**ANNOTATION**
**for the dissertation Kengesbekov Aidar Bakytbekuly presented for taking the degree of Doctor of Philosophy (PhD) of the specialty 6D072300 - "Technical Physics on the theme "Development of air-plasma method of wear-resistant coatings on the basis of TiN on the surface of high-speed steels".**

The dissertation work is devoted to the improvement and development of air-plasma method of wear-resistant coatings on the surface of high-speed steels as well as to the study of the influence of spraying technological parameters on the formation of the structural-phase state and tribological properties of TiN-based coatings.

**Topicality of the research topic.**

Technological processes in which the material is exposing to concentrated energy flows in the form of plasma are at present quite common in industry. Plasma jet is widely used as a source of heating, atomization and acceleration of particles during spraying of coatings. The task of developing plasma spraying technology is to obtain a hardened layer with specified operating characteristics (wear resistance, hardness, adhesion strength, etc.) on the surface of a part.

One of the plasma spraying methods is air plasma spraying. This technology is based on heating the sprayed material to liquid and plastic state, its transfer by high-temperature plasma jet to the substrate with subsequent formation of coating layer. Despite the successes achieved in the field of practical implementation of air-plasma processes, the issue of increasing the thermal efficiency of plasma spraying remains relevant. This issue is solved by creating high resource plasmatrons. The task of developing a plasmatron is to create a relatively simple, repairable design that ensures conversion of electric arc energy into thermal energy of the plasma jet with high performance, which allows to effectively apply powder materials with different properties.

In air plasma spraying, powders of metals, alloys and oxides are widely used as spraying material. Powders based on oxygen-free refractory compounds, in particular nitrides, are less common. In some cases, for obtaining nitride coatings, special requirements are put forward due to the peculiarities of the technological process. The process of air plasma spraying of nitride coatings is accompanied by oxidation due to the reaction of coatings with oxygen at high temperatures. The solution to such problems is the use of a "shield cover" in the design of the plasmatron. It is proposed to use a special plasmatron, which is equipped with an additional channel through which the powder and nitrogen are fed. These features of the plasmatron provide the formation of nitrides due to the reaction of nitrogen with metal powders, as well as the formation of a nitrogen shell around the plasma jet, which prevents strong oxidation of powders and coatings. This method is simple and versatile, making it possible to process parts of large size and complex configuration. However, this method of applying nitride coatings is not widespread and has not been introduced into production

and requires detailed study of the law of formation of coatings depending on the structural features and technological parameters of the sputtering. Nitride coatings are most often obtained by PVD and CVD methods and are widely used for hardening of cutting tools made of high-speed steels. The air plasma technology can be considered as a high-performance alternative method of applying wear-resistant nitride coatings on cutting tools.

Thus, despite the noticeable progress in the field of air plasma spraying, there is a need to address a number of issues: the development of small-sized, simple equipment for air plasma spraying of nitride coatings, providing the expansion of technological capabilities of the process; development of high resource plasmatron with increased thermal efficiency, characterized by relative simplicity and maintainability; automation of plasma spraying process by using industrial robots; development of experimentally substantiated concept about the influence of plasma nitride coatings on the durability of cutting tools made of high-speed steels.

Due to the above, the topic of the dissertation work devoted to the improvement and development of air-plasma method of wear-resistant coatings on the surface of high-speed steels, as well as the influence of the technological parameters of sputtering on the formation of the structural-phase state and tribological properties of coatings based on TiN seems to be relevant.

**Aim of the research work:** the development of air-plasma method of obtaining wear-resistant TiN coatings on the surface of cutting tools made of P6M5 steel and the study of the effect of spraying technological parameters on the formation of the structural-phase state and tribological properties of TiN-based coatings.

In accordance with the aim, the following **objectives** were formulated:

– design of an air-plasma unit for the application of powder coatings;

– development and research of characteristics of a plasmatron for air-plasma spraying of powder coatings;

– study of the structural-phase state and characteristics of TiN coatings depending on the parameter of air plasma spraying;

– study of mechanical and tribological properties of TiN coatings obtained by air plasma spraying;

– carrying out bench tests of cutting tools with TiN coatings obtained by the method of air plasma spraying.

**The object of the research** is TiN-based coatings obtained on the surface of high-speed steel P6M5 by air plasma spraying.

**The subject of the research** is the operation mode of the plasmatron, structural-phase states and mechanical and tribological properties of TiN coatings on the surface of cutting tools, bench tests of cutting tools with TiN coating.

**Research methods.** Modern experimental methods of research of composition, structure and properties of coatings: electron microscopy; X-ray phase analysis; methods of micro- and nanoindentation, scratch testing; determination of adhesion by

tear-off method; potentiometric method of corrosion testing; tribological tests according to "ball-on-disk" and "linear reciprocating wear" scheme; drill bench tests; thermal analysis of plasmatron design by finite element method in the software SolidWorks. The following equipment and instruments were used as instrumentation: X-ray diffractometer X'PertPRO, electron scanning microscope TESCAN MIRA3 with energy dispersive X-ray detector (EDAX) model INCA ENERGY; potentiostat-galvanostat P-150; Elcometer 510 adhesimeter; CSEM Micro Scratch Tester; Metolab 502 micro-hardness tester; NanoScan-4D-Compact nano-hardness tester; Model 130 profilometer; TRB$^3$ tribometer; as well as the developed, manufactured and and tested by us the stand for an estimation of wear resistance of materials and forces of a friction in the course of cutting.

The resources and equipment of the Research Center "Surface Engineering and Tribology" of Sarsen Amanzholov East Kazakhstan University, Buketov Karaganda University, the research and production firm LLP "PlasmaScience", Wroclaw University of Science and Technology (Wroclaw, Poland) and Center for measuring the properties of materials FSEI of HE "National Research Tomsk Polytechnic University" (Tomsk, Russia) were used during the work.

**Scientific novelty of the research work:**

– developed a high-resource plasmatron for air-plasma spraying of powder coatings, which is protected by a patent for the invention "Plasmatron for spraying" (№34334 published 14.08.2020). The advantage of the developed plasmatron is that the anode is made all-welded and its surface has a radiator profile, which provides effective cooling and reliability at high pressures of the coolant;

– the method of air-plasma spraying of wear-resistant TiN coatings on the surface of cutting tools made of high-speed steel R6M5 and the proposed method of assessing the wear resistance of the drill bit and friction forces in the process of cutting on the newly developed test bench.

**The main provisions carried out for the defense:**

1. The results of theoretical and experimental research, substantiating the thermal efficiency of the plasmatron with an all-welded anode, the surface of which has a radiator profile.

2. Technological methods of obtaining coatings based on TiN with high hardness and resistance to wear by air plasma spraying.

3. The results of development and introduction of special technological equipment of air-plasma spraying of wear-resistant TiN coatings on the surface of cutting tools from high-speed steel R6M5, which allows increasing the resource of drills from steel R6M5 up to 2 times.

**The practical significance of the scientific results.** The practical significance of the work consists in the development of:

– high-resource plasmatron for air-plasma spraying, which allows to apply nitride coatings with high tribological characteristics;

– methodology for determining the friction forces of the drill bit in the process of cutting, which is implemented on special newly developed equipment in the form of a stand made on the basis of a screw-cutting lathe.

The data obtained as a result of research allow us to recommend air-plasma spraying technology, as well as the proposed model of plasmatron in the application of coatings based on titanium nitride on the surface of cutting tools made of high-speed steel for practical use in industry.

**Relation of the work to research projects.** The thesis on "Development of air-plasma method of applying wear-resistant coatings based on TiN on the surface of high-speed steels" corresponds to the priority direction of science "Energy and mechanical engineering" and was performed in accordance with the following projects funded by the Committee of Science of the MSHE of RK:

– BR05236748 "Research and development of innovative technologies for obtaining wear-resistant materials for mechanical engineering products", program-targeted funding for 2018-2020;

– AP14972882 "Development of scientific and technological bases for obtaining intermetallide coatings by air plasma spraying for use in power engineering", grant funding for young scientists under the project "Zhas galym" for 2022-2024.

**Author's personal contribution.** The main results presented in the thesis were obtained by the author himself or with his direct participation. Aims and objectives were formulated together with scientific advisors. The publications were prepared jointly with the co-authors.

**The degree of validity and reliability of the results** is ensured by using modern methods of studying the structure, chemical and phase composition, mechanical and tribological tests, determination of coating adhesion strength. The results of the thesis do not contradict the known scientific ideas and correspond to the studied materials.

**Approbation of the results of the work.** The main results of the thesis have been presented and discussed at the following scientific events: the 14th International Symposium "Powder Metallurgy: Surface Engineering, New Powder Composites. Welding", Minsk, Belarus, September 9-11, 2020; VI International conference "Laser, plasma researches and technologies - LaPlaz-2020", Moscow, Russia, February 11-14, 2020; International scientific conference "The international conference - Advanced materials manufacturing and research: New technologies and methods", Ust-Kamenogorsk, Kazakhstan, February 19, 2021; International conference "World Conference on Engineering, Technology and Applied Science", Bangkok, Thailand, September 14, 2020. Bangkok, Thailand, 07 November 2022, and also were discussed at scientific seminars of the Faculty of Basic Engineering Training of D. Serikbayev East-Kazakhstan Technical University, the Research Centre "Surface Engineering and Tribology" of Sarsen Amanzholov East-Kazakhstan University and scientific-production LLP "PlasmaScience".

**Publications.** The topic of the dissertation has been covered in 13 articles, including 1 article in the peer-reviewed scientific journals indexed in the Web of Science and Scopus databases, and 4 articles in the journals recommended by the

Committee on Quality Assurance in the field of science and higher education of the MSHE of the Republic of Kazakhstan, 6 articles in the proceedings of national and international conferences, 1 monograph in co-authorship and 1 patent for invention of the Republic of Kazakhstan.

Structure and volume of the dissertation. The dissertation work consists of an introduction, three chapters, a conclusion, a list of references from 131 references and 4 appendices. The total volume of the dissertation is 103 pages, including 70 figures and 15 tables.