Translation from Bulgarian

REVIEW

on a dissertation work for acquiring the academic scientific degree "Doctor of Science"

Higher Education Area - 5 Technical Sciences

Professional field - 5.6 Materials and Material Science

Specialty - "Material Science and Technology of Machine Building Materials"

Author: Associate Professor PhD Engineer Tsanka Dimitrova Dikova

Topic: Properties of additively manufactured dental materials

Reviewer: Professor PhD Engineer Stoyko Atanasov Gyurov

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1. Topic and timeliness of the dissertation work

3D printing of dental constructions is a key technology for the future of dental medicine. The possibility to have in an easy way customized dental objects like tools, prosthesis, dental implants, etc. at an affordable price, is an alternative of the classical technologies. Bio printing is developing very fast, i.e. creating 3D tissue-like structures. The professionals in the dental medicine have already the possibility to perform on their own an intraoral scanning and CAD design. Moreover, they are able to print 3D materials with their own 3D desktop printer or use an online 3D printing service. Dental medicine companies improve and develop constantly new technologies and tools as 3D printers and 3D scanners, intended for dental work. Dental engineering laboratories use them increasingly for developing new working methods and creating new devices like 3D printed brackets for faster teeth alignment, orthodontic appliances or 3D printed implants and dental caps. It can be certainly argued that 3D printing has the potential to revolutionize dental constructions manufacture.

Characteristic feature of the additive technologies is that the properties of the built object are depending not only on material properties, but also on the specificity of technological process. The combination of a large number of materials for the 3D printing and the existence of very fundamentally different technologies, each one using a specific material, do create some

limitations on method application. In order to overcome these constraints are needed data, lacking so far, on the quality of dental constructions, obtained through different methods and materials. This requires performing a deep and extensive research of geometrical features, and physical and mechanical properties of dental constructions, created with various 3D technologies and materials. The dissertation work constitutes such a completed research, including theory, experiment and technology in the most modern direction of dental constructions manufacturing - 3D printing.

2. Overview of the cited bibliography

The bibliography comprises 359 text sources, 19 in Bulgarian, 1 in Russian and 339 in English. Twenty-four of the mentioned sources have as author or co-author the Associate Professor PhD Engineer Mrs. Dikova.

Thematic cited bibliography is connected with the dissertation work and includes publications dealing with the dental medicine development – used technologies and materials; creation and development of the additive technologies; 3D printing application in the dental medicine; used materials and additive technologies in the dental medicine; peculiarities of applying the 3D printing in the stomatology; quality of the surface of built objects; accuracy of manufactured dental constructions; physical and mechanical features of 3D printed dental constructions; chemical composition, microstructure and density of additively manufactured dental constructions; tensile strength and adhesion strength of coatings to dental alloys, as well as tasks, related to mathematical modeling and computer simulations. The major part of the bibliographic sources are dating from the last decade, which shows knowledge of the most modern trends in the topic in question. It enables the author to either set accurately the goals and the tasks of the dissertation work, either compare and evaluate the results obtained from its own research with the results of leading researchers in the field of dental materials and technologies.

3. Research Methodology

Dissertation work has a volume of 260 pages, it includes 23 tables and 162 figures. The quality of figures and tables is excellent, text under the figures is clear and completely informative.

The material is exposed in a logical sequence:

- Texts overview – current state of the problem;
- Research Methodology;
- Results and Analysis;
- Conclusions to each Chapter;
- General conclusions;
- Scientific contributions.

For the research are being prepared three types of test samples, whose shape and size are completely appropriate for the scheduled experiments. I do accept without reserves the author's argumentation for their selection.

Four types of additive technologies and two groups of materials are used for manufacturing of dental constructions: 1) different types of plastics; and 2) dental alloys Co-Cr and Ni-Cr. For comparison, samples of two Co-Cr and one Ni-Cr dental alloys with close composition are cast through a traditional casting. The selected materials are intended and applied in the dental medicine and are appropriate for the technology and equipment used so far.

The obtained samples were analyzed for the following properties:

1. Roughness and Accuracy

- The roughness of the additively manufactured dental materials is being analyzed through measuring the average surface roughness deviation R_a with a profile meter.
- The precision of fitting is being analyzed in two ways – through the widely used silicon test and a **new methodology, especially conceived by the author**, using engineering CAD software.

2. Density, microstructure and chemical composition

- The density of test bodies, made of Co-Cr alloys is being determined 1) using the water displacement method; and 2) calculated through the quantitative ratio dense structure/pores, using CAD software.
- The microstructure and chemical composition of Co-Cr dental alloys are being analyzed with the aid of optical and electron microscopes.

3. Hardness

- The hardness is being measured in accordance with the methods of micro-Vickers and Rockwell and is performed an analysis through the model of Weibull.

4. Tensile strength and adhesion strength of coatings to dental alloys.

- It has been performed a combined analysis of tensile and adhesion strength of porcelain and composite coatings to dental alloys through experiments, regression analysis and numerical modeling, using the finite element method.

5. Bending strength

- Bending strength is being investigated according to **a methodology, developed by the author**, including an experiment and a CAD software simulation of four-unit dental bridge constructions, manufactured through a conventional casting, casting with 3D printed models and selective laser melting.

6. Tribocorrosion

- Tribological properties of Co-Cr dental alloys, made through casting and selective laser melting, are being set with a ball on disk tribometer, equipped with a tribocorrosion device.

The dissertation author uses successfully a set of experimental and analytical methods, numerical modeling and simulation analysis, selected in such a way to ensure the solving of dissertation problems. They do correspond to the modern level of science and technology, ensuring accuracy, analysis data repeatability and reliability of the results obtained.

4. Contributions from the dissertation work

I do accept fully the scientific contributions in the dissertation and I do define them as scientific and scientifically applied with original and confirmatory nature.

Scientific Contributions

- For the first time a theoretical explanation was proposed for the decisive impact of the optical properties of dental plastics on the accuracy of constructions, manufactured by stereolithography, which is proved by an experiment.
- An improved criterion for evaluating the nature of the fracture of porcelain coating on dental alloys is developed.
- A fracture mechanism of porcelain and composite coatings on dental alloys is proposed and proved.
- There were developed a new methodology and a tool for analyzing tensile strength of dental alloys, in which are used the most engaged four-piece bridge constructions of the 1-st premolar to the 2-nd molar and is ensured the use of the loading as close as possible to the real one.

- There is developed a new non-destructive in-vitro method for evaluating the fitting accuracy of dental constructions of the type of inlays, onlays, crowns and bridges.

Applied science contributions

- Original data has been received about the roughness of dental constructions, made of plastics, created through stereolithography and was explained the impact of thickness of the building layer, the location of the workpiece in respect to the printing direction, surface forming at the beginning and at the end of the process and optical properties of used monomers.
- Original data are obtained about the strength characteristics of Co-Cr dental alloys, manufactured by casting and selective laser melting, as well as their various fracture mechanisms are explained.
- For the first time was performed an experimental research and the possibility to determine adhesion strength of porcelain and composite surfaces was proved in respect to dental alloys through tensile testing.
- Original data have been obtained about the bending strength of the most loaded four-unit bridge constructions from the 1-st premolar to the 2-nd molar of Co-Cr dental alloys, cast with 3D printed models and manufactured by selective laser melting.
- For the first time a research was conducted of tribocorrosion in an artificial saliva (Fusayama-Meyer) of Co-Cr alloy Co212-f, obtained through selective laser melting. Original data about the type of the surfaces wear was obtained and the impact of microstructure, hardness and the oxide layer on the corrosion and abrasion rate was explained.
- There were confirmed the higher mechanical properties - hardness (356 HV0.1 - 407 HV0.1) and yield strength (720 MPa) of the selectively laser melted Co212-f alloy in comparison with the cast Biosil-F alloy (326 HV0.1 – 343 HV0.1 and 410 MPa respectively).
- It is established that the hardness of both alloys – selectively laser melted Co212-f and cast Biosil-F, is changed differently after firing of double-sided porcelain coating on them and is being explained the impact of the thermal regime on the microstructure, respectively their hardness after firing.
- For the first time 3D printing casting models were created through multicriterial optimization of the regimes of 3D printing, enabling higher adhesion strength of a porcelain coating to a cast dental alloy.

- For the first time correction coefficients and algorithms were offered designing virtual models, intended to ensure high accuracy to temporary and permanent fixed partial dentures in a production by additive technologies.

5. Publications and citations on the dissertation work and authorship of the obtained results

The results obtained in the dissertation work are being popularized through one book chapter and twenty-three publications.

Associate Professor Dikova is an independent author of the book's chapter, two publications in referenced journals and two reports on conferences. In nine publications in referenced journals and in three publications in non-referenced journals, the dissertation writer is first author. In the other publications (without one) the dissertation writer is second author. This allows me to conclude that in all said works the dissertation writer has a leading contribution, i.e. formulation of analyzed issue, research methods selection, planning and conduct of the relevant experiments, data analysis and results publications are all a merit of the dissertation writer.

In each one of the publications on the dissertation work, various aspects of the developed topic are being analyzed. There is no any difference between research methodology, analysis and conclusions in the dissertation and in the presented scientific articles. I am convinced that the personal contribution of the dissertation author is beyond any doubt, and the dissertation work is an individual, creative product, made by the dissertation writer.

The citations of publications, related to the dissertation work are 22, 12 of which in editions, referenced and indexed within worldwide databases with scientific information.

6. Abstract and author's reference

The abstract of dissertation work consists of 92 pages, it meets the general requirements with the remark that it is not needed to have such a big volume. In contents and structure it is corresponding to the dissertation work, it contains the research methodology, basics, conclusions, contributions and a list of author's publications on the topic. The conclusions ending the abstract provide a sufficient insight on the dissertation work.

All contributions are defined clearly, they respond to the achievements and do reflect adequately and accurately the solution of goal set and tasks in the dissertation work.

7. Statements, recommendations and remarks on the dissertation work

In general, I have no significant critical remarks regarding the dissertation work, nor I have noticed ineligible gaps, but:

In the dissertation is being used the term „models“. According to the Dictionary of the Bulgarian language a „model“ is “Indicative or test item“. The correct term in this case is „sample“. For instance BDS EN ISO 377:2018 „Steel and steel products. Location and preparation of sample and test pieces for mechanical testing (ISO 377:2017)“. It is obvious that are tested „samples“, and not „models“.

General conclusions are redundant as they are repeating the contributions to some extent.

8. Conclusion

I believe that the submitted thesis corresponds to the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria.

The achieved results give me the conviction to offer to the honorable jury to award the scientific degree "Doctor of Sciences" to Assoc. Prof. PhD Eng. Tsanka Dimitrova Dikova in the higher education area 5. Technical Sciences; professional field 5.6 Materials and Material Science; scientific specialty „Material Science and Technology of Machine Building Materials“.

June 4, 2019 **Signature:**

/Prof. PhD Eng. Stoyko Atanasov Gyurov/