2C , WC , VC , TiC , B_4C , Mo_2C , *etc.*, as well as carbides, iron nitrides and alloying elements. At present, metal, non-metallic and composite materials, monolithic and porous, with both homogeneous and heterogeneous structures, are used in machine friction units.

To obtain a modifying composite material in the form of a sinter, it is possible to use traditional methods of powder metallurgy, which include the stages of preparing a charge of powder components, pressing, and sintering [3]. The main disadvantages of powder metallurgy methods include the use of expensive large-size equipment, the duration and energy intensity of the production cycle.

A promising method for obtaining new materials, including composite materials, is self-propagating high-temperature synthesis (SHS), which is based on the local initiation of highly exothermic reactions between the starting reagents, which makes it possible to generate a significant amount of heat to propagate the front of physical and chemical transformations with the formation of synthesis products [4–10].

The advantages of SHS technologies over conventional metallurgical production technologies are minimal material losses during the synthesis process, simplification and reduction of the number of technological operations, and energy savings. SHS technologies are based on three main operations: preparation of the initial charge, the SHS reaction itself, and processing and analysis of the resulting product. This method belongs to the *in situ* methods of obtaining composite materials and has all the advantages of such methods [11, 12].

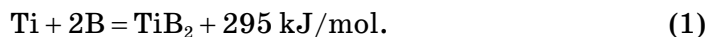
The aim of this work is to study the possibility of obtaining a com-

posite modifying material, using the SHS process to increase the abrasive wear resistance of deposited coatings with an alloy of the Ni–Cr–B–Si system, using oxides instead of expensive boron in the charge.

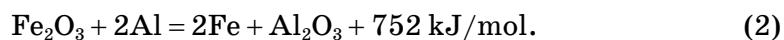
2. MATERIAL AND RESEARCH METHODS

At the beginning of the study of the possibility of obtaining a composite modifying material (MCM) by the SHS method to increase the abrasive wear resistance of deposited coatings with an alloy of the Ni–Cr–B–Si system, the following powder materials were selected: Ti, C, B, Al, Fe_2O_3 , PT–NA–01. Titanium reacting with carbon forms titanium carbide (TiC) and generates a large amount of heat (310 kJ) [13]. As a result of the heat released, the temperature of solid and molten reaction products reaches 2500–3500 K, so, the reaction does not depend on external heating sources and can propagate as a combustion wave that generates energy for its propagation. Despite the high temperature, the transition of any of the components of the mixture to the gas phase is insignificant and can be neglected.

Boron is one of the most effective and economical microalloying elements in steel. In most cases, the minimum concentration of boron in the metal to obtain a positive result is about one thousandth of a percent. The uniqueness of boron lies in the fact that, with such a low content in steel, it is able to exert an effect on its properties equivalent to that of a much larger number of alloying elements such as Cr, Mo, Ni, *etc.* Therefore, to obtain a composite material, we synthesize titanium diboride:



In addition, to increase the thermal effect in the synthesis of titanium carbide and titanium diboride, thermosetting nickel aluminide powder PT–NA–01, aluminium powder (powder) PAP-1 of GOST 5494-95, and iron oxide Fe_2O_3 were introduced into the mechanical mixture. As a result of the thermite reaction, molten iron and aluminium oxide are formed, a large amount of energy is released, and the temperature reaches approximately 2500°C [2]:



The selected components were mixed, and the resulting powder mixture was subjected to mechanical activation in a ball mill. In the experiments, the volume of the mill drum was of 160 cm³, the diameter of the balls was of 4–5 mm, and the weight of the balls was of 200 g. The time of the mechanical activation process varied from 2 to 6 minutes.

The CM was prepared in two stages: 1) mixing of Ti, B, C, Fe_2O_3 , Al, PT-NA-01 powders and their joint mechanical activation, addition of a binder—Metylan glue, cylinder formation and drying, initiation of the SHS process, during which titanium boride particles, chromium, *etc.* are synthesized; 2) crushing the material obtained during sintering and mixing the resulting powder with the matrix material—powder grade PG-10N-01 TUU 322-19-004-96, mechanical activation of the resulting powder mixture, adding liquid glass of GOST 13078 to the mechanically activated powder mixture until it becomes a paste [2].

The prepared paste was applied to the surface of the steel plate (steel 20) prepared for surfacing, and, after drying, surfacing was performed with a graphite electrode with a diameter of 10 mm, surfacing current of 80–120 A, and direct polarity. Arc surfacing was performed, using an inverter power source Paton VDI-200R DC TIG.

In addition, the composition of the initial charge of the second composite-modifying material was studied, which differed from the first in that instead of expensive boron (B); silicon oxides SiO_2 and aluminium oxides Al_2O_3 were included in the charge in the form of refractory clay of the PGOSA-0 brand.

The microstructure was studied using a metallographic microscope. The microhardness of the coatings was measured by the PMT-3 device in accordance with DST 9450.

Comparative wear tests of the deposited samples were performed on a friction machine of the MI type according to the ‘disk–pad’ scheme in industrial oil of the I-20 grade under the following conditions: average circumferential sliding speed of 0.42 m/s, specific pressure on the pad under normal wear of 8.0 MPa, friction surface area of 1.8 cm². The wear rate was determined by the formula

$$U_w = \frac{G_1 - G_2}{\gamma Ft} [\text{mm}^3/(\text{cm}^2 \cdot \text{s})], \quad (3)$$

where G_1 , G_2 are the weights of the sample before and after the test [mg], γ is the density of the material [mg/mm³], F is the sample area [cm²], t is the test time [s].

The materials were tested for abrasive wear under friction against fixed abrasive particles in accordance with GOST 17367. The abrasive particles used were green silicon carbide, grade 64C, with a grain size of 8 H. The relative wear resistance of the materials was estimated by the formula

$$\varepsilon = \frac{\Delta l_e}{\Delta l_t} (d_e/d_t)^2, \quad (4)$$

where Δl_e , Δl_t are the absolute linear wear of the reference and test

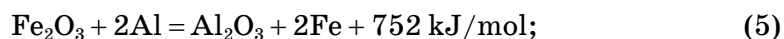
specimens [mm], d_e , d_t are their actual diameters [mm], respectively.

The phase composition of the deposited layers was determined using a DRON-3 diffractometer in monochromatic CuK_α radiation in the angular interval $2\theta = 10\text{--}80^\circ$. X-ray diffraction patterns were recorded in a discrete mode. The samples were prepared for analysis by grinding with abrasive paper and polishing to achieve the required surface roughness. The data from the ASTM file were used to decipher the diffractograms.

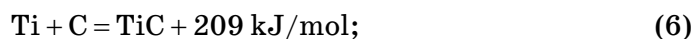
3. RESULTS AND DISCUSSION

The study of the process of producing CMC from a charge consisting of powders of Ti, B, C, Fe_2O_3 , Al, PT-NA-01, involved the use of reactions of iron reduction by aluminium from oxide, carbonization, and titanium-boride formation. In other words, this composition of powdered materials was intended to carry out three combined reactions of the SHS process:

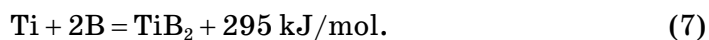
– thermite reaction



– carbonization reaction



– boron-formation reaction



These reactions, which have large thermal effects, can proceed in the combustion mode independently of each other. The relative content of components corresponded to stoichiometric Eqs. (5)–(7). The combustion of a cylindrical sample formed from a mixture of powders with the addition of a binding adhesive of the ‘Methylan’ brand was carried out in air in an open reactor. The initiation of the SHS process was carried out after drying the sample for 72 hours from a heated nichrome spiral. The combustion front of the powder mixture moved uniformly along the length of the cylindrical sample from the place of its initiation without emission of powder components and reaction products. As a result of the SHS process, a sinter was obtained (Fig. 1), which was easily crushed.

Further, the obtained MCM in the amount of 10 and 20% was added to the filler powder of PG-10N-01 grade and, according to the above method, a paste was obtained, which was applied to the surface of the steel plate (steel 20) prepared for surfacing, and after drying, surfac-



Fig. 1. A speck.

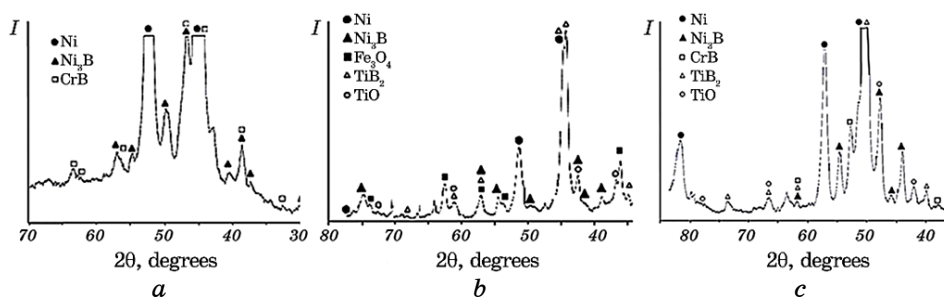


Fig. 2. X-ray diffractogram of deposited coatings: PG-10N-01 (a); CM (10% MCM + 90% PG-10N-01) (b); CM (20% MCM + 80% PG-10N-01) (c).

ing was performed with a graphite electrode with a diameter of 10 mm.

In the previous work [2], the following phase composition was established: titanium diboride (TiB_2), nickel boride (Ni_3B), titanium oxides (TiO) and iron oxides (Fe_3O_4) for the CM containing 10% CMC, and titanium diboride (TiB_2), chromium boride (CrB), nickel boride (Ni_3B) and titanium oxide (TiO) for the CM (20% CMC + 80% PG-10H-01). Aluminium oxide (Al_2O_3) and titanium carbide (TiC), which corresponds to Eqs. (5) and (6), were not detected (Fig. 2).

The absence of aluminium oxide is explained by a higher temperature, which reaches 2500°C as a result of a thermite reaction, than, the melting point of aluminium oxide of 2050°C , that leads to its melting and removal from the deposited CM in the form of a slag phase. Titanium carbide has a higher melting point of $3260 + 150^\circ\text{C}$ compared to the temperature of solid and molten products of the titanium carbide formation reaction, which reaches 2500–3500 K.

However, x-ray phase analysis did not reveal titanium carbide in the deposited layer, which can be explained by its low percentage in the initial CM powder mixture and the preparation of the sample surface for the study. The thermodynamic assessment of the possibility of interaction between the components was carried out using the Gibbs energy, since any reaction or process is accompanied by a change in the Gibbs energy (ΔG) of the system, the value of which is a measure of the ability

of the reaction to develop in the conditions under consideration: the greater the decrease in the Gibbs energy, the greater the affinity between the reacting substances.

The Gibbs energy is calculated according to the expression

$$\Delta G = \Delta H - T\Delta S \text{ [kJ/mol]}, \quad (8)$$

where ΔH is the enthalpy, T is the temperature, ΔS is the entropy.

$$\Delta H_{\text{reaction}} = \sum \Delta H_{\text{products}}^0 - \sum \Delta H_{\text{reactants}}^0 \text{ [kJ/mol]}. \quad (9)$$

Using the reference data of the standard enthalpies of substances, given that the enthalpies of formation of simple substances are zero, we find:

$$\Delta H_{\text{reaction}} = \Delta H_{\text{TiC}}^0 - \Delta H_{\text{Ti}}^0 - \Delta H_{\text{C}}^0 = -209 - 0 - 0 = -209 \text{ kJ/mol}. \quad (10)$$

$$\Delta S_{\text{reaction}} = \sum \Delta S_{\text{products}}^0 - \sum \Delta S_{\text{reactants}}^0 \text{ [J/(mol·K)]}. \quad (11)$$

Using the reference data of the standard entropies of substances, we find:

$$\Delta S_{\text{reaction}} = \Delta S_{\text{TiC}}^0 - \Delta S_{\text{Ti}}^0 - \Delta S_{\text{C}}^0 = 24.7 - 30.63 - 5.74 = -11.67 \text{ J/(mol·K)}. \quad (12)$$

$$\Delta G = \Delta H - T\Delta S = -209 + 298 \cdot (11.67/1000) = -205.52 \text{ kJ/mol}. \quad (13)$$

At $T = 298^\circ\text{C}$, $\Delta G < 0$, and the reaction is spontaneous, *i.e.*, the reaction will proceed in the forward direction. Thus, the thermodynamic calculation of the change in the Gibbs energy confirms the possibility of the formation of titanium carbide TiC.

The average microhardness of the CM coating (10% MCM + 90% PG-10N-01) is of 740 *HV*, and, for the CM coating (20% MCM + 80% PG-10N-01), it is of 978 *HV* that exceeds the average microhardness of the PG-10N-01 coating, which is of 520 *HV*. The microhardness distribution of the CM containing 20% CMC is more stable compared to the coating containing 10% CMC. This can be explained by a more uniform distribution of solid particles in the matrix material PG-10N-01 with an increase in their concentration [2].

The second composite modifying material was investigated, which was obtained from a charge consisting of powders of Ti, C, Fe_2O_3 , Al, PT-NA-01, silicon oxide SiO_2 and aluminium oxide Al_2O_3 in the form of refractory clay of the PGOSA-0 brand. This composition, unlike the previous one, instead of expensive boron (B), includes aluminium and silicon oxides, which are solid refractory substances ($\alpha\text{-Al}_2\text{O}_3$ with 20.6–29.4 *HV*, 2050°C, and SiO_2 with 8 *HV*, 1710°C) with high wear

and corrosion resistance. Such a composition of powder materials provided for the implementation of two combined reactions of the SHS process: a thermite reaction (5) and a carbonization reaction (6).

As a result, the following phase composition was determined by XRD analysis: γ -Ni, nickel boride (Ni_3B), titanium carbides (TiC), boron (B_4C), chromium (Cr_3C_2), and silicon (SiC) for the CM containing 10% of MCM [5]. Figure 3 shows the microstructure of the deposited CM coating (10% MCM–90% PG-10N-01).

The obtained results confirm the possibility of the formation of titanium carbide TiC during the SHS process. In addition, the deposited coating contains carbides of boron (B_4C), chromium (Cr_3C_2), and silicon (SiC) formed during the arc surfacing of CM from the matrix material of the self-fluxing alloy PG-10N-01 TUU 322-19-004-96 (chemical composition: Cr—14–20%, B—2.8–4.2%, Si—4.0–4.5%, Fe—3–7%, C—0.6–1.0%, Ni—base).

It should also be noted that the deposited coating does not contain aluminium and silicon oxides, which are part of the original composition of the charge. This can be explained by the self-fluxing effect of the PG-10N-01 matrix material, since the boron and silicon included in its composition form fusible eutectics with nickel with a melting point of 950–1080°C during heating, and also restore oxide films on the surface of the sample to form borosilicate slags that float to the surface of the deposited layer. Taking into account the high melting point of aluminium oxide (2054°C) and silicon oxide (1710°C), as well as their low density of 3.99 and 2.65 g/cm³, respectively, it can be concluded that most of them float to the surface in the form of a slag phase.

The average microhardness of the deposited CM layer (10% MCM + 90% PG-10N-01) is of 660 HV, and that of the CM layer (20%

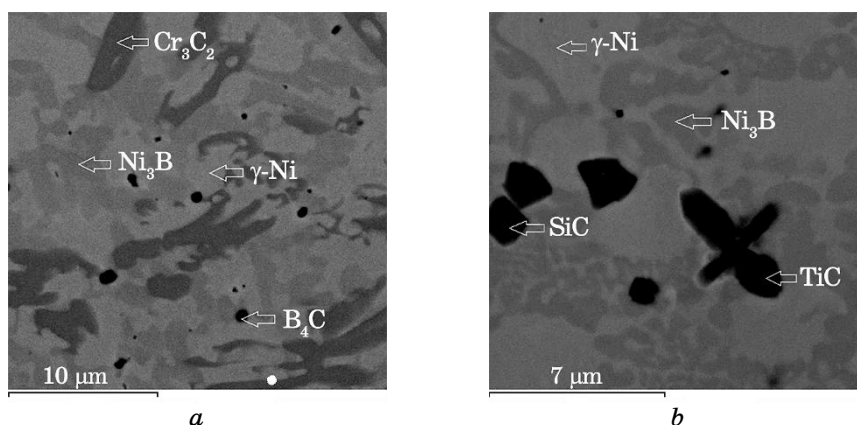


Fig. 3. Microstructure and phase composition (wt.%) of deposited coatings: PG-10N-01 (a); 10% MCM + 90% PG-10N-01 (b).

MCM + 80% PG-10N-01) is of 720 *HV*, which also exceeds the average microhardness of the PG-10N-01 coating, which is of 510 *HV*.

The combustion of the CMC compositions of the first and second types occurred evenly, with no emissions of the initial components and reaction products, and the addition of CMC up to 10% improves the technological properties of the arc surfacing process and contributes to a better formation of the deposited layer [14].

According to the results of tests for wear resistance of materials deposited by the arc method (Fig. 4), the abrasive wear resistance of CM (10% MCM + 90% PG-10N-01) of the first type is 1.5 times higher than that of CM (10% MCM + 90% PG-10N-01) of the second type, and 1.8 times higher than that of the self-fluxing alloy PG-10N-01.

With an increase in the content of CMC in the CM, the wear resistance of the deposited coatings during operation in an abrasive environment increase. Thus, at a content of 20% MCM, the wear resistance of the deposited layer of the first type of the deposited CM increases by 1.7 times, and the second type by 2.4 times.

The morphology of the friction surfaces is also in a good agreement with the results of friction tests on the fixed abrasive particles of the deposited coatings PG-10N-01 and CM (Fig. 5).

During wear under the influence of fixed abrasive particles, quite deep parallel grooves were found on the coating made of PG-10N-01 alloy (Fig. 5, *a*). The relief of the wear surface is uneven. Shallow, small, and evenly spaced friction scratches are observed on the surfaces of the deposited coatings made of CM (Fig. 5, *b* and *c*). This is explained by the introduction of CMCs, which contribute to the forma-

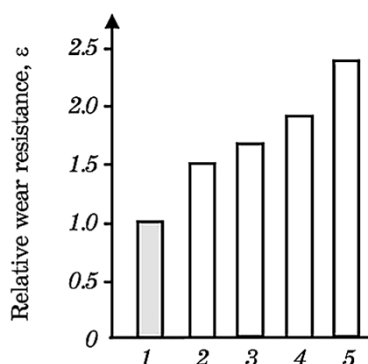


Fig. 4. Wear resistance of materials deposited by the arc method in the process of friction under the influence of fixed abrasive particles: 1—PG-10N-01 alloy, 2—CM (10% CMC + 90% PG-10N-01) of the first type, 3—CM (20% CMC + 80% PG-10N-01) of the first type, 4—CM (10% CMC + 90% PG-10N-01) of the second type, 5—CM (20% CMC + 80% PG-10N-01) of the second type.

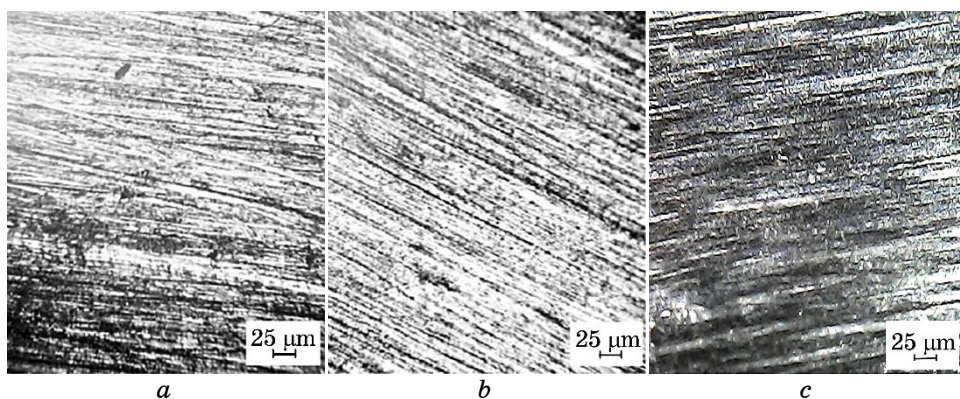


Fig. 5. Morphology of friction surfaces during wear against fixed abrasive particles of deposited coatings: PG-10N-01 (*a*), CM (10% MCM + 90% PG-10N-01) of the first type (*b*), CM (10% MCM + 90% PG-10N-01) of the second type (*c*).

tion of new crystallization centres during surfacing and, as a result, leads to the grinding of the structure. The plastic matrix based on nickel PG-10N-01 redistributes stresses, providing conditions in which solid components occupy a favourable position. This eliminates the local increase in contact pressure and reduces the conditions for the detachment of hardwearing particles.

4. CONCLUSIONS

The results of studies of the wear resistance of CM consisting of the matrix material of the nickel-based alloy PG-10N-01, modified CMC of the first and second types, which differ in that the second type, instead of the boron component, introduced silicon oxides SiO_2 and aluminium oxides Al_2O_3 in the form of refractory clay, showed increased wear resistance during operation in an abrasive environment compared to the coating with PG-10N-01 alloy. CM of the first type contains solid inclusions in the structure in the form of titanium diboride (TiB_2), nickel borides (Ni_3B) and chromium (CrB), titanium oxides (TiO) and iron (Fe_3O_4), which provides an average microhardness of 740–978 *HV* and increased wear resistance in an abrasive environment. The wear resistance of the deposited layer of the first type of CM (10% MCM + 90% PG-10N-01) at friction against fixed abrasive particles is 1.5 times higher, and that of the first type of CM (20% MCM + 80% PG-10N-01) is 1.7 times higher compared to the PG-10N-01 alloy.

The second type of CMC contains Cr_3C_2 , B_4C , TiC , SiC , and nickel boride (Ni_3B) carbides in its structure. The average microhardness of

the deposited layer of 10% MCM + 90% PG-10N-01 is of 660 *HV*, and that of 20% MCM + 80% PG-10N-01 is of 720 *HV*. The wear resistance of the deposited layer of 10% MCM + 90% PG-10N-01 composition is 1.8 times higher, and that of 20% MCM + 80% PG-10N-01 composition is 2.4 times higher in comparison with the layer deposited with self-fluxing alloy PG-10N-01.

The second type of welded cermets has higher wear resistance, when operating in abrasive environments. This is due to the content of chromium, titanium, silicon, and boron carbides in its structure.

Thus, the research results indicate the expediency of using oxides in the charge instead of expensive boron, when using the SHS process for producing CMC.

REFERENCES

1. M. Yu. Osipov, *Innovative Materials and Technologies in Metallurgy and Mechanical Engineering*, **1**: 52 (2014).
2. S. O. Luzan, V. A. Bantkovskiy, and A. S. Luzan, *Metallofiz. Noveishie Tekhnol.*, **44**, No. 4: 531 (2022).
3. R. M. German, *Powder Metallurgy and Particulate Materials Processing* (Princeton, USA: Metal Powder Industries Federation: 2005).
4. A. Makino, *Prog. Energy Combust. Sci.*, **27**: 1 (2001).
5. S. O. Luzan and P. A. Sytnykov, *Herald of Khmelnytskyi National University. Technical Sciences*, **323**, No. 4: 194 (2023).
6. S. O. Luzan and P. A. Sytnykov, *Funct. Mater.*, **30**, No. 4: 526 (2023).
7. V. I. Savuliak, *Syntez Znosostykykh Kompozytsiynykh Materialiv ta Poverkhnevyykh Shariiv z Ehkzotermichnykh Komponentiv* [Synthesis of Wear-resistant Composite Materials and Surface Layers of Exothermic Components] (Vinnitsia: UNIVERSUM-Vinnitsia: 2002) (in Ukrainian).
8. S. O. Luzan and P. A. Sytnykov, *Visnyk Kremenchutskoho Natsionalnoho Universytetu im. Mykhaila Ostrohradskoho*, **4**: 88 (2022) (in Ukrainian).
9. B. Trembach, Y. Silchenko, O. Balenko, D. Hlachev, K. Kulahin, H. Heiko, O. Bellorin-Herrera, S. Khabosha, O. Zakovorotnyi, and I. Trembach, *Int. J. Adv. Manuf. Technol.*, **134**: 309 (2024).
10. B. O. Trembach, Yu. A. Silchenko, M. G. Sukov, N. B. Ratska, Z. A. Duriagina, I. V. Krasnoshapka, O. V. Kabatskyi, and O. M. Rebrova, *Mater. Sci.*, **59**: 733 (2024).
11. A. Chrysanthou, *Adv. in Sci. and Techn.*, **63**: 273 (2010).
12. E. G. Dyadko, *Samorasprostranyayushchiysya Vysokotemperaturnyi Sintez Kompozitsionnykh Materialov na Osnove Karbida Titana i Oksida Alyuminiya dlya Abrasivnoy i Magnitno-Abrasivnoy Obrabotki* (Self-Propagating High-Temperature Synthesis of Composite Materials Based on Titanium Carbide and Aluminum Oxide for Abrasive and Magnetic-Abrasive Machining) (Ph.D. Thesis Abstract) (Kiev: Frantsevich Institute for Problems in Materials Science: 1988) (in Russian).
13. S. A. Luzan, A. Y. Sydashenko, and A. S. Luzan, *Tekhnichniy Servis Ahropromyslovoho, Lisovoho ta Transportnoho Kompleksiv*, **6**: 152 (2016) (in Ukrainian).