ABSTRACT

of the dissertation for the degree of Doctor of Philosophy (PhD) in the specialty 8D05301 – Physics

Zhilkashinova Assel Mikhailovna

"Study of the structural-phase state and properties of the Cr-Al-Co-Y composite coating"

The dissertation work is devoted to the study of the structural-phase state and properties of the composite coating Cr-Al-Co-Y, obtained on the basis of the developed method of magnetron deposition. The effect of heat treatment on the structural-phase state and properties of Cr-Al-Co-Y composite coatings is established in the work.

Relevance of the research topic. As is known, one of the urgent problems of condensed matter physics and its applied directions is the development of technology to improve the strength and operational properties of coating materials of critical parts of power plants. Of great importance are the development of new methods of influencing the structure and properties of coatings, the integrated use of existing developments, the optimal combination of which can create new opportunities for directed effects on the structure and properties of the coatings obtained. The application of protective coatings can provide an increase in the durability of parts without significantly increasing their cost.

Methods of studying the states and properties of coatings are widely covered in the scientific literature. Along with a large number of publications devoted to original research, there are reviews of works on this topic, author's monographs, textbooks and reference books.

However, the above-mentioned studies were mainly based on coating methods, while studies in terms of the structural-phase state and the relationship between the structure and properties of the coating were not fully investigated, in our opinion.

At the same time, the research of composite coatings is of great interest from a scientific point of view. They may have effects that are not present in other materials. The microstructure of the film may differ significantly from the structure of a bulk material of the same composition, and the properties of thin films are largely determined by their morphology. Structural defects in massive materials that do not significantly affect the properties in thin films can dramatically affect their behavior. Surface roughness practically does not affect the characteristics of massive materials, while for film materials it can be a factor determining many parameters. Therefore, in the study of thin-film materials, it is possible to discover new phenomena and patterns that can become the basis for the creation of fundamentally new technologies and devices.

At the same time, the analysis showed the relevance of the study of the structural-phase state and properties of composite coatings, since at present, in conditions of limited material resources in the industrial complex, technologies that increase the durability (resource) of machine parts and assemblies are of particular importance.

Despite the increasing flow of publications on the technology of application and properties of composite coatings, many issues of the process of their formation are still open at the moment.

The relevance of the research topic is also justified by the increased interest of materials scientists in methods of modifying the surface of materials - by applying coatings from various materials with a given structure and physico-mechanical and chemical properties. With the help of such coatings, it is possible to significantly change the mechanical, magnetic, thermal and other properties of the source material, obtaining products with the required properties (for example, anticorrosive, wear-resistant, etc.).

As is known, high values of operational properties of various materials are achieved due to changes in a wide range of structural characteristics of materials: type, number and size of phases; density, nature and distribution of defects in the crystal structure and many other factors. Therefore, the need to establish a relationship between the properties of any material and its structure is beyond doubt. At the same time, in order to fully understand how changes in various technological parameters of any of the processes of modifying the surface layers of products affect the structure and, accordingly, operational characteristics, a comprehensive research approach is needed that would allow us to obtain complete data on the structural and phase state of the materials under study. This further makes it possible, using classical dependencies, to assess the level of the most important mechanical characteristics of materials (strength, ductility, crack resistance, etc.), as well as structural factors that make the maximum contribution to these properties. The results obtained, in turn, will allow us to offer recommendations for improving surface engineering technologies.

Thus, the topic of the dissertation work is justified and is aimed at studying the structural-phase state and properties of the composite coating Cr-Al-Co-Y.

The purpose of the work is to investigate the structural-phase state and properties of the Cr-Alloy composite coating obtained on the basis of the developed magnetron deposition method.

To achieve the goal set in the work, it is necessary to solve the following tasks:

1) to develop a magnetron method for applying a composite coating Cr-Al-Co-Y;

2) to investigate the structural-phase states and properties of the composite coating Cr-Al-Co-Y;

3) to establish the effect of heat treatment on the structural-phase states and properties of the composite coating Cr-Al-Co-Y.

Subject of research:

Composite coating Cr-Al-Co-Y, obtained on the basis of the developed magnetron method of application.

The object of the study:

Structural-phase states and properties of Cr-Al-Co-Y composite coating.

Research methods:

Classical research methods: optical, electron transmission and scanning microscopy, X-ray diffraction analysis. Mechanical tests and thermal methods of surface treatment were also used.

The scientific novelty of the work is that for the first time:

- a magnetron method of applying multilayer composite coatings Cr-Alloy with a controlled concentration of constituent elements has been developed and studied. Optimal modes of application of composite coatings have been determined;

- the regularities of the structural-phase states of the Cr-Al-Co-Y composite coating are determined;

- the effect of heat treatment on the structural-phase states and properties of the Cr-Al-Co-Y composite coating has been established.

The main provisions submitted for protection:

1. Magnetron method of applying a composite coating Cr-Al-Co-Y.

2. Results characterizing the structural-phase state and properties of the composite coating Cr-Al-Co-Y.

3. Regularities of changes in the structural-phase state and properties of the Cr-Alloy composite coating depending on temperature.

Scientific and practical significance of the work:

The obtained results of computational and experimental studies provide new, deeper insights into the processes of formation of composite coatings obtained by magnetron sputtering. The developed method of applying a wear-resistant coating is protected by patents for inventions of the Republic of Kazakhstan. The practical significance of the dissertation work is confirmed by the act of introduction into production.

The field of research of the results obtained are metallurgical enterprises engaged in the creation of high-strength metal products, the creation of innovative technologies for surface treatment of materials.

Personal contribution of the author:

The author's personal contribution consists in setting research objectives, analyzing literary data, participating in electron microscopic, metallographic and X-ray structural studies of composite coatings, statistical processing. The analysis of the results obtained and the formulation of the main conclusions were carried out jointly with scientific consultants. The experimental results were obtained personally by the author in collaboration with the staff of the Federal State Educational Institution of Higher Education "National Research Tomsk Polytechnic University (Tomsk, Russia), the Center for Collective Use of Devices and Equipment "High Technologies and Diagnostics of Nanosystems" of the Federal State Educational Institution of Higher Education "Novosibirsk National Research State University" (Novosibirsk, Russia), the National Scientific Laboratory of Collective Use of the. S. Amanzholov and engineering profile of D. Serikbayev EKTU on the basis of contracts.

Connection of the topic with research programs:

The main work on the content of this dissertation began with the participation of the author in the development of the g/b project of the Ministry of Education and Science of the Republic of Kazakhstan No. 306/2020 (Contract No. 113 dated June 01, 2020) on the topic: "Creation of composite coatings to improve the operational properties of critical components of industrial equipment" (2020-2022)".

The degree of validity and reliability of the results obtained in the work is provided by:

By studying and comparing with the experimental results obtained earlier by well-known scientists of the CIS and far abroad using "direct", well-tested experimental research methods, interpretation of the results and decoding of diffraction patterns. The results obtained do not contradict the basic provisions of condensed matter physics. Phase and structural transformations occurring in the Cr-Al-Co-Y composite coating as a result of heat treatment are explained from the standpoint of the known laws of metastable phase transformations.

The sources of the research are the main experimental and theoretical provisions of modern condensed matter physics, physics of metals and alloys, experimental results of original scientific works of recent years, given in the list of sources used.

Approbation of the results of the work:

The main provisions and results of the dissertation work were presented at international conferences:

1. "23rd International Conference on Wear of Materials", Canada, 26-29 April 2020;
2. International online conference "Advanced manufacturing materials and research: new technologies and techniques AMM&R2021", D. Serikbayev EKTU, Ust-Kamenogorsk, Kazakhstan, February 2021;
3. "14th International Conference "NEW MATERIALS AND TECHNOLOGIES: POWDER METALLURGY, COMPOSITE MATERIALS, PROTECTIVE COATINGS, WELDING", Minsk, Belarus, 09-11 September 2020;
4. "Powder metallurgy: Surface Engineering. New powder composite materials. Welding" Minsk, Belarus, 07-09 April 2021;
5. «XXXIX. Jesiennej Szkoły Tribologicznej", Poland, 01-04 September 2021;
6. "III International Scientific Forum "Nuclear Science and Technologies", Almaty, Kazakhstan, 20-24 September 2021;
7. At the round table of S.Amanzholov EKU "Innovative technologies in thermonuclear energy and mechanical Engineering", Ust-Kamenogorsk, Kazakhstan, 19 April 2021;
8. "IX International Scientific Conference "ACTUAL PROBLEMS OF SOLID STATE PHYSICS" (APSSP-2021) with a poster on the topic: "Study Of Structural-Phase State And Mechanical Properties Of Heat-Protective Coating Cr-Al-Co-Y", Minsk, Belarus, 22-26 November 2021;
9. "IX International Conference Semipalatinsk Test Site: heritage and prospects for the development of scientific and technical potential", Kurchatov, Kazakhstan, 07-09 September 2021;
10. "15th International Conference "New Materials and Technologies: powder metallurgy, composite materials, protective coatings, welding"", Minsk, Belarus, 14-16 September 2022;
11. "The 10th International Conference on Nanomaterials and Advanced Energy Storage Systems", Nur-Sultan, Kazakhstan, 04-06 August 2022;
12. International scientific and practical conference " Ualievsky readings-2022" on the topic "Actual problems of science and education in the context of modern challenges", Ust-Kamenogorsk, Kazakhstan, 23 September 2022.

In addition, the main results were reported and discussed at scientific seminars of the Department of Physics, joint scientific seminars, at the Scientific and Technical Council of the S.Amanzholov EKU.

Publications:

The main results of the dissertation have been published in 13 publications, including 2 foreign scientific publications included in the Scopus and Web of Science database (1. «Coatings», percentile – 51%, quartile (Q) – Q2, IF – 2.436, CiteScore 2,4; 2. «Crystals», percentile – 50%, quartile (Q) – Q2, IF – 2.67, CiteScore 3,2); in 4 editions recommended by the Committee for Quality Assurance in Education of the Ministry of Education of the Republic of Kazakhstan (1. «Bulletin of NNC RK», physical science series; 2. «Reports of the national academy of sciences of the Republic of Kazakhstan», physical and chemical sciences series; 3. «Physical Sciences and Technology», physical science series; 4. «Reports of the national academy of sciences of the Republic of Kazakhstan», physical and chemical sciences series); 7 materials of international conferences and 3 patents for inventions of the Republic of Kazakhstan (1. №35716, мәлімд. 03.04.21, жариял. 17.06.22, Бюл. №24; 2. №35713, мәлімд. 03.04.21, жариял. 17.06.22, Бюл. №244; 3. №35088, мәлімд. 02.04.20, жариял. 28.05.21, Бюл. №21).

Based on the conducted research and analysis of the results obtained, it can be argued that the magnetron sputtering method is recommended for Cr-Al-Co-Y composite coating as a simple, economically more profitable method of coating. In the future, in order to improve the performance characteristics of the coating, it is advisable to improve the technology of magnetron sputtering of composite coatings.

The conducted studies of the structural-phase state and mechanical properties of the composite coating in the future will allow us to apply the obtained dependencies and evaluate structural factors that make the maximum contribution to the operational properties of finished products, in particular the blades of the gas turbine engine, and will also allow us to offer recommendations for improving surface engineering technologies.

The tasks set in the dissertation have been solved in full, the purpose of the dissertation work has been achieved. All planned, difficult to perform, experimental work and a comparative analysis of the results obtained together with scientific consultants and colleagues were carried out. The obtained results and conclusions do not contradict the basic provisions of condensed matter physics and thermodynamics of phase transformations of metals and alloys.

The composite coatings obtained by the proposed method can be used in various industries to harden parts, increase their erosion resistance and wear resistance. The computational and experimental method of predicting the life of coatings allowed us to establish that the blades have uneven wear. These results allow us to offer recommendations for the application of gradient thickness coatings.

The high level of work performed is ensured by the fact that the results were obtained using well-tested “classical” methods of experimental research in specialized laboratories of the National Scientific Laboratory for Collective Use of S. Amanzholov EKU, engineering profile of D. Serikbayev EKTU. The literary review on the topic of the dissertation covers the modern works of scientists from leading countries of the

world. The obtained results are analyzed in comparison with the known data. They have been published in well-known specialized foreign journals included in the Thomson Reuters and Scopus database, discussed at a number of international conferences held in the CIS and in non-CIS countries, protected by patents for inventions.

The analysis of the obtained results of theoretical and experimental studies allows us to draw the following main conclusions:

1. A magnetron method of applying Cr-Al-Co-Y composite coatings has been developed, which allows forming dense coatings without a pronounced columnar structure characteristic of metal coatings. Optimal modes of application of composite coatings have been determined. Multilayer (1-, 2-, 4- and 8-layer) coatings with a controlled concentration of the constituent elements Cr, A, C, Y were obtained.

2. The structural-phase state of multilayer Cr-Al-Co-Y coatings has been studied. Studies have shown that the coatings form a developed interfacial boundary between the coating and the substrate, as well as between the layers themselves, which is clearly visible on all samples. It is established that multilayer coatings in the initial state are predominantly X-ray amorphous. At the same time, the presence of polycrystalline phases (CoO, $AlSi_{0.5}O_{2.5}$ and SiO_2) is observed for a 2-layer coating. It was noted that the chromium concentration in the coating increases with an increase in the number of layers, with a proportional decrease in the amount of cobalt. It is established that the 4-layer coating has a maximum value of surface roughness and microhardness, which makes it the most crack-resistant system of all studied in this work. It was found that the level of erosion (abrasive) resistance of all samples averages 9.8598 e-15 kg/(s*m^2), while 4- and 8-layer coatings, unlike 1- and 2-layer coatings, show an increase in resistance by 7-9 %.

3. The peculiarities of the effect of heat treatment on the structural-phase states and properties of the composite coating Cr-Al-Co-Y. It is revealed that the main process occurring during heat treatment is the formation of a spinel-type phase (SiO_2, CoO, $AlSi_{0.5}O_{2.5}$, $CrAl_{0.4}2Si_{1.58}$, Co_3O_4, Y_2O_3, $CoCr_2O_4$). Their final formation for all multilayer coatings occurs in the temperature range of 800-1000 ^oC. It was found that the structure of the thermally exposed samples is columnar, the presence of layers is clearly distinguishable in all TEM and SEM modes. It has been observed that the cobalt content decreases with increasing annealing temperature. It is shown that with increasing temperature, the values of microhardness and roughness of coatings increase. A slight increase in erosion (abrasive) resistance was found (9.0122e-15 kg/(s*m^2)) after heat treatment at 400 ^0C, compared to the same samples in the initial state. As a result of the research, it was found that the value of the erosion (abrasive) resistance of annealed samples decreased by an average of 16 %.

4. According to the results of the computational and experimental method of forecasting the resource of coatings and the scheme of the structure of coatings, it was found that the working surface of the blades of the GTE has uneven wear. At the same time, calculations have shown that the resource of the working surface of the blades of the GTD with coatings based on Cr-Alloy is about twice as high as the material without coatings.