ANNOTATION

dissertations for the degree of Doctor of Philosophy (PhD) in specialty 8D05301 – "Technical Physics"

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Formation of structure, phase composition and properties of WC-Co-Cr coatings during high-velocity flame spraying

General characteristics of the work. This dissertation is devoted to the development of metal-ceramic coatings based on tungsten carbide with a cobalt-chromium binder (WC-Co-Cr) with high wear and corrosion resistance, as well as to the study of the formation patterns of their structure, phase composition, and performance properties depending on the process regimes of high-velocity oxygen-fuel spraying (HVOF). The paper presents the results of a study of the microstructure, phase and elemental composition, mechanical, tribological, and corrosion properties of WC-Co-Cr coatings applied to the surfaces of 30Kh13 steel used for critical components of gate valves. Comprehensive experimental studies of the wear resistance of WC-Co-Cr coatings obtained by high-velocity oxygen-fuel spraying were conducted. As part of the dissertation work, a technology was developed for obtaining a wear-resistant WC-Co-Cr coating for gate valve parts, which is protected by the patent of the Republic of Kazakhstan for the utility model "Gate valve with coating" No.10138, published on January 31, 2025.

The aim of the work: Development of metal-ceramic coatings based on WC-Co-Cr with high resistance to wear, erosion and corrosion, as well as the establishment of patterns of formation of their structure and properties depending on the technological regimes of high-velocity oxygen-flame spraying (HVOF) and the characteristics of the original powder material.

In accordance with the stated goal, the following **tasks were formulated**:

- to establish the heating and acceleration behavior of WC-Co-Cr powder particles of different size fractions during HVOF spraying using CFD modeling and to substantiate the rational particle size distribution of the powder;
- to establish the influence of the fractional composition and morphology of the powder on the structural-phase state of WC-Co-Cr coatings;

the WC-Co-Cr coating structure depending on the spraying distance and the flow rate of working gases;

- to determine the influence of microstructural parameters on the mechanical, tribological and corrosion characteristics of WC-Co-Cr coatings;
- to conduct a comprehensive assessment of the operational durability of WC-Co-Cr coatings under conditions of abrasive, hydroabrasive and erosive impact.

The object of the study is a WC-Co-Cr coating obtained by high-velocity flame spraying.

The subject of the study is the structural-phase state, mechanisms of formation and destruction of WC-Co-Cr coatings, as well as their relationship with the

technological parameters of spraying and the characteristics of the original powder material.

Research methods. The work was carried out using a set of modern experimental and computational methods: scanning electron microscopy, energy-dispersive analysis, X-ray phase analysis, microhardness testing (GOST 9450-76), tribological tests using the ball-on-disk scheme (ASTM G99), abrasive wear resistance tests (GOST 23.208-79), hydroabrasive wear resistance tests (ASTM G134-95), adhesion tests by the pull-out method (ASTM C633-01), salt spray corrosion tests (MEMCT 9.308-85), electrochemical corrosion studies (ASTM G59-13), erosion resistance tests (ASTM G76-04) and CFD modeling of particle dynamics in an HVOF jet. The methodological approach is based on a systems analysis of the relationship between the parameters of the technological process, the structural-phase state and the performance properties of the coatings.

In carrying out the work, we used the resources and equipment of the scientific center “Protective and Functional Coatings” of the D. Serikbayev EKTU, the research center “Surface Engineering and Tribology” of the S. Amanzholov EKU, scientific laboratories of PlasmaScience LLP and the Buketov Karaganda University, as well as the Wroclaw University of Science and Technology (Wroclaw, Poland) .

Scientific novelty of the work:

- For the first time, rational HVOF spraying parameters for WC-Co-Cr coatings on 30Kh13 steel were scientifically substantiated, ensuring the formation of a dense structure and improved physicomechanical and tribological properties;
- For the first time, the influence patterns of the temperature-velocity characteristics of WC-Co-Cr particles on the WC/W_2C phase ratio and coating porosity were established;
- The relationship between the microstructural parameters, phase composition, and porosity of WC-Co-Cr coatings and the mechanisms of abrasive, hydro-abrasive, erosive, and corrosion degradation was identified.

The main provisions to be defended:

1. Based on CFD modeling of gas-dynamic and thermal processes in a high-velocity jet during HVOF spraying, a rational particle size distribution of WC-Co-Cr powder was scientifically substantiated. It provides an optimal combination of particle flight velocity (800-900 m/s) and heating temperature (approximately 1300°C), resulting in increased plasticity of the metallic binder, intensive particle deformation upon impact, and the formation of a dense coating without overheating.

2. The influence patterns of HVOF spraying distance, process gas flow rate, and powder particle size distribution on the phase composition, porosity, and physicomechanical properties of WC-Co-Cr coatings were established.

3. Laboratory and bench tests confirmed that the deposition of a WC–Co–Cr coating on 30Kh13 steel by the HVOF method at a spraying distance of 300 mm, an oxygen flow rate of 170 L/min, and a powder fraction of 21–35 μm provides a significant improvement in wear resistance: abrasive wear resistance increased by 9

times, hydro-abrasive wear resistance by 5 times, erosion resistance by 1.4 times, and corrosion resistance by 5.2 times.

Main Results of the Study. The conducted studies showed that the technological parameters of HVOF spraying have a significant influence on the properties of WC-Co-Cr coatings. CFD modeling demonstrated that the temperature, pressure, and velocity of the gas flow play an important role in coating formation. The study revealed that powders with a particle size of 21-35 μm provide an optimal balance between temperature and velocity, while a spraying distance of 300 mm was found to be the most effective condition. Experimental results showed good agreement with the simulation data, confirming the reliability of the applied method. It was also established that oxygen flow rate, powder particle size distribution, and spraying distance significantly affect the structure, phase composition, microhardness, and wear resistance of the coatings. Under optimal parameters, the coatings were characterized by high hardness, low porosity, and strong adhesion strength. The obtained results demonstrated that WC-Co-Cr coatings significantly improve the corrosion, erosion, abrasive, and hydro-abrasive wear resistance of 30Kh13 steel. These findings provide a scientific basis for developing effective protection technologies for components operating under severe wear and aggressive environmental conditions.

Practical significance of the scientific results . The obtained results contribute to the development of physical and metallurgical concepts regarding the formation of thermal spray cermet coatings and can be used in the development of theoretical models of structure formation under high-velocity spraying conditions. A scientifically based technology for producing WC-Co-Cr coatings has been developed, providing a significant improvement in the tribological and corrosion properties of 30Kh13 steel, widely used for the manufacture of gate valve components. The developed technology is an environmentally safer alternative to galvanic chromium plating and can be implemented at enterprises manufacturing pipeline valves. The practical significance is confirmed by a patent of the Republic of Kazakhstan for a utility model («Gate valve with a coating» No. 10138, published on January 31, 2025).

Connection of the work with research projects. The dissertation, «Formation of structure, phase composition and properties of WC-Co-Cr coatings during high-velocity flame spraying», corresponds to the priority scientific development area of «Power Engineering and Mechanical Engineering» and was completed as part of a project funded by the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan:

AP14870977 «Improving the performance characteristics of gate valve components used in the oil industry», grant funding for scientific and (or) scientific and technical projects for 2022-2024.

BR24992854 «Development and implementation of competitive science-based technologies to ensure sustainable development of the mining and metallurgical industry of the East Kazakhstan region», 2024-2026.

Author's Personal Contribution. The author's personal contribution consists of conducting experimental research, analyzing the results presented in the dissertation, and writing scientific articles. The goal and objectives of the dissertation were defined and the main conclusions were formulated in collaboration with the academic advisors.

The validity and reliability of the results are ensured by the use of modern methods for studying the structure, chemical and phase composition, mechanical and tribological testing, and determining the adhesion strength of coatings. The dissertation's results are consistent with existing scientific concepts and are consistent with the materials studied.

Approbation of the work results . The main results of the dissertation were presented and discussed at the following scientific events: International Conference «XL Jesienna Szkola Tribologiczna», Bukovina, Poland, September 13-16, 2022; International Scientific and Practical Conference «Actual Problems of Science and Education in the Context of Modern Challenges» dedicated to the 70th anniversary of the S. Amanzholov Higher School of Economics, Ust-Kamenogorsk, Kazakhstan, September 16-17, 2022; International Conference «Fundamental and Applied Problems of Modern Physics», Tashkent, Uzbekistan, October 19-21, 2023; The 10th International Scientific and Technical Conference «Creativity of the Young - Innovative Development of Kazakhstan», dedicated to the 125th anniversary of Kanysh Satpayev, Ust-Kamenogorsk, April 11-12, 2024, and were also discussed at scientific seminars of the Faculty of Basic Engineering Training of the D. Serikbayev East Kazakhstan Technical University and the Research Center «Surface Engineering and Tribology» of the Sarsen Amanzholov East Kazakhstan University.

Publications. The dissertation research results have been published in 12 scientific works, including 4 articles in peer-reviewed scientific journals indexed in the Web of Science and Scopus databases, 4 articles in journals recommended by the Committee for Quality Assurance in Science and Higher Education of the Ministry of Science and Higher Education of the Republic of Kazakhstan, 4 papers published in the proceedings of national and international conferences and in other scientific publications, as well as 1 utility model patent of the Republic of Kazakhstan.

Structure and scope of the dissertation . The dissertation consists of an introduction, five chapters, a conclusion, a list of references (including 137 titles), and one appendix. The total length of the dissertation is 141 pages, including 77 figures and 20 tables.