

## **REVIEW**

of the dissertation work by Hu Wenjie

«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 speciality 132 Materials science

### **Relevance of the Dissertation Topic.**

Cold gas dynamic spraying is an emerging coating preparation process technology developed recently. It is widely used in the field of aerospace technology. The cold gas dynamic spraying system is mainly divided into two essential parts: the powder particles are accelerated by the high-speed gas flow in the nozzle, and the powder particles are deposited on the substrate to form a coating.

Wear, mechanical damage, and corrosion are the main reasons for reducing their resource, as well as the occurrence of failures of the unit and the mechanism as a whole. The wear problem is especially relevant for parts made of titanium alloys. 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 repair and restoration methods of parts made of titanium alloys.

The dissertation studies a new type of special nozzle with broad applicability, then makes many numerical simulations of titanium alloy substrate, gives suggestions for deposition onto titanium alloy, and puts forward a new definition method for the critical velocity of cold spraying. Therefore, the content of this dissertation is closely related to the topic.

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

The scientific propositions, conclusions, and recommendations developed by the author and presented in the dissertation are sufficient to be valid. Hu Wenjie elaborated and analysed a significant number of literary sources devoted to cold gas-dynamic spraying, in particular, the use of numerical modelling methods to study and describe the motion process of particles in special nozzles and the deposition characteristics of different particles on the surface of titanium alloy substrate. General

scientific and unique techniques and methods of cognition were used in the research; their use allowed the applicant to scientifically substantiate the theoretical and practical aspects of the influence of the spraying process parameters on the formation of coatings onto titanium alloy substrate.

The validity and reliability of the obtained research results, scientific provisions and dissertation recommendations were confirmed by their approval at international and all-Ukrainian scientific and practical conferences. In addition, some scientific results of the applicant were verified within 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, 2020-2022) 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.

The author mainly presents two works: one is to study a new special multi-channel nozzle suitable for particle spraying of titanium alloy, which can be used not only for conventional surfaces but also for internal surfaces that are difficult to spray; the second one is to explore the deposition characteristics of titanium alloy surface, do a large number of numerical simulations, and summarise the particle deposition range of titanium alloy. It has practical value for cold spray fields.

Thus, the practical significance of the results obtained in the dissertation research lies in the results obtained in the dissertation research, which can be used to solve a wide class of practical problems for titanium alloy when developing

technologies and technological recommendations for spraying protective and restorative coatings. This purpose has been fully accomplished, and the applicant has extensively acquired the methodology of scientific research throughout the dissertation work.

### **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 academic program «Materials science».

The presented dissertation work was completed at a high scientific level and is a fully completed scientific work and testifies to the presence of the recipient's personal contribution to the scientific direction 13 Mechanical engineering.

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 dissertation consists of an abstract, 4 chapters, conclusions and appendixes. The total volume of the dissertation is 186 pages, of which 176 pages are the main text. The dissertation contains 96 figures, 34 tables, 171 references and 2 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 summarised 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 the cold gas-dynamic spraying of coatings on titanium alloys were identified.

Using numerical simulation, Chapter 2 developed a rotary nozzle for spraying coatings on interior and hard-to-reach surfaces. 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. 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.

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. For the first time, the use of the criterion  $Y$  (the ratio of the depth of the crater 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, which can be used to determine the critical speed of the particle at the moment of collision, necessary for its adhesion to the surface and to predict the possibility of formation adhesive bonds between them. The simulation results are compared with the calculated values of the critical speed and the results of other scientists.

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.

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

The Appendix includes 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 5 articles in scientific periodical publications included in category «A» of the List of scientific specialized publications of Ukraine or in 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»); and 5 conference proceedings (4 of them indexed in the Scopus database), and 1 Chinese patent.

Thus, the scientific results are described in the dissertation work, and the necessary volume is 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. The dissertation does not describe what quantitative characteristics of coating adhesion can be achieved by following the recommendations and ensuring the powder particles' velocity at the nozzle's exit and what minimum adhesion values can be acceptable for the reliable operation of titanium parts with coatings.

2. There is no explanation for the choice of powder materials for the study and the particle sizes chosen (20  $\mu\text{m}$  for titanium; 30  $\mu\text{m}$  for aluminium, 15  $\mu\text{m}$  for copper) as it would be useful to see the results for a range of sizes for each material.

3. The applicant considered the process of impact of powder particles from the point of view of energy balance, so it would be worthwhile to indicate the value of the kinetic energy of the particles necessary for forming bonds between the particle and the substrate.

4. The practical use of the proposed criterion Y is not resolved since its dependence on the velocity of the particles at the moment of contact with the substrate and not on the spraying modes is shown.

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.

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