

REPORT OF OFFICIAL OPPONENT
of the dissertation by Hu Wenjie
on the topic «Cold spraying of protective and restorative coatings on parts
of aviation engineering made of titanium alloys»
applied for the degree of Doctor of Philosophy
in the field of knowledge 13 Mechanical Engineering
in the specialty 132 Materials science

Relevance of the Dissertation Topic.

Cold gas dynamic spraying technology is a new additive manufacturing technology often used in coating preparation. It can prepare target coatings on the surface of parts or repair damage on the surface of parts. It is widely used in the field of aerospace surface engineering technology. By improving equipment components and optimizing spraying patterns to form coatings from given powder materials, the productivity of the process can be improved, and high-performance indicators of coating quality can be ensured. Spraying complex external surface parts or difficult-to-reach surfaces inside parts depends mainly on the cold spray nozzle structure. Therefore, based on the traditional linear cold spray nozzle, further exploring the new structure of the cold spray nozzle is a significant work. The deposition time of powder particles on the substrate is very short. Therefore, the deposition process of powder particles on the substrate is studied by numerical simulation to more accurately understand the deformation of powder particles after hitting the substrate and the formation process of coating. Hence, it is crucial work to study the nozzle structure and the deposition characteristics of titanium alloy substrate surface.

Evaluation of the Scientific Validity, Credibility, and Novelty of the Dissertation's Research Findings.

The scientific propositions, conclusions and recommendations formulated in the dissertation are based on the fundamental propositions of gas dynamics and mechanics. The validity and reliability of the obtained results are ensured and confirmed by the rigour of theoretical conclusions, the correct use of modern mathematical analysis software, the justified choice of assumptions and limitations during the formulation and formulation of the solved scientific problem, the results of numerical simulations, sufficient scientific approval of the results in specialized scientific publications approved by the Ministry of Education and Sciences of Ukraine, journals that are indexed in Scopus/Web of Science databases, in proceedings of international scientific conferences.

The results of the dissertation obtained by the author were carried out at the Department of Aircraft Engine Manufacturing Technology of the National Aerospace University "Kharkiv Aviation Institute" in the implementation of the state budget research project of the Ministry of Education and Science of Ukraine: "Development

of aggregate technology of restoration and repair of aviation (helicopters) parts by cold spraying with post process machining of deposited coatings" (№ ДП 0122U001341, 2022-2023) and "Development of technology and equipment for cold spraying of restorative coatings on aircraft parts" (№ ДП 0124U000553, 2024).

The scientific novelty of the dissertation's research is as follows:

1) for the first time, based on the results of numerical modeling, the dependence of the speed of a powder particle at the exit from a profiled single-channel nozzle for spraying on the gas parameters at the nozzle entrance (temperature and pressure), powder characteristics (material and particle size), and geometric characteristics of the nozzle (diameter of the critical section, its length, the angle of rotation of the flow in the critical section, the length of the expanding part of the nozzle, the powder supply point).

2) for the first time, the features of the acceleration and trajectory of the movement of powder particles in the profiled rotating nozzle were determined depending on the temperature and pressure of the main gas flow, the pressure of the transporting flow, the material of the powder and the size of its particles.

3) A scientifically based comprehensive approach was further developed, which is based on the use of theoretical calculations and the results of numerical modeling and makes it possible to predict the speed of particles of various powder materials at the exit from the nozzle, which made it possible to obtain and generalize the ways of ensuring the formation of bonds between powder particles and substrate.

Assessment of the Dissertation Content, Its Completeness, and Adherence to the Principles of Academic Integrity.

The dissertation of applicant Hu Wenjie fully complies with the standard of higher education in specialty 132 materials science and corresponds to the areas of scientific research in accordance with the relevant educational program. The presented dissertation work was completed at a high scientific level and is a fully completed scientific work.

Based on the report on the dissertation's originality, it can be concluded that Hu Wenjie's dissertation is the result of independent research and does not contain elements of falsification, compilation, fabrication, plagiarism or borrowing. The ideas, results and texts of other authors presented in the dissertation work have appropriate links to sources.

The dissertation does not contain signs of violation of the principles of academic integrity.

Language and Style of Presenting the Results.

The dissertation is written in English. Chapters and subsections have a logical structure, and the material of the dissertation is presented consistently in a scientific style using generally accepted professional and general scientific terminology. The

work achieves thematic completeness and full disclosure of the main scientific ideas of the recipient.

The dissertation consists of an abstract, 4 chapters, conclusions and appendixes. The total volume of the dissertation is 186 pages, of which 177 pages are the main text.

The introduction substantiates the relevance and necessity of the chosen research direction, formulates the goal and task of the research, outlines the scientific novelty and practical significance of the obtained results, and provides information about their approval, publications and the structure of the dissertation work.

The first chapter examines the use of titanium alloys in the aviation and aerospace industries, operational defects, their causes, and possible ways of prevention and elimination. An analysis of publications dedicated to the use of technology for spraying wear-resistant coatings on titanium alloys and materials used to restore the worn surfaces of parts from these alloys was conducted. Based on the analysis results, unsolved issues in cold gas-dynamic spraying of coatings on titanium alloys were identified, and ways of solving them and improving the technology were outlined.

The second chapter presents these results: the main equations of gas dynamics are given, which describe the flow in narrowing-expanding nozzles for cold gas dynamic spraying and the calculation of their geometric characteristics. The models were analysed to find the temperature-velocity characteristics of powder particles in the gas flow in the nozzle channel. The optimal minimum length of the rotating expanding part of the nozzle was determined to ensure the required speed of the particles at its exit. The simulation results of the influence of this nozzle's geometric characteristics on the powder particles' acceleration and speed at the moment of contact with the substrate are given. Dependencies are built, and recommendations are given for choosing the radius of rotation of the nozzle, the length of the extended part and the distance of spraying to ensure the maximum values of the velocity of the particles at the moment of contact with the surface of the substrate. A multi-channel rotary nozzle is offered for cold spraying on surfaces of internal and hard-to-reach parts. The effect of particle diameter, pressure of the gas transporting the powder, channel dimensions, recovery coefficient, and powder material on the acceleration and trajectory of particle movement in and out of the nozzle was studied.

The third chapter is devoted to the numerical modelling of the high-speed collision of powder particles with the substrate in cold gas-dynamic spraying. For the first time, the use of criterion Y (the ratio of the crater's depth in the surface, formed as a result of the collision of a powder particle with it, to the height of the deformed particle) is proposed. The process of collision of powder particles of various materials with a titanium surface is considered from the point of view of energy balance for a better understanding of the influence of the particle speed at the time of collision with the substrate on the process of cold gas dynamic spraying. When spraying on a

titanium alloy surface, the results of the numerical simulation of the collision of a set of particles of a pure metal powder, as well as a powder mixture.

The fourth chapter provides recommendations for the practical use of the obtained results of the dissertation work, in particular, the geometry of the channels of supersonic nozzles for cold spraying of direct and rotary spraying coatings on the inner surfaces of parts made of titanium alloys, the developed device for feeding powder into the extended part of the nozzle during cold high-pressure spraying. Recommendations for further studies of the cold gas dynamic spraying process are given.

The conclusion briefly describes the main results of the dissertation research and proposes promising tasks for further research.

The Appendixes presents the simulation guide for Abaqus software particle deposition processes and the applicant's list of publications.

The dissertation adheres to the requirements outlined in the order of the Ministry of Education and Science of Ukraine dated January 12, 2017, No. 40, "On Approval of the Requirements for the Dissertation Formatting".

Publication of Dissertation Results.

The results of the dissertation work were published in 19 articles. Among them, 7 articles in scientific periodical publications included in category «A» of the List of scientific specialized publications of Ukraine or foreign publications indexed in the Web of Science Core Collection and/or Scopus database; 6 articles in scientific periodical publications included in the List of scientific specialized publications of Ukraine (category «B»); and 5 conference proceedings (4 of them indexed in the Scopus database), and 1 Chinese patent.

Thus, the dissertation's publications fully cover the scientific results described in the scholar's publications.

Disadvantages and comments to the dissertation work.

Among the disadvantages and comments, the following should be noted:

1. The dissertation does not explain the practical significance of the developed nozzles shown in Fig. 2.12.

2. There is no justification for selecting factors for multifactor analysis (section 2.5).

3. In Tables 2.4–2.6, the applicant made a conclusion about the possibility of adhesion of powder particles to the surface by comparing the particle velocities obtained from the results of numerical simulation under certain initial conditions with the values of the critical velocity. However, such a comparison is not correct since the velocity of the particles is measured at the nozzle exit, and the critical velocity is calculated at the moment of contact of the particle with the surface; that is, the spraying distance is not taken into account, which affects the drop in velocity in the distance from the nozzle exit to the substrate.

4. In section 3.3, a new method for determining the critical velocity is proposed, based on the use of the introduced criterion Y, but there are no explanations and research on the influence of the particle diameter and material temperatures on the criterion Y.

5. The text contains spelling and punctuation mistakes.

I believe that the comments expressed are not decisive, don't reduce the general scientific novelty and practical significance of the results and don't affect the positive evaluation of the dissertation work, but are aimed at further research in this area.

Conclusion on the dissertation work.

The dissertation work of the applicant for the scientific degree of Doctor of Philosophy Hu Wenjie on the topic "Cold spraying of protective and restorative coatings on parts of aviation engineering made of titanium alloys" is a fully completed work at a high scientific level. The applicant adhered to the principles of academic integrity. The presented dissertation work is a comprehensive scientific study that solves a research problem that is important for the field of Knowledge 13 Mechanical Engineering. The dissertation work is relevance, practical value, and scientific novelty, fully meeting the requirements of the current legislation of Ukraine as outlined in paragraphs 6-9 of the "Procedure for awarding the degree of Doctor of Philosophy and revoking the decision of a one-time specialized academic council of a higher education institution, research institution, on awarding the degree of Doctor of Philosophy," approved by the Resolution of the Cabinet of Ministers of Ukraine on January 12, 2022, No. 44.

The applicant Hu Wenjie deserves to be awarded the degree of Doctor of Philosophy in the field of Knowledge 13 Mechanical Engineering, in the specialty 132 Materials science.

Official Opponent:

Candidate of Technical Sciences,
Associate Professor, the Head of
the Department of Technical
Service and Industrial Engineering
of the Sumy National Agrarian
University

14.11.2024

Ievgen KONOPLIANCHENKO

