

REPORT OF OFFICIAL OPPONENT

of the dissertation by Tan Kun
on the topic «Development of supersonic nozzles for cold spraying»
applied for the degree of Doctor of Philosophy
in the field of knowledge 13 Mechanical Engineering
in the specialty 134 Aerospace Engineering

Relevance of the Dissertation Topic.

The topic of Tan Kun's dissertation, "Development of supersonic nozzles for cold spraying", is relevant because cold gas dynamic spraying is an emerging coating preparation process technology that has developed in recent years. It is a part of surface additive manufacturing and repair technology suitable for the field of aerospace technology. Research and exploration of cold gas dynamic spraying technology can better and more widely develop the application of this technology.

The relevance and necessity of research are due to the development of cold gas dynamic spraying technology in the field of surface engineering and the use of technology to create volumetric additive materials. Increasing the productivity of the process and ensuring high-performance indicators of coating quality can be achieved by improving equipment elements and optimizing spraying modes for forming coatings from given powder materials. In addition, the expansion of technological capabilities of equipment for spraying coatings on internal and hard-to-reach surfaces of parts will open new directions of the practical application of technology in spraying protective and restorative coatings.

The aim of the research is to develop a supersonic nozzle for cold gas-dynamic spray coating on surfaces both inside and outside the field of view and to study the acceleration pattern of powder particles in the nozzle and the contact zone between the particles and the substrate during high-speed deposition.

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 is ensured and confirmed by the rigor of theoretical conclusions, the correct use of modern mathematical apparatus, 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 the M.N.B.D. Scopus/Web of Science, in proceedings of international scientific conferences.

The results of the dissertation obtained by the author were carried out at the Department of Aircraft Engine Production Technology of the National Aerospace University named after M. E. Zhukovsky "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) during 2020-2022.

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

- 1) for the first time, a method of profiling supersonic single- and multi-channel right-angle nozzles for cold gas-dynamic spraying of coatings on internal and out-off-view surfaces was proposed, which provides the necessary values of the speed of powder particles at the exit of the nozzle for their adhesion to the substrate when the flow is turned by 90° .

- 2) For the first time, based on the results of numerical modeling, the dependence of the temperature-velocity characteristics of the powder particles at the exit from the right-angle nozzle on the material of the particles, their size, temperature and gas pressure at the entrance to the nozzle was obtained.

3) For the first time, an approach to assigning cold gas-dynamic spraying modes is proposed, based on the planning of a multi-factor experiment, response surface methodology and GA+BPNN, which allows assigning the technological parameters of coating sputtering, which ensure that the powder particles achieve the speed necessary for their adhesion to the substrate.

4) For the first time, on the basis of numerical modeling and the planning methodology of a multifactorial experiment, the dependences of porosity on particle speed, its temperature, and the temperature of the substrate in the studied ranges of values were obtained.

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

The dissertation of applicant Tan Kun fully complies with the standard of higher education in specialty 134 Aerospace Engineering 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 originality of the dissertation, it can be concluded that Tan Kun'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, 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, introduction, 4 chapters, conclusions and an appendix.

The introduction provides the rationale for choosing the research topic and its significance, as well as the object, subject, purpose and objectives of the research, as well as the relationship of the work with scientific topics, scientific novelty and practical results of the research and its validation.

Chapter 1 provides an overview of the research problems and the current status of publications, focusing mainly on solving problems in the dissertation work, in particular the use of numerical modeling methods to study the gas dynamics of two-phase flows in supersonic nozzles for cold aerodynamic spraying and the interaction of powder particles with substrates during high-speed deposition and coating formation. The analysis of the publications leads to the conclusion that there is no comprehensive approach to design nozzles or to optimize the parameters of the cold aerodynamic spraying process based on the criterion of particle velocity at the time of deposition with the substrate.

Chapter 2 presents the main equations describing the aerodynamic characteristics of the flow in supersonic nozzles for cold gas dynamic spraying, which are used to design reduction-enlargement nozzles for spraying. The phenomena occurring when powder particles interact with surfaces during the spraying process are also presented. Models describing the interaction of powder particles with substrates are analyzed, which are used for numerical simulations of high-speed deposition of particles with surfaces in homogeneous and heterogeneous materials.

Chapter 3 studies the effect of cold spray nozzles on the acceleration of powder particles, and uses single factor analysis methods and multi-parameter coupling analysis methods to optimize spraying parameters to achieve particle deposition on the substrate; and presents the development results of rotating single-channel and multi-channel nozzles for high-pressure cold gas dynamic spraying for coating the

inner surface of parts. The acceleration process of powder particles in these nozzle channels is studied, which depends on the sputtering pattern and characteristics of the powder and the scheme of feeding the powder into the nozzle. Based on the multi-criteria analysis using the experimental planning method, a response surface method of the powder particle velocity on a large range of spraying parameters is constructed. According to the maximum velocity criterion of the particles at the nozzle outlet, scientific recommendations are made for the selection of the spraying pattern of the proposed nozzle for the studied powder particles.

Chapter 4 presents the results of numerical simulations of the high-speed interaction of powder particles of homogeneous and inhomogeneous materials with the substrate at the moment of deposition during cold gas dynamic spraying. The methods used to simulate the deposition of particles on the substrate (The SPH, the ALE, and the CEL methods) are compared. The temperature-velocity characteristics of powder particles when contacting the substrate and the influence of substrate temperature on the degree of particle deformation according to the input particle deformation coefficient K are studied. Based on the minimum porosity criterion, the spray pattern was optimized using Al6061 coating as an example by modeling the deposition of the powder particle number using the developed and implemented software code in a computational model.

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

Appendix is a multi-particle model established using Python programming code.

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 20 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; 8 articles in scientific periodical publications included in the List of scientific specialized publications of Ukraine (category «Б»); and 7 conference proceedings (5 of them indexed in the Scopus database).

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

Disadvantages and comments to the dissertation work.

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

1) The applicant proposed nozzles for spraying on internal and hard-to-reach surfaces of parts. It would be worthwhile to specify what these parts are, their materials and operation conditions, and the minimum internal diameter of the surfaces for spraying.

2) The applicant shows the dependence of the temperature and speed of the powder particle at the exit from the nozzle on the spraying modes, but these parameters are of interest at the moment of contact with the surface, taking into account the effect of the spraying distance.

3) To simulate the impact of powder particles with the substrate, it would be expedient to choose the values of their temperature and speed at the moment of collision, obtained from the results of the simulation of the flow with particles in the nozzle. However, the applicant used other values of these parameters as initial data.

4) The applicant should explain the influence of the substrate temperature on the porosity of the coatings and justify the need to take this parameter into account, which was studied in Chapter 4, since the substrate temperature has a more significant effect on the coating-substrate interface and, accordingly, on the adhesion strength. There is also a question of managing this parameter during the spraying process.

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 Tan Kun on the topic "Development of supersonic nozzles for cold spraying" 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 Tan Kun deserves to be awarded the degree of Doctor of Philosophy in the field of Knowledge 13 Mechanical Engineering, in the specialty 134 Aerospace Engineering.

Official Opponent:

Candidate of Technical Sciences,
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27.08.2024

Учений сержант



А.Розуменко