**REVIEW**

of the dissertation work

by Tan Kun on the topic «Development of supersonic nozzles for cold spraying»

presented 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.**

Cold gas dynamic spraying is an emerging coating preparation process technology developed in recent years. Therefore, the relevance and necessity of the research are attributed to the development and widespread application of cold gas dynamic spraying technology in the field of aerospace surface engineering technology, as well as the application of this technology in the manufacture of volumetric additive materials. By improving equipment components and optimizing the spraying pattern to form a coating from a given powder material, the productivity of the process can be improved and high performance indicators of coating quality can be ensured. In addition, the expansion of the technical capabilities of spraying equipment for internal and difficult-to-reach surfaces of parts will open up new directions for the practical application of the technology in the field of spraying protective and repair coatings.

The dissertation emphasizes studying the acceleration characteristics of various powder particles in various nozzles, exploring new nozzle structures, and more accurately analyzing the critical speed. Thanks to the special method of numerical simulation, the deformation of powder particles on the substrate and the deformation at each moment of the deposition process can be analyzed, to understand the coating formation process more accurately.

**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 have a sufficient level of validity. The doctoral student elaborated and analyzed a significant number of literary sources devoted to cold gas-dynamic sputtering, in particular, the use of numerical modeling methods to study and describe the processes that occur during the acceleration and heating of powder particles in the sputtering nozzles and when the particles collide with the substrate. General scientific and special techniques and methods of cognition were used in the research; their use allowed the doctoral student to scientifically substantiate the theoretical and practical aspects of the influence of the parameters of the sputtering process on the formation of coatings.

The validity and reliability of the obtained research results, scientific provisions and recommendations of the dissertation were confirmed by their approval at international and all-Ukrainian scientific and practical conferences. In addition, some scientific results of the acquirer were verified within the framework of the National Development Program "Development of aggregate technology of restoration and repair of aviation (helicopters) parts by cold spraying with post process machining of deposited coatings" (No. DR 0122U001341) during 2020-2022, which was carried out at the Department of Aviation Engine Production of the National Aerospace University named after M. E. Zhukovsky "Kharkiv Aviation Institute".

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.

In the presented work, the author used modern theoretical and numerous modeling methods. The theoretical part of this work is based on computational fluid dynamics, gas dynamics and finite element numerical analysis of solid-liquid two-phase flow composed of micron particles and gas. methods for simulating particle deposition include: The SPH, the ALE, and the CEL methods. Among them, the multi-particle deposition model is implemented using Solidworks, CaitaV5, and Python programming code. The response surface analysis method was used to optimize the coating porosity.

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" (№ ДР 0122U001341) during 2020-2022. This research was funded by the China Scholarship Council (No. 201908360307).

Thus, the practical significance of the obtained results lies in the fact that the results obtained in the dissertation research can be used in solving a wide class of practical problems 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 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 academic program «Aerospace Engineering».

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 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 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 an appendix. The total volume of the dissertation is 273 pages, of which 226 pages are the main text. The dissertation contains 83 figures, 38 tables, 190 references 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 a detailed overview of the relationship between additive manufacturing technology and cold spray technology. And an overview of the development and current situation in the field of cold spray technology is given. Focuses primarily on problem solving in thesis work. Numerical simulation is used to study the acceleration characteristics of particles in supersonic nozzles in cold spray technology, and to study the deposition process of powder particles on the substrate.

Chapter 2 gives the main equations describing the aerodynamic characteristics of powder particles in supersonic nozzles, and some equations used to design narrow-enlarged nozzles for spraying. Models of methods currently used to simulate the deposition of cold spray particles are also presented, as well as the main equations for studying the deformation of particles during deposition.

Chapter 3 studies the acceleration characteristics of powder particles in the supersonic cold spray nozzle; using single factor method and multi-parameter coupling method (the response surface method and GA+BPNN method) to optimize the spraying parameters to obtain the optimal particle velocity for particles Necessary conditions for deposition on substrates. A set of multi-channel mixed cross-section nozzles were also developed for spraying the interior surfaces of parts, which can accelerate a variety of particles to critical velocities for deposition on the substrate.

Chapter 4 introduces the numerical simulation results of the interaction between powder particles when deposited on the substrate; and proposes the particle deformation coefficient K to characterize the degree of particle deformation. Python programming code is used to build a multi-particle model, and the CEL method is used to predict the porosity of the Al6061 coating, and multi-parameter coupling is used to optimize the coating porosity by the RSM.

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 are described in the dissertation work, and the necessary volume is explained in the scientific publications of the acquirer.

**Disadvantages and comments to the dissertation work.**

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

1. The applicant should provide examples of parts for spraying on the inner surfaces on which it is proposed to use developed rotary nozzles, as well as indicate the minimum diameter for spraying.
2. In paragraph 3.1, the applicant investigated the effect of gas pressure at the inlet to the nozzle of the DYMET-405 machine in the range from 0.8 MPa to 1.2 MPa. However, according to the technical characteristics of the equipment, a working pressure of 0.5 MPa to 0.8 MPa is recommended. Therefore, the question arises as to the expediency of increasing and investigating the pressure up to 1.2 MPa.
3. The resolution of the images in Figures 3.28, 3.32, 3.35, 4.28 and 4.29 is too small, making it difficult to perceive the given simulation results.
4. It would be good to supplement the fourth chapter of the dissertation with experimental studies of the porosity of the coating and compare it with the predicted values obtained using empirical dependencies and modelling.

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 reviewer**:

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