ABSTRACT
of the dissertation submitted for the degree of Doctor of Philosophy (PhD)
in the specialty 8D05301 – "Technical Physics"
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"The effect of pulsed plasma treatment on the structure and properties of detonation coatings"

General overview of the work. This dissertation examines the effect of pulsed plasma treatment on the structure and properties of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings. Changes in the phase composition, structure, hardness, roughness, adhesion strength, wear resistance, tribological, and corrosion properties of the coatings after pulsed plasma treatment are examined. A correlation was identified between the structure and properties of the coatings, which depend on the treatment conditions. As a result, an optimal process regime was developed for modifying the surface of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings using pulsed plasma treatment. It has been established that pulsed plasma treatment changes the microstructure of Cr_3C_2-NiCr and Fe-TiB_2-CrB_2 detonation coatings, increasing their hardness, wear resistance, and corrosion resistance by reducing porosity and surface roughness.

The relevance of the research topic. Given the current state of development in the mechanical engineering, metallurgical, energy, mining, and oil and gas industries, there is a growing need to improve the performance characteristics of machine components operating under conditions of severe wear. In most cases, the failure of machine parts begins with the surface layer, as the surface layer is the first to be affected by external mechanical, thermal, and chemical factors. In this regard, the development and improvement of technologies that enable the formation of coatings with high functional characteristics is one of the priority areas of modern surface treatment.

Among the effective methods for improving the performance characteristics of components, detonation spraying for the production of coatings holds a special place. Detonation coatings based on carbide and boride systems are of particular interest. In particular, Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 coatings are highly effective and offer excellent protective properties for steel components operating under heavy loads. Coatings based on the Cr_3C_2-NiCr system have found wide application due to their optimal combination of high hardness, heat resistance, corrosion resistance, and wear resistance. In turn, boride coatings based on Fe-CrB_2-TiB_2 are of significant interest as promising composite materials that provide high hardness and high resistance to abrasive wear. However, despite the advantages of detonation spraying, the resulting coatings are often characterized by a certain degree of structural inhomogeneity, porosity, and microdefects.

In this regard, an important scientific and practical task is the development of effective methods for the subsequent modification of detonation coatings, aimed at improving their structure and enhancing their performance characteristics. One of the most promising areas in this field is combined processing methods based on the application of concentrated energy fluxes. These include laser, electron beam, pulsed plasma, and other types of treatment that allow for the targeted modification of the structural and phase state of surface layers. Due to the local high-energy impact, the coating is densified, porosity is reduced, defects are partially melted, phases are redistributed, and a more refined structure is formed. Among such methods, pulsed plasma treatment holds a special place. Its essence lies in exposing the material's surface to short-duration, high-energy plasma pulses, which cause rapid heating and intense cooling of the surface. In addition, during the treatment process, large-scale physicochemical processes may occur in the coating structure, such as phase transformations, redistribution of alloying elements, changes in structural morphology, reduction of porosity, elimination of microdefects, and the formation of a hardened surface layer. Due to these characteristics, pulsed plasma treatment is considered one of the most effective methods for improving the hardness, wear resistance, corrosion resistance, and overall strength of detonation coatings.

Nevertheless, many aspects of the effect of pulsed plasma treatment on the structure and properties of detonation coatings based on carbide and boride systems remain unclear. In particular, a deeper understanding is needed of the specific structural changes and properties of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 coatings following pulsed plasma treatment. Insufficient study of these issues hinders the scientific optimization of treatment parameters, limiting the practical application of this technology for hardening various machine parts.

Thus, studying the effect of pulsed plasma treatment on the structure, phase composition, and properties of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings is a pressing scientific challenge that is of great importance both for developing theoretical models of the modification processes of carbide and boride coatings and for developing effective technological solutions to improve the operational reliability of components.

Aim of the study: To determine the regularities of the influence of pulsed plasma treatment on the microstructure and phase composition, as well as the physical and mechanical properties, of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings.

To achieve this goal, the following tasks must be addressed in this work:

- To study the effect of pulsed plasma treatment regimes on the structural-phase state, surface morphology, and defect density of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings;

- Determine the characteristics of changes in the physical and mechanical properties of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 coatings depending on the pulsed plasma treatment conditions;

- Evaluation of the effect of pulsed plasma treatment on the tribological and corrosion characteristics of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 coatings;

- Determination of the main mechanisms of hardening of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings during pulsed plasma treatment.

Object of study: Cr_3C_2-NiCr, Fe-CrB_2-TiB_2 detonation coatings.

Subject of the study: The effect of pulsed plasma treatment on the structure and properties of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings.

Research Methods. The following methods were used to study the structural and phase states of the Cr_3C_2-NiCr and Fe-CrB_2-TiB detonation coatings: X-ray phase analysis, scanning electron microscopy, transmission electron microscopy, and profilometry. The following methods were used to investigate the properties of the coatings: nanoindentation for hardness determination; tribological testing using the "ball-on-disk" and "reciprocating" schemes; abrasive wear testing using the "rotating roller–flat surface" scheme in accordance with GOST 23.208–79; scratch test, a method for determining coating adhesion strength; a method for determining porosity in accordance with ASTM E2109; an electrochemical method for studying corrosion resistance.

During the course of the work, resources and equipment from the following research centers were utilized: the "Protective and Functional Coatings" Research Center and the "VERITAS" Center of Excellence of the Daulet Serikbayev East Kazakhstan Technical University, the research and production company "PlasmaScience" LLP, the "Surface Engineering and Tribology" Research Center of the Sarsen Amanzholov East Kazakhstan University, Wrocław University of Science and Technology (Wrocław, Poland), and the E.O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine (Kyiv, Ukraine).

Scientific novelty of the research:

– The effect of pulsed plasma treatment on the microstructure, physical-mechanical, and tribological properties of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings has been investigated for the first time;

– A combined method for producing wear-resistant Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 coatings based on detonation spraying and pulsed plasma treatment has been developed.

The main principle to be defended:

1) A combined coating deposition method has been developed that combines detonation spraying and pulsed plasma treatment, thereby improving the physical and mechanical properties of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 coatings.

2) Following pulsed plasma treatment, the wear rate and coefficient of friction of the Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 detonation coatings decrease, while their resistance to contact fracture increases.

3) The features of the structural transformation of Cr_3C_2-NiCr and Fe-CrB_2-TiB_2 coatings under the influence of pulsed plasma treatment and the main mechanisms of their hardening have been identified.

Main results of the work. It has been established that pulsed plasma treatment has a significant effect on the microstructure, surface morphology and defect density of detonation coatings. It has been demonstrated that pulsed plasma treatment improves the physical and mechanical properties of the coatings. Following pulsed plasma treatment, a positive effect on the tribological and corrosion properties of the coatings was observed. After treatment, the coefficient of friction decreases, the depth and volume of wear are reduced, and resistance to abrasive and impact-abrasive wear is increased. It has been established that the improvement in the properties of the coatings following pulsed plasma treatment is associated with a combination of structural, phase and defect changes occurring in the surface layer.

Practical significance. The practical significance of this work lies in the development of a scientifically grounded approach to improving the properties of Cr_3C_2-NiCr and Fe-CrB_2-TiB detonation coatings using pulsed plasma treatment. The results obtained allow us to propose a rational processing regime that reduces coating porosity and increases the hardness and wear resistance of the protective layers. The developed technology is of practical interest for strengthening components of power, metallurgical, and mining equipment, where a comprehensive improvement in hardness, wear resistance, and corrosion resistance is required.

Relationship of the work to research projects. This dissertation was completed as part of the targeted funding program BR24992854, "Development and Implementation of Competitive, Science-Based Technologies to Ensure the Sustainable Development of the Mining and Metallurgical Industry in East Kazakhstan Region" (2024–2026), funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan in accordance with the priority area of scientific development "Advanced Manufacturing, Digital, and Space Technologies."

The author's personal contribution. The author's personal contribution consists of conducting experiments, conducting research, analyzing the results obtained, and writing scientific articles on the topic of the dissertation. The formulation of research questions and the main conclusions of the dissertation were developed in collaboration with the academic advisors.

The degree of validity and reliability of the results. The degree of validity and reliability of the results ensures that they are scientifically sound and reliable, based on a comprehensive analysis of structural, elemental, and phase composition, as well as the use of standardized research methods in surface profile analysis, mechanical and tribological testing, the analysis of large volumes of experimental data, and the verification of their reproducibility.

Validation of the results. The main findings of the dissertation were presented and discussed at the following international scientific conferences: the 40th Autumn School of Tribology Conference 2022 (Poland, 2022); the 15th International Scientific Conference "Solid State Physics" (Astana, Kazakhstan, December 8–10, 2022); the IEEE 13th International Conference on Nanomaterials: Applications & Properties (NAP-2023) (Slovakia, September 10–15, 2023); 2024 IEEE 14th International Conference on Nanomaterials: Applications & Properties (NAP-2024) (Riga, Latvia, September 2024); International Conference "Materials Science and Composite Engineering" (Istanbul, Turkey, December 25–26, 2025).

Publications. Nine works have been published on the topic of the dissertation, including three articles in scientific journals indexed in the Web of Science and Scopus databases, 2 articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of National Education and Science of the Republic of Kazakhstan, 3 papers in the proceedings of national and international conferences, and 1 invention patent of the Republic of Kazakhstan.

Structure and Scope of the Dissertation. The dissertation consists of an introduction, four chapters, a conclusion, a bibliography of 150 references, and one appendix. The total length of the dissertation is 116 pages, including 60 figures and 8 tables.