To the Chairperson of the Scientific Jury
Appointed by order № 3-01-298/15.07.2025
of the Technical University of Gabrovo

R E V I E W

of a dissertation thesis for the acquisition of the educational and scientific degree "Doctor" (PhD) in

the field of higher education – 5. Technical Sciences

professional field 5.6. Materials and Material Science

scientific speciality – "Materials Science and Technology of Engineering Materials"

Author: Eng. Simeon Tsankov Tsenkulovski

Form of doctoral studies: Part-time

Scientific organisation: Technical University of Gabrovo

Title of the dissertation: Peculiarities of laser marking of layer-reinforced composites on a polymer basis

Scientific supervisor: Assoc. Prof. Dr. Eng. Ivan Nenov Mitev

Reviewer: Prof. DSc Maria Plamenova Nikolova

1. Brief biographical data of the doctoral candidate

Simeon Tsankov Tsenkulovski is an engineer with extensive experience in mechanical engineering and the management of technical projects. He graduated in Electrical Power Engineering from the Technical University of Sofia and in International Economic Relations from the D.A. Tsenov Academy of Economics in Svishtov. The author of the dissertation is a part-time doctoral student at the Department of Materials Science and Mechanics of Materials, Faculty of Mechanical and Precision Engineering, Technical University of Gabrovo. His professional career includes management positions in companies such as *Impuls JSC*, *GTM Engineering*, *Novotika 95*, *Mashtech BG*, and *ADTECH*, where he has led teams and processes related to the development and implementation of innovative products, ERP systems, and technologies. He has an excellent command of English and skills in CAD/CAM, ERP platforms, and CNC technologies. He possesses strong experience in team, project, and production process management.

2. Relevance of the topic and appropriateness of the set objectives and tasks

Layered fibre-reinforced composites are increasingly used due to their low weight, high strength, chemical resistance, and design flexibility, which makes the demand for efficient, non-contact, and precise marking methods on these surfaces steadily grow. With the introduction of Industry 4.0, traceability during production has become crucial, and laser marking enables direct action on the surface for applying serial numbers, QR/2D barcodes, engineering information, and more. Laser marking of layered fibre-reinforced polymer composites is a current interdisciplinary subject that combines laser physics, materials science, surface processing, and manufacturing metrology. However, this approach faces challenges related to the difference in absorption of laser energy between the reinforcing element and the matrix, as well as the need to optimise the parameters for different types of composites. The objective of the dissertation is precisely the development of a setup for laser marking, as well as the investigation and optimisation of the parameters of the laser marking process of layered fibre-reinforced polymer matrix composites, which makes the work both relevant and important for contemporary engineering research.

3. Review of the cited literature

The dissertation makes use of 186 sources, including textbooks, dissertations, articles, reports, regulatory literature, and technical catalogues. The sources in Bulgarian are nearly 90, in English – 75, and about 20 are in Russian. Publications from the last 5 years (2019–2024) number around 40, including up-to-date studies on laser marking, process optimisation, and new materials. The literature is comprehensive, balanced, and current, combining a theoretical foundation from classical works, practically oriented sources for industrial applications, and recent scientific publications, including those with an impact factor. This selection provides a solid scientific and applied basis for the research in the dissertation.

4. Research methodology

The methodology encompasses an experimental-analytical approach, including the following key stages: 1) development of an experimental setup – a 50 W fiber laser with capabilities for precise control of focus and movement; 2) determination of the geometric parameters of the marking using a PHILIPS URD measuring microscope and INSIZE ISD-V150 software – in point and plane; 3) measurement of surface roughness with a ZEISS profilometer according to standards; 4) modeling using cybernetic and second-order regression models, verified through Student's t-test, Fisher's F-test, and the multiple correlation coefficient R. The methodology is logically structured and scientifically justified. It combines experimental measurements, standardised procedures, and mathematical modelling, enabling quantitative investigation of the influence of input parameters on the output characteristics of the marking. With minor exceptions, the methodology provides an adequate basis for achieving the stated objective, addressing the defined tasks, and obtaining applicable results of practical significance for the optimisation of laser marking of non-metallic composite materials.

5. Characteristics and evaluation of the dissertation

The dissertation consists of 130 pages and is divided into 5 main chapters. The total number of figures is 74, and the number of tables is 21.

Chapter 1 reviews the fundamentals of laser technology and presents the principles of interaction between laser radiation and materials – absorption, melting, evaporation, and plasma formation. The application of lasers in marking and micromachining is discussed, along with a comparative analysis with other methods. This chapter provides a solid scientific foundation, setting the theoretical framework of the study, and justifies the choice of laser technology for non-metallic composites.

Chapter 2 describes the types of reinforcements (glass, carbon fibres), types of polymer matrices, and the characteristics of their composition. The physical and mechanical properties, surface thermal conductivity, and resistance to laser processing are analysed. The chapter also presents the types of effects/damages during marking: delamination, charring, and deformations. It justifies the choice of material (textolite, glass-textolite) and highlights the key properties influencing the process, thereby creating the context for the subsequent experiments.

Chapter 3 focuses on the influence of power, speed, and focus on surface heating and on the modelling of heat transfer during pulsed marking. Dependencies for calculating the depth and width of the thermal imprint are introduced. This chapter serves as a bridge between theory and practice and provides quantitative parameters that support the experimental design in the following chapter.

Chapter 4 – "*Determination of technological parameters of the process*" describes the experimental setup: fibre laser system, types of samples, and measurement methods (microscope, profilometer). Experiments were carried out with variable parameters: power, speed, pulse frequency. Qualitative and quantitative characteristics of the markings were measured – geometry, roughness, and visual contrast. This chapter is central to the empirical part of the dissertation. The approach used is systematic and well-founded.

Chapter 5 – "*Mathematical models and optimisation of technological processes*" employs an experimental design and second-order regression analysis to derive equations describing the influence of factors on the results (depth, roughness, and width of the marking). Statistical verification was carried out using Student's t-test and Fisher's F-test, confirming the reliability of the models. Optimal parameters for high-quality marking are proposed. The chapter concludes the research with quantitative optimisation. The methods are correctly applied, the results are interpreted logically, and the conclusions are practically applicable.

The content of each chapter is consistent and logically connected. The research progresses from theory through materials science and physical foundations to real experiments and optimisation, which fully aligns with the objectives and tasks of the dissertation. The conclusions drawn are adequate to the stated aims and objectives.

6. Contributions and significance of the work for science and practice

The contributions of the dissertation are significant from both a scientific-applied and an applied perspective. Four contributions are formulated, three of which are scientific-applied (original and confirmatory) and one applied.

Among the main **scientific-applied achievements** are:

- A conceptual model for the development of a laser setup for marking layered fibre-reinforced polymer matrix composites.
- Mathematical models of the influence of beam power and marking speed on penetration depth and line width during laser marking of textolite and glass-textolite.
- Established responses of two materials (textolite and glass-textolite) in terms of the characteristics of the marking line, as influenced by the parameters of the laser marking process.

The **applied contribution** formulated by the author is related to the creation of a laser setup for marking layered fibre-reinforced polymer matrix composites.

The scientific-applied and applied achievements provide a new contribution to the study of laser marking of non-metallic composite materials – a field that has been scarcely studied so far. They include experimentally validated mathematical models, real engineering implementations, and optimisation algorithms applicable in actual industrial production. These results support the objectives and tasks of the dissertation and have high practical value for mechanical engineering, electronics, and related fields.

7. Evaluation of the publications related to the dissertation

The doctoral candidate has submitted 8 publications related to the dissertation. Of these, three are in academic journals (Industrial Technologies of Burgas State University "Prof. Dr. Assen Zlatarov" and the Proceedings of the Technical University of Gabrovo). Two of the publications are indexed in Scopus (International Scientific and Practical Conference 2023 and 2024), which ensures international visibility and accessibility of the results. In five of the articles (including one of those indexed in Scopus), the doctoral candidate is the first author, while in the remaining three, he is the second author.

Thematically, the articles cover all key aspects of the dissertation research: modelling, experiments, analysis, and optimisation. At the time of the dissertation, the two Scopus-indexed publications had a total of 10 documented citations. The results have been presented at international symposia in Bulgaria (International Scientific Symposium "Metrology and Metrology Assurance" 2022 and 2023) and abroad (International Scientific and Practical Conference), which suggests further future citations by specialists in the fields of laser processing, composite materials, and industrial metrology. For broader visibility, I recommend that the doctoral candidate direct his future research towards publication in refereed international journals.

8. Personal contribution of the doctoral candidate, originality, and authenticity of the dissertation

I do not know eng. Simeon Tsankov Tsenkulovski personally do not have direct impressions of him. My evaluation is based on the content of the dissertation and his professional experience. Particularly noteworthy is his active involvement in the development of useful models and patents—both directly related to the dissertation topic and beyond its scope. This unequivocally demonstrates the author's leading role in the achieved scientific results and his potential for future development in the scientific field.

9. Abstract of the dissertation

The abstract has a length of 34 pages. Each of the five chapters is described briefly yet sufficiently substantively. The illustrations included contribute to a better understanding and perception of the work. Overall, the abstract is well-structured. It provides a clear overview of the dissertation's content, the results achieved, and the contributions of the research.

10. Comments, Recommendations, and Remarks on the Dissertation

The following **comments and recommendations** are made regarding the dissertation:

- It would be useful to specify in the methodology the equipment used for capturing the macroimages shown in Figures 4.1 and 4.2.

- For Figures 4.1 to 4.4, the magnification used is not indicated.
- Figures 4.17 to 4.19 lack scale lines on the images.
- Several technical inaccuracies are present, including punctuation, grammatical errors, and formatting mistakes.

The following **critical remarks** are addressed to the author:

- I cannot agree with the classification presented on page 57, namely: "Organic non-metallic materials include silicate materials: glass and glass products, ceramics and ceramic products," and "Inorganic non-metallic materials include the large group of polymers. They represent a significant portion of modern materials (plastics, rubbers, wood, textiles, etc.)." Furthermore, the matrix in composite materials is not necessarily a "polymer binding phase" and can differ from what is indicated. In my opinion, "biomaterials" can naturally be included in one of the other three groups (A, B, or C) rather than being separated into an additional group.
- For specimens with low reflectivity and low contrast, due to surface charring and high roughness, analysing the depth of laser impact based solely on optical methods may be misleading because of uneven scattering, unclear contours, and other effects visible in microscopic images. High roughness and locally altered microgeometry prevent proper focusing at all levels. Therefore, some results—especially those of marks obtained at higher power and lower speeds, where charring is significant and penetration depths are greater—should be confirmed using contact profilometry. This measurement inaccuracy could explain the larger deviations between experimental and theoretical results for such specimens.

Conclusion

The dissertation contains scientific-applied and applied results that represent an original contribution to science and comply with the requirements of the **Law on the Development of the Academic Staff in the Republic of Bulgaria (LDASRB**) and its implementing regulations. The achieved results demonstrate that the doctoral candidate possesses theoretical knowledge and professional skills in the scientific speciality and also shows the ability to independently conduct scientific research.

Based on the above, I have grounds to **recommend to the academic jury the awarding of the educational and scientific degree of "Doctor" to Eng. Simeon Tsenkulovski** in
the field of higher education – 5. Technical Sciences,
professional field – 5.1. Mechanical Engineering,
speciality – "Materials Science and Technology of Mechanical Engineering Materials."

19.08.2025 г. ………………………………………………
Rousse /Prof. DSc Maria P. Nikolova/