

REVIEW
of the dissertation work by Hu Wenjie
on the topic «Cold spraying of protective and restorative coatings on parts of
aviation engineering made of titanium alloys»
presented 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.

The increase in maintenance and repair costs stimulates the search for new technical solutions to extend the service life of parts and return them to operation. This problem is especially relevant for parts made of titanium alloys, the use of which for the manufacture of parts of aviation and aerospace equipment is explained by their excellent properties of the material - high specific strength, good corrosion resistance, high heat resistance and other properties. However, existing disadvantages, such as low wear resistance and sensitivity to high temperatures, limit their wide use in industry.

One of the main directions of maintaining the performance of parts made of titanium alloys, increasing the durability and resources of aviation equipment in modern conditions is the improvement of low-cost technological processes of their strengthening at the stage of production and restoration during repair in combination with the use of available and cheap materials with guaranteed high reliability indicators of repaired products. The solution to this problem is limited by the limited use of modern methods of repair and restoration of parts made of titanium alloys.

The technology of cold gas dynamic spraying, in contrast to existing alternative methods of coating, is characterized by relatively low operating temperatures of the process and spraying of powder material without its melting. The absence of structural and phase changes in the coating and substrate materials allows applying durable coatings with minimal porosity to temperature-sensitive materials, in particular titanium alloys, which opens up wide opportunities for introducing the technology into industry. This can be realized under the condition of a deeper study of the processes of cold gas-dynamic spraying. The development of cold spraying technology through the improvement of equipment, optimization of spraying modes, selection of powder material will allow to offer new technical solutions and technologies for prolonging the service life of aviation equipment parts made of titanium alloys.

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

The results of the dissertation obtained by the author were carried out at the Department of Aircraft Engines 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" (№ ДР 0122U001341, 2022-2023) and "Development of technology and equipment for cold spraying of restorative coatings on aircraft parts" (№ ДР 0124U000553, 2024). This research was funded by the China Scholarship Council (No. 202008100011), under Natural Science Project of Nanchang Institute of Technology (NLZK-22-05): "Optimization of protective and restorative cold spraying process for aircraft titanium alloy parts"; Science and Technology Project of Jiangxi Provincial Department of Education (GJJ2202721): "Study on protective and restorative cold spraying technology for aircraft titanium alloy parts."

In the presented work, the author used modern theoretical and numerous modeling methods. The theoretical part of this dissertation uses computational fluid dynamics, gas dynamics, and finite element numerical analysis of solid-liquid two-phase flows consisting of micron particles and gases. Multi-parameter coupling optimization of the velocity of powder particles uses the response surface analysis method and GA+BPNN method.

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 modelling 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.

Thus, the scientific tasks proposed in the dissertation – the study of velocity characteristics of particles in a cold spray nozzle, development of a cold spray nozzle and single/multi-particle deposition onto titanium alloy – have been fully accomplished, and the applicant has fully mastered the methodology of the scientific activity.

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

Language and Style of Presenting the Results.

The dissertation has been written in English and presented consistently, in a scientific style, using generally accepted terminology. The dissertation material, description and mathematical calculations are laid out consistently, logically and in an accessible form. For all abbreviations that are not generally accepted or little-known, transcriptions are provided at the first mention in the text.

The structure and scope of the dissertation. The dissertation consists of an abstract, introduction, 4 chapters, conclusions and an appendixes.

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.

Chapter 1 analyses the influence of the parameters of cold gas-dynamic spraying on the properties of coatings and the efficiency of the process. An analysis of publications dedicated to using technology for spraying wear-resistant coatings on

titanium alloys and materials used to restore the worn surfaces of parts from these alloys was conducted.

Chapter 2 analyses the models to find the temperature-velocity characteristics of powder particles in the gas flow in the nozzle channel. Analysis of rotary nozzle for spraying coatings on interior and hard-to-reach surfaces using numerical simulation. A multi-channel rotary nozzle is offered for cold spraying on surfaces of internal and hard-to-reach parts. Study 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.

Chapter 3 is devoted to the numerical modelling of the high-speed impact of powder particles with the substrate in the process of cold gas-dynamic spraying. The simulation results are compared with the calculated values of the critical speed and the results of other scientists. 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.

Chapter 4 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, selection of spraying parameters (pressure and temperature of the gas at the entrance to the nozzle, the size of the powder particles).

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

The appendix consists of Abaqus software that simulates key particle deposition processes and the list of publications in this dissertation.

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 «Б»); 1 Chinese patent, and 5 conference proceedings (4 of them

indexed in the Scopus database: Integrated computer technologies in mechanical engineering (ICTM). ICTM 2021; International Conference on Mechanical Engineering and Materials (ICMEM2020); International Conference on Artificial Intelligence and Advanced Manufacturing (AIAM2021 and AIAM2023)).

Thus, the scientific results described in the dissertation are fully explained in the applicant's scientific publications.

Disadvantages and comments to the dissertation work.

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

1. It would be appropriate to pay more attention to proving the scientific novelty of the obtained results of the dissertation based on their comparison with existing analogues and proving the superiority of the obtained over the existing ones.

2. The second chapter of the thesis presents the results of numerical modeling of the influence of individual geometric parameters of the nozzle for spraying on the particle velocity at the nozzle exit. However, this work can be replaced by calculating the optimal geometry of the nozzle for the required velocity, considering the initial gas parameters at the nozzle inlet.

3. The intervals of factor variation chosen for multivariate analysis should be set in a wider range.

4. The given recommendations for choosing the introduced criterion Y according to the claims of the applicant make it possible to predict the possibility of adhesion formation between the particle and the substrate, which is not confirmed by experiments, and no values of this adhesion and its changes in the given ranges of Y criteria are given.

5. There are spelling, stylistic and punctuation errors in the text of the dissertation.

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 reviewer:

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