Review Report on PhD Thesis

University: Brno University of Technology

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Reviewer: Ing. Jan Kudláček, Ph.D.

PhD thesis title: Advanced abrasion resistant coatings for vacuum systems

The PhD thesis contains 91 pages, 62 figures, 27 tables, 14 graphs, 132 references and 7 references from the author's publications.

The PhD thesis deals with the issue of suitable surface treatments with abrasion resistant properties applicable to vacuum system components. Specifically, it is concerned with abrasion resistant coatings and coatings for spiral dry vacuum pumps primarily applicable to mass spectrometers. The research was carried out on a specific type of spiral vacuum pump part made of a specific material (aluminium alloy) used in industrial practice.

The selected surface treatments were divided into three groups. The first group was the currently used hard anodic oxidation technology, used to compare the proposed new types of surface treatments. The second surface treatment was a combination of hard anodic oxidation with PTFE sealing. The third surface treatment was a DLC coating.

The chosen topic of the PhD thesis is very topical due to the continuous improvement of the technical level with the possibilities of increasing the functional properties of surface treatments, especially for its application in industrial practice.

The individual objectives of the PhD thesis are listed in the following points:

- Design of the optimal solution for increasing the utility properties of the spiral pump.
- Taking into account the requirements and trends of the industrial field.
- Consideration of economically acceptable materials or finishes.
- Tribological behaviour of layers or coatings using topographical and metallographic analyses.
- Numerical modeling of coating or coating degradation.
- Evaluation of different layers or coatings.

The main purpose of the PhD thesis was to compare the selected types of surface treatments applied on experimental specimens and the EN AW 6082 spiral pump specimen and to evaluate the tribological parameters with the design of a suitable surface treatment.

The work is divided into three parts:

- Theoretical part.
- Experimental part.
- Conclusion.

The theoretical part is clearly presented. It presents a theoretical overview of vacuum technology, materials used for vacuum systems. In the field of surface treatment of aluminium and its alloys, the problems of anodic oxidation of aluminium and its alloys and the principles of formation of thin functional layers with specific properties are described. Finally, the problem is addressed by the use of PTFE in functional coating applications.

The experimental part was divided into the preparation of samples with the proposed surface treatments and partial evaluation of these formed layers and coatings. Two types of specimens were used (prepared specimens for tribological measurements and specimens taken directly from the spiral pump section). Specifically, the experimental evaluation included chemical composition analysis, comparison of the samples by optical and electron microscopy (analysis of the microstructure and surface of the formed layers and coatings), surface roughness measurements, hardness measurements and tribological evaluation of the layers and coatings. The different analyses and measurements are always discussed and the partial conclusions are summarised for each chapter. Finally, a numerical model of the variation of tribological parameters with load force and a brief economic analysis are proposed.

The conclusion of the dissertation is general, missing here a specific description of the results obtained from the experimental research and a description of the specific contribution of the work presented.

Designing a suitable experiment and comparing the results obtained was considered to be beneficial in the scientific work. Thus, the work describes the dependence of the different types of chosen surface treatments and their investigated properties. However, an evaluation based on the choice of appropriate process parameters or surface modifications performed would have been more beneficial. The experiments provided a comprehensive data set on the properties of the compared samples.

The experiments performed correspond to the overall focus of the work and provide a number of new results that can be beneficial for further scientific research work aimed at improving the utility properties of spiral pumps.

Formally, the presented work can be criticised for a few minor grammatical errors, incorrect use of technical terminology or unprofessional comments.

p. 5 - optical plating, electrical plating

p. 15 - incorrectly described division of coatings into groups

p. 15 - confusion of natural anodising with decorative anodising

p.15 - "The Bible of Anodising"

p.16 - incorrect statement that hard anodic oxidation is the most widely used method in practice

p.23 - Figure 12 has the wrong source from which it was drawn

p.34 - incomprehensible notation of coating thickness

p.35 - no description of the formation of the coating with PTFE

p.41 - absence of the image where the chemical composition was measured

p.49 - only the chemical composition of the substrate is given in Table 16, although the description states that it is the chemical composition of the particles.

p.68 - Figure 60 - absence of the source from which it was drawn

p.62 - Figure 61. absence of the source from which it was drawn

p.63 - Figure 62. absence of the source from which it was drawn

Three different terminologies for the term anodic oxidation occur frequently in the work and it would be useful to unify these terms.

In the thesis I also missed the reason for which higher resistance to abrasive wear is required for the spiral pump parts and thus the chosen types of surface treatments. Currently, research is directed towards micro-arc oxidation, which could be a tool to achieve the required parameters. It is surprising that this technology is not mentioned in the paper.

For a more objective evaluation, the results from tribological measurements, such as friction coefficient measurements, are missing in the thesis. Table 26 shows that only one measurement was made for each surface treatment, which is statistically inappropriate. More specific results are only given in Section 4.9 for the numerical model determination. For the chapter entitled numerical model of coating and coating damage, I miss the practical sense of where the model is useful in practice and how it can be used to support in deciding what type of coating would be appropriate to use.

Questions about the submitted thesis:

- Explain what is the difference between natural, decorative and hard anodic oxidation of Al and its alloys?

- On page 34, you refer to a DLC coating thickness of 13 m and a total thickness of 313-2 m. Please explain the chosen notation for the coating thickness in the context of the thicknesses for the other coatings?

- On page 63, relation 128 is given for the calculation of the wear coefficient K. Is this a wear coefficient or is it a wear rate? Explain the difference in these terms?

- What is the effect of normal load on friction coefficient and what is the effect of normal load on wear rate?

- What is the method of measuring the microhardness of layers or coatings in the event that the layer or coating breaks?

- What methods are you aware of for incorporating PTFE particles into an anodically formed layer?

- What other surface treatments or modifications used would be suitable for application to spiral vacuum pump parts?

In conclusion, despite the comments and deficiencies, it can be concluded that the aims and objectives have been accomplished by the author and are presented at an appropriate professional level for the author's defense. The thesis is an initial research, and the results can contribute to the practical application and set further direction of research activities in increasing the functional properties not only of spiral vacuum pump parts. The author has demonstrated that he has sufficient theoretical knowledge and is capable of scientific work.

For the above reasons, after defending the PhD thesis before the committee, Ing. Eduard Hégr, I will recommend him for the award of the academic degree of Ph.D.

Jaroměř, 22 March 2022

Ing. Jan Kudláček, Ph.D.