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Application of new plasma coatings for restoration of the surface of material

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The study analyzed powder materials to obtain wear-resistant coatings. Field tests for wear resistance were conducted using the method of friction between two surfaces. The tests were carried out on the universal SMC-2 unit according to the roller-shoe scheme at a rotational speed of the moving sample of 200 rpm. A pressure of 100 kgf was applied to the test sample. The wear resistance test cycle comprised 200,000 revolutions, with lubrication provided through the drop method. Special powders were used in the experiment, including PG-SR3, PN55T45, and PR-Ni70Cr17S4R4 + 20% PT-Al5N with a PT-Al5N underlayer. The selection of wear-resistant coatings was based on the analysis of the following properties: adhesion strength of the coating to the base material, wear resistance of the coatings, hardness, and porosity. Metallographic analysis of the structure of plasma coatings obtained from powders PG-SR3, PN55T45, and PR-Ni70Cr17S4R4 + 20% PT-All5N with three different plasma heater power levels (10 kW, 15 kW, and 20 kW) indicated that the densest and most reliable coating among those studied is the coating made from PR-Ni70Cr17S4R4 + 20% PT-Al5N powder. Therefore, there is no need to increase the heater power beyond 15 kW when spraying this type of powder. The research concluded that when obtaining wear-resistant coatings, the optimal choice is PR-Ni70Cr17S4R4 + 20% PT-All5N powder with a PT-Al5N underlayer.
Keywords: plasma coating, wear resistance, properties, structural composition, phase composition.

Застосування нових плазмових покриттів для відновлення поверхні матеріалів. *В.М. Волчук Д.Б. Глушкова,*

В роботі проведений аналіз порошкових матеріалів з метою одержання зносостійких покриттів. Натурні іспити матеріалів на зносостійкість проводилися з використанням методу тертя двох поверхонь. Випробування проводилися на універсальній установці СМЦ-2 а схемою ролик-колодочка при швидкості обертання рухомого зразка 200 об\хв. На досліджуваний зразок здійснювався тиск 100 кгс. Цикл випробувань на зносостійкість склав з 200000 оборотів. При цьому використовували мастило за допомогою крапельного методу. В експерименті використовувалися спеціальні порошки: ПГ-СР3, ПН55Т45 і ПР-Н70Х17С4Р4 + 20% ПТ-Ю5Н з підшаром ПТ-Ю5Н. Вибір зносостійкого покриття базувався на аналізі наступних властивостей: міцність з'єднання покриття з основним матеріалом; зносостійкість покриттів; твердість покриттів; пористість. Металографічний аналіз структури плазмових покриттів, отриманих з порошків ПГ-СР3, ПН55Т45 і ПР-Н70Х17С4Р4+20%ПТ-Ю5Н з використанням трьох потужностей плазмового нагрівача (10 кВт, 15 кВт і 20 кВт), свідчить про те, що самим щільним і надійним покриттям серед досліджуваних являється покриття з порошку ПР-Н70Х17С4Р4+20%ПТ-Ю5НТому не існує необхідності підвищувати потужність нагрівача при напилюванні цього виду порошку більше ніж 15 кВт. Проведені дослідження показали, що при отриманні зносостійкого покриття пріоритетним є вибір порошку ПР-Н70Х17С4Р4 + 20% ПТ-Ю5Н, що має підшар ПТ-Ю5Н.

1. Introduction

The structure of a material formed under various thermodynamic factors has a significant impact on its properties [1-3]. Applying a coating to the surface of a material involves creating a relatively thin layer from another material, aimed at improving the surface properties of the base material (substrate), complementing other methods such as heat treatment or alloying [4-6]. Surface restoration of materials undergoing tribological processes is a critical challenge in modern materials science [7-9]. The process of restoring the surfaces of various materials has become a necessity due to various scientific and technical reasons [10, 11]. For instance, the demand for materials is partly met by using materials with rejuvenated surfaces [12-14]. Additionally, surface restoration allows for continued use of components that are not entirely worn out [15]. Furthermore, restoration contributes to material savings in the production of new machinery, as restoring components requires 20-30 times less material compared to manufacturing them from scratch [16, 17].

One of the most effective methods to combat wear is the application of protective coatings [18, 19]. This approach creates a composite material that combines the strength of the base material with the high durability of the outer layer (coating), which can withstand environmental exposure and contact loads. In recent years, thermal spray coating methods have become increasingly popular [20, 21]. This is due to their versatility, allowing for the application of various coatings with minimal thermal impact on the base material, enhancing the reliability and durability of machine parts and mechanisms by increasing their resistance to wear, while also restoring the dimensions of worn-out components. Additionally, these methods help conserve high-alloy steels and non-ferrous alloys, as they enable the replacement of parts made from these materials with components made from standard-grade steel or cast iron with applied coatings.

One of the most effective methods for thermal spray coating is plasma arc coating with powdered materials. The practical use of this technology in various engineering fields demonstrates its broad potential in terms of material, energy, and labor resource savings.

2. Objective and problem statement

Given the above, the aim of this study is to determine the characteristics of plasma coating used for material restoration to improve their wear resistance. The work explores the processes of forming the structure and properties of plasma coatings applied using powdered materials with varying chemical compositions.

3. Material and methods

Coatings with high hardness are achieved by spraying PT-Yu5N powders with a final layer of PR-Ni70Cr17S4R4 + 20% PT-Al5N, PG-SR3, and PN55T45 (Table 1). The PT-Al5N powder is known for its high wear resistance, as well as its resistance to corrosion and impact loads. These powders are used for surface restoration and as a base layer for applying harder coatings. Coatings made from PR-Ni70Cr17S4R4 powder exhibit insufficient resistance to abrasive wear, but the addition of 20% PT-Al5N powder enhances their abrasive resistance.

The PG-SR3 powder is used for cladding and coating components subjected to intense wear at temperatures up to 600°C and under aggressive environments. The PN55T45 powder (with a melting point of 1240°C) is utilized as a wear-resistant coating for shaft-type components due to its high resistance to alkaline and oxidizing environments.

For spraying coatings on steel samples used in crankshaft manufacturing, an argon-nitro-

Table 1 – The composition and properties of the investigated powders

Powder	Composition	Hardness
PT-Al5H	Ni is a base, Al – 4.30%	210 HB
PR-Ni70Cr17S4R4	C – 0.8-1.2%, Si – 3.8-4.5%, Cr – 16-18%, B – 3.1-4,0%, Fe < 5 %, Ni is a base	55 – 60 HRC 534 – 601 HB
PG- SR3	C – 0.4-0.7%, Si – 2.5-3.5%, Cr – 13.5-16.5%, B – 2.0-2.8%, Fe < 5 %, Ni is a base	44 – 48 HRC 415 – 461 HB
PN55T45	C – 0.07%, Fe – 0.2%, Ti – 43-47%, Ni is a base	55 – 60 HRC 534 – 601 HB

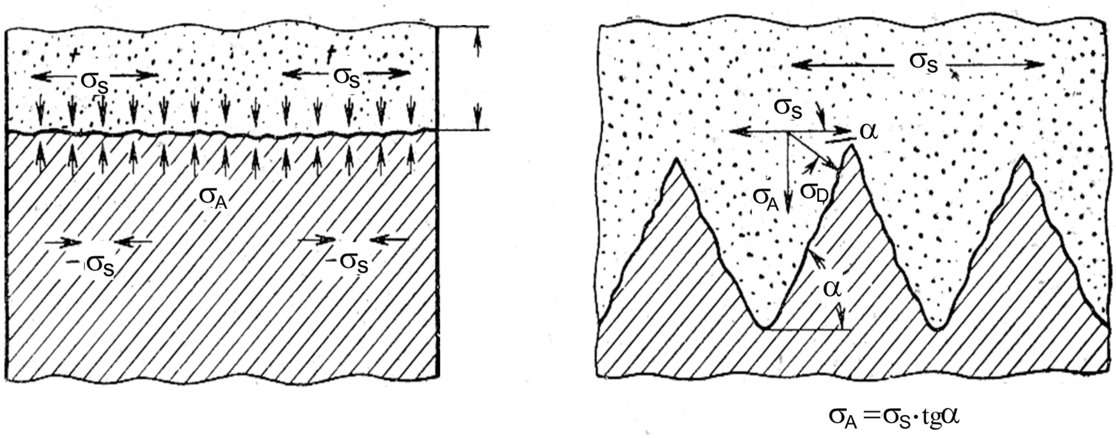


Fig. 1. Occurrence of coupling stresses.

gen plasma generated on the UPU-3D installation was employed.

The main quality criterion for plasma coatings is the adhesive strength between the coating layer and the base metal, which depends on several factors. Adhesion primarily depends on the surface preparation and the properties of both the applied coating and the base metal. Residual stresses can also impact the adhesion strength.

4. Results and its discussion

As illustrated in Figure 1, compressive stresses (σs) in the coating may lead to additional stresses (σA) directed toward the base metal. The resultant compressive force (σD) can exert pressure on the sidewalls of the thread profile, potentially causing a stressed state in the applied coating.

Thorough surface preparation and pre-heating of the component to 200°C, along with uniform and gradual cooling, help prevent shrinkage and delamination of the coating from the base metal. The adhesion strength of the coating to the base metal was assessed through a pull-off test using adhesive (adhesive bonding test).

The wear resistance of materials and coatings is largely determined by their microstructure, as it defines the dislocation nature of wear. Wear resistance was measured using the SMC-2 machine, designed for wear testing and evaluating the antifriction properties of materials during sliding and rolling friction at normal temperatures. The machine used sample pairs of the types “disk-to-disk”, “disk-to-block”, and “sleeve-to-shaft”.

Comparative tests to determine the adhesive strength of coatings using an adhesive bonding test were conducted. The following

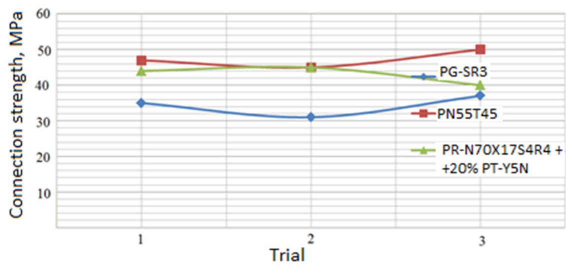


Fig. 2. Results of materials testing for adhesion strength.

materials were used for plasma spraying: PG-SR3, PN55T45, and PR-Ni70Cr17S4R4 + 20% PT-Al5N with a PT-Al5N underlayer.

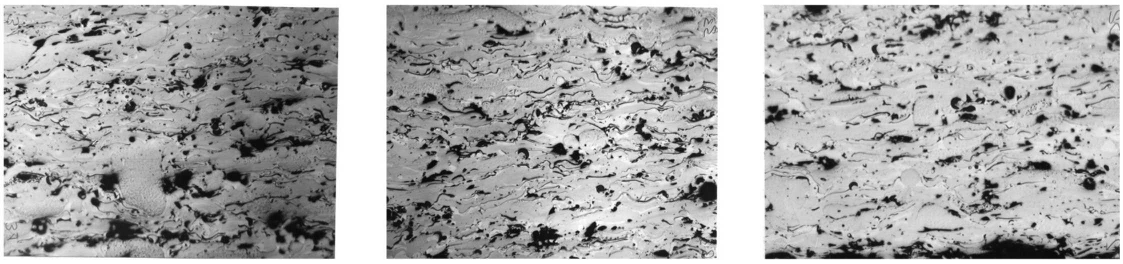
To assess the properties of each material, three samples were prepared, with dimensions in accordance with DSTU standards. Before testing, they were conditioned for 16 hours. The tests were conducted on a tensile machine at a temperature of 20°C, and the results are shown in Figure 2.

The material PR-Ni70Cr17S4R4 + 20% PT-Al5N showed the highest result (maximum adhesion strength of 52 MPa), but with significant variance in the measurements. Therefore, the material PN55T45 is preferred, as it showed less variance in results while maintaining sufficiently high adhesion strength.

Comparative tests were conducted to evaluate the wear resistance of materials using the two-surface friction method. Wear resistance tests were carried out on the SMC-2 machine according to the roller-shoe scheme. During the tests, the rotating sample was spun at a speed of 200 rpm, with a pressure of 100 kgf applied to it. The test cycle consisted of 200,000 revolutions, and lubrication was applied using the drip method.

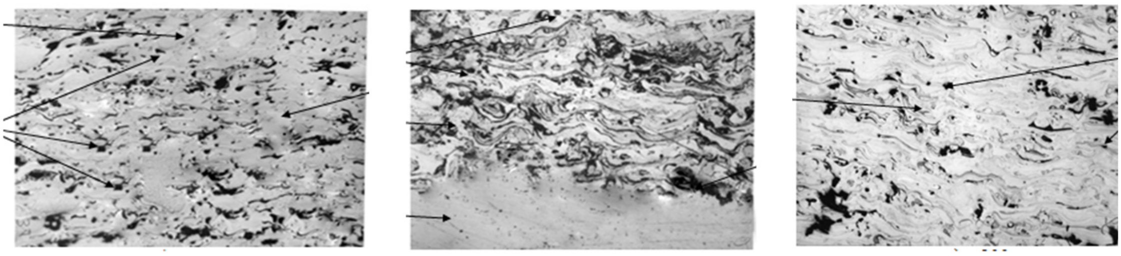
Table 2 – Results of Wear Resistance Tests Conducted

№ п/п	A couple of tests	Wear, grams		Total wear, grams Friction moment, kgf*cm Friction coefficient	Total wear, grams Friction moment, kgf*cm Friction coefficient	Total wear, grams Friction moment, kgf*cm Friction coefficient
		rotating sample	stationary sample			
1	Steel 45 (without surfacing)	0.037	0.0513	0.0880	15 – 16	0.10 – 0.11
2	Steel 45 + PG-SR3	0.1023	0.0855	0.1878	15 – 18	0.12 – 0.26
3	Steel 45 +PN55T45	0.069	0.0860	0.1479	18 – 19	0.10 – 0.12
4	Steel 45 + PR-Ni70Cr17C4P4 + 20% PT-Al5H	0.030	0.0405	0.0705	15 – 16	0.10 – 0.11



a *b* *c*

Fig. 3. Microstructure of plasma coating obtained from PG-SR3 powder at different plasma torch power levels: a - at 10 kW; b - at 15 kW; c - at 20 kW, ×200 magnification.



a *b* *c*

Fig. 4. Microstructure of plasma coating obtained from PR-Ni70Cr17S4R4 + 20% PT-Al5N powder at different plasma torch power levels: a - at 10 kW; b - at 15 kW; c - at 20 kW, ×200 magnification.

The samples for rotation were cut from a crankshaft without a coating layer, as well as with a coated layer from the alloys PG-SR3, PN55T45, Cr20Ni80, and PR-Ni70Cr17S4R4 + 20% PT-Al5N (with a coating thickness of 0.3-0.4 mm), without surface machining. The results of the experiments are presented in Table 2.

The analysis of the obtained results indicates that the material that wears out the fastest is PG-SR3, as shown in Table 2. The best wear resistance results were achieved with the material pair of St45 (without coating) and PR-Ni70Cr17S4R4 + 20% PT-Al5N.

An analysis of the microstructures of plasma coatings obtained from PG-SR3, PN55T45, and PR-Ni70Cr17S4R4 + 20% PT-Al5N powders, using different plasma torch power levels (10 kW, 15 kW, and 20 kW), as illustrated in Figures 3 and 4, revealed the following characteristics:

– All samples exhibit a layered structure, typical of sprayed coatings, resulting from the formation process where molten particles impact a solid surface.

– The presence of pores and non-metallic inclusions in the form of oxides and nitrides was identified, arising from the interaction of the powder with nitrogen plasma and the contact of heated powder with oxygen from the air that enters the plasma jet.

– The densest coating was obtained from PR-Ni70Cr17S4R4 + 20% PT-Al5N powder, and to maintain high quality, a heater power of 15 kW is sufficient; higher power is not necessary.

An analysis of the microstructures of plasma coatings from PG-SR3, PN55T45, and PR-Ni70Cr17S4R4 + 20% PT-Al5N, along with studies on the adhesion strength of the coating to the surface, hardness, wear resistance, and porosity, indicated that the best coating for restoring crankshafts is Ni70Cr17S4R4 + 20% PT-Al5N.

5. Conclusion

1. The studies showed that the most common types of crankshaft wear are the wear of connecting rod journals (96%) and main journals (94%). Other forms of wear include keyway wear (50%), wear in the hole for the guide pin (17%), crankshaft bending (10%), and the occurrence of cracks (7%).

2. It was found that the most effective technology for crankshaft restoration is plasma spraying. Among the powders used for spraying, the following are recommended for comparison: a PT-Yu5N underlayer with a final layer of Ni70Cr17S4R4 + 20% PT-Al5N (where PR-Ni70Cr17S4R4 is very hard, thus adding 20% PT-Al5N improves its wear resistance), as well as PG-SR3 and PN55T45.

3. An analysis of the microstructures of plasma coatings made from PG-SR3, PN55T45, and PR-Ni70Cr17S4R4 + 20% PT-Al5N, along with tests for adhesion strength, hardness, wear resistance, and porosity, indicated that the best option for crankshaft restoration is Ni70Cr17S4R4 + 20% PT-Al5N.

References

1. B.O. Trembach, D.V. Hlushkova, V.M. Hvozdetskyi et al., Materials Science, 59, 18–25 (2023). https://doi.org/10.1007/s11003-023-00738-7
2. V. Lozynskyi, B. Trembach, M.M. Hossain et al., Heliyon, 2024 (2024). https://doi.org/10.1016/j.heliyon.2024.e25199
3. D.B. Hlushkova, V.A. Bagrov, V.A. Saenko et. al., *Problems of Atomic Science and Technology,* **149(1)**, 138 (2023). https://doi.org/10.46813/2022-149-138
4. D.B. Hlushkova, V.M. Volchuk, P.M. Polyansky et. al., *Functional materials,* **30(2)**, 275-281 (2023). https://doi.org/10.15407/fm30.02.275
5. O. Haponova, V. Tarelnyk, T. Mościcki et. al., *Coatings*, **14(5)**, 563 (2024). https://doi.org/10.3390/coatings14050563
6. D.B. Hlushkova, A.V. Kalinin, N.E. Kalinina et. al., *Problems of Atomic Science and Technology,* **144(2)**, 126-129 (2023). https://doi.org/10.46813/2023-144-126
7. D.B. Hlushkova, V.A. Bahrov, O.D. Hrinchenko et. al., *Problems of Atomic Science and Technology,* **132(2)**, 136 (2021). https://doi.org/10.46813/2021-132-136
8. D.B. Hlushkova, I.H. Kyrychenko, V.A. Bahrov et. al., *Problems of Atomic Science and Technology,* **135(5)**, 139 (2021). https://doi.org/10.46813/2021-135-139
9. N.E. Kalinina, D.B. Glushkova, A.I. Voronkov et. al., *Functional materials,* **26(3)**, 514 (2019). https://doi.org/10.15407/fm26.03.514
10. N.E. Kalinina, D.B. Hlushkova, O.D. Hrinchenko et. al., *Problems of Atomic Science and Technology,* **120(2)**, 151-154 (2019).
11. V.N. Korzh, T.V. Vorona, A.V. Shovel. Combined methods of surface engineering. Comprehensive quality assurance of technological processes and systems: Mater. 4th International science and practice conference, May 19-21, 2014, Chernihiv: ChNTU, 2014, 159-163.
12. D.B. Hlushkova, V.A. Bagrov, V.M. Volchuk et. al., *Functional Materials*, **30(1)**, 74 (2023). https://doi.org/10.15407/fm30.01.74
13. D.B. Hlushkova, O.D. Hrinchenko, L.L. Kostina et al., *Problems of Atomic Science and Technology*, **1(113)**, 181-188 (2018).
14. D.B. Hlushkova, Yu.V. Ryzhkov, L.L. Kostina S.V. et al., *Problems of Atomic Science and Technology*, **1(113)**, 208-211 (2018).
15. V.M. Shulaev, A.A. Andreev, V.P. Rudenko, *PSE*, **4(3-4)**, p. 136–142 (2006).
16. T.A. Roik, O.A. Gavrysh, I.I. Vitsiuk et. al., *Powder Metall. Met. Ceram.* **62**, 215–224 (2023). https://doi.org/10.1007/s11106-023-00385-2
17. O.P. Gaponova, B. Antoszewski, V.B. Tarelnyk et. al., *Materials* **14**, 6332 (2021). https://doi.org/10.3390/ma14216332
18. D. Leontiev, O.I. Voronkov, V. Korohodskyi, D. Hlushkova, I. Nikitchenko, E. Teslenko, O. Lykhodii. Mathematical Modelling of Operating Processes in the Pneumatic Engine of the Car: SAE Technical Paper 2020-01-2222 (2020). https://doi.org/10.4271/2020-01-2222
19. V. Subbotina, V. Bilozerov, O. Subbotin et. al., *Functional materials,* **30(4)**, 590 (2023). https://doi.org/10.15407/fm30.04.590
20. D.B.Hlushkova, V.M.Volchuk, P.M.Polyansky et. al., *Functional Materials*, **30(3)**, 453 (2023). https://doi.org/10.15407/fm30.03.275
21. D.B. Hlushkova, V.A. Bagrov, V.A. Saenko et. al., *Problems of Atomic Science and Technology*, **2(144)**, 105 (2023). https://doi.org/10.46813/2023-144-105