OPINION

for a dissertation

for the acquisition of the educational and scientific degree “Doctor”

Author of the dissertation: M.Eng. Simeon Tsankov Tsenkulovski
Title of the dissertation: Peculiarities of laser marking of layer-reinforced composites on a polymer basis

Field of Higher Education: 5. Technical Sciences
Professional Field: 5.6. Materials Science
Scientific Specialty: Materials Science and Technology of Engineering Materials

**1. Relevance of the dissertation topic in scientific and applied-scientific terms**

With the development of industry and the implementation of new technologies, lasers have emerged as an effective alternative to conventional methods of processing various types of materials. Laser technology is widely applied in precision cladding, welding, and heat treatment of metallic materials, as well as in cutting operations of both metallic and non-metallic materials.

In recent years, the precision and flexibility in adjusting technological parameters during laser processing have enabled its broad application in the marking of individual machine components. More complex, however, is the issue of marking composite materials, particularly those with non-metallic matrices. In practice, it is relatively difficult to determine precise technological parameters to achieve a clear and high-quality relief of the marking line. This is due to the heterogeneity of the main composite elements – the matrix and the reinforcing component. The thermal, optical, and mechanical properties of different polymer matrix composites make this field both challenging and of significant interest for process optimization and control.

The investigation of laser marking of layered fiber-reinforced polymer matrix composites, which constitute a substantial portion of industrial materials, is an important step towards clarifying the process in both theoretical and experimental terms. The results obtained provide opportunities for evaluation and expansion of the practical application of this innovative technology in industry.

The main goal and tasks formulated in the dissertation, along with the applied methods and approaches, are contemporary and relevant.

## 2. Adequacy of the chosen research methodology

Based on the comparative analysis in the literature review, a conceptual model of a system for laser marking of layered fiber-reinforced polymer matrix composites was developed, including alternative solutions, evaluated according to selected indicators. These include dynamic generation of marking programs, servo-control of movement axes, number of additional movement axes, need for supplementary cooling, minimum laser spot size, durability of equipment, need for consumables and maintenance, optical guiding of the laser beam with minimal losses, low energy consumption of the process, and the quality and durability of the applied marking.

Based on this conceptual model and a constructed laser installation for composite marking, an experimental methodology was developed to determine the optimal technological parameters of the process.

Methods for determining the geometric parameters of the marking line were also established, with two types of measurements – point and surface. For evaluating the quality of the marking line, a methodology for determining surface roughness was created. The experiments were carried out on two types of material – fiberglass laminate and textolite. Penetration depth of the laser beam into these non-metallic materials was studied under different technological regimes. The surface roughness of the resulting relief was analyzed as a function of material type and process parameters.

The applied methodology for planning experiments was based on literature data and aimed at achieving the objectives of the dissertation.

## 3. Scientific and applied contributions of the dissertation

The dissertation presents 4 scientific-applied and applied contributions, classified as follows:

A.1. Development of new classifications, methods, designs, models, and methodologies
1. Conceptual model for the construction of a laser installation for marking layered fiber-reinforced polymer composites.
2. Mathematical models describing the influence of beam power and marking speed on penetration depth and line width during laser marking of fiberglass laminate and textolite.

A.2. Establishment and validation of new facts
3. Identification of the responses of two materials (textolite and fiberglass laminate) in terms of marking line characteristics influenced by laser marking parameters.

B. Applied contributions
4. A functional laser installation for marking layered fiber-reinforced polymer composites.

**4. Evaluation of publications and citations related to the dissertation**

Eight publications are presented in connection with the dissertation. In five of them the doctoral candidate is the first author, in collaboration with the supervisor and other co-authors. The results have been published in scientific journals in Bulgaria and abroad, two of which are referenced and indexed in the internationally recognized Scopus database.

**5. Use of dissertation results in scientific and social practice**

The doctoral candidate has contributed to two utility models related to the dissertation research:

1. Utility Model №3214U1 – System for Laser Marking (04.09.2019).
2. Utility Model №3564U – System for Laser Marking of Complex Surfaces (18.05.2020).

I do not know the doctoral student, but based on the publications provided on the dissertation, I can conclude that the results obtained are personal work.

**6. Opinions and recommendations on the dissertation**

In modern technology, polymer matrix composites are increasingly applied, in some areas serving as the primary material (e.g., unmanned aerial vehicles, rocketry, sports equipment, chemical industry, etc.). This is due to their ease of forming complex shapes and their high strength-to-weight ratios, which in some cases surpass metallic materials.

The dissertation represents an innovative contribution to the field of laser marking of polymer matrix composites, a process directly connected with the wide variety of next-generation technological products.

During laser marking, zones with fiber breakage in the surface layer may occur, while the matrix may form stress concentrators. This could create conditions for fatigue crack initiation under cyclic loading. It is therefore recommended that future work should include fatigue testing to determine long-term durability. The next step for the doctoral candidate and the research team should be the industrial implementation of the developed laser installation.

**7. Remarks on the dissertation**

- In figures illustrating the marking relief (Figures 4.17, 4.18, 4.19, 4.20), magnifications are not indicated and no scale bars are provided.
- No other remarks.

**CONCLUSION**

The reviewed dissertation addresses a current and significant issue – the laser marking of layered fiber-reinforced polymer matrix composites. A sufficient number of scientific

publications on the topic have been produced, covering the essential parts of the research. I believe that the dissertation fully complies with the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria, the related regulations, and the methodological guidelines of the Technical University of Gabrovo.
I therefore give a positive evaluation of the dissertation of M.Eng. Simeon Tsankov Tsenkulovski and confidently propose that he be awarded the educational and scientific degree Doctor in the field of higher education 5. Technical Sciences, professional field 5.6. Materials Science, specialty Materials Science and Technology of Engineering Materials.

Date: 28.08.2025 Member of the scientific jury: .....
Place: Varna /Assoc. Prof. Yaroslav Argirov, PhD/