INSTITUTE OF MACHINE AND INDUSTRIAL DESIGN

FME

Faculty of Mechanical Engineering
Brno University of Technology

Review of Doctoral Thesis

1. PhD candidate
Ing. Jan Suchý / Jan.Suchy1@vut.cz
2. Name of PhD programme
Design and Process Engineering (Mechanical Engineering Design)
3. Title of PhD thesis
Processing of magnesium alloys by selective laser melting method

4. Principal supervisor
doc. Ing. David Paloušek, Ph.D. / david.palousek@one3d.cz
5. Co-supervisor
doc. Ing. Libor Pantělejev, Ph.D. / pantelejev@fme.vutbr.cz

6. Reviewer
Prof. Dr.-Ing. Norbert Hort/ norbert.hort@hereon.de
Leuphana University Lüneburg

7. Overview of the scope of PhD thesis[1]
Evaluate: excellent
Implants are of outstanding importance for the treatment of bone fractures, for example. Very often, revision surgery is also necessary because implants can fail or infections can occur after the surgery or in the course of years after the surgery. In order to avoid the necessary second surgery here, the use of degradable implant materials is an option. However, with regard to such implants, the use of magnesium alloys can be advantageous. Their property profile is similar to that of bone, they dissolve over time and a second surgery can be avoided. Conventionally, Mg-based implants are currently manufactured with a series of process steps. However, additive manufacturing is an advantageous process here, especially for the production of small series or customised implants in particular. This is precisely where the present work comes in and investigates the generation of components with the aid of selective laser melting.

8. Significance of the topic and clarity of problem statement
Evaluate: excellent

[1] Overview of the scope of PhD thesis is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.

Selective laser melting is already a well-established process for a number of materials, but the same cannot be said for magnesium alloys. One problem here is the tendency of magnesium and its alloys to oxidise. It is therefore necessary to create an environment for selective laser melting in which a material can be processed in such a way that an individual, reproducible product is created. The high vapour pressure of magnesium at higher temperatures or as a melt opens up another problem area. During vapourisation, the laser beam is scattered and can then also easily react with oxygen, which may still be present in the chamber in which the implant is created.In addition to determining suitable process parameters, both problems are approached in a meaningful way and are also investigated and discussed in depth.

9. Knowledge of existing literature

Evaluate: excellent

The literature review is complete and in-depth. The state of the art is adequately described. From the available sources, it is also well deduced which problems and challenges currently exist.

10. Choice of methods and technical soundness

Evaluate: excellent

The choice of selective laser melting as a manufacturing process is very good. Essentially, this process can produce parts that are of high quality and at the same time can be customised. The produced parts were investigated with suitable methods with regard to microstructure, strength and degradation behaviour. The methods used correspond to the state of the art and are also used by other research groups and industry, thus allowing good comparability with other work in the field of degradable materials and not only degradable magnesium implant materials. In the combination of manufacturing process and characterisation, it is also very likely that the present results can also be reproduced and confirmed by third parties.

11. Quality, originality and significance of the results

Evaluate: excellent

The present work impresses with the level of detail and the clearly recognisable thread. It focuses on a process that is particularly suitable for the production of individualised implants. This is not the case with other process routes. Overall, a parameter space is created that can be used directly for industrial applications. At the same time, however, incentives are given for further development in research. This makes the work as a whole of outstanding importance.

12. Quality of attached papers

Evaluate: excellent

Five papers were listed. These papers appeared in journals that are very well recognised today. They meet the current requirements for high quality papers and will have an impact on ongoing and future research in the field of degradable magnesium implants produced via selective laser melting.

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13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Evaluate: excellent
Overall, the work presented is outstanding and contributes significantly to the state of knowledge. The entire presentation, the choice of methods, the work packages described, the results and the conclusions drawn make sense. The hypotheses and research questions posed in chapter 4 are clear and focused. They are also answered in a clear and coherent way. The thesis is strong overall and weaknesses are not apparent as such.

14. Questions and comments

15. Conclusion
This PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.
YES

16. Date and signature	
Date:22.06.2022	

Please note

A. *Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.*
B. *E-mail the completed form to:* Klara.Javorcekova@vut.cz

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6. Reviewer
Dr.techn. Fernando Gustavo Warchomicka/ fernando.warchomicka@tugraz.at
Graz University of Technology

7. Overview of the scope of PhD thesis[1]
Very good
The candidate focuses the goals of the thesis on two main scientific questions, after a detailed analysis of the literature and the formulation of the hypotheses. During the research activities, he is finding the best parameters for printing, reducing defects, improving surface quality, and trying to control the vaporization and oxidation of Mg during the processing. These findings help to characterize also the material by metallography and mechanical properties. In section 7, the candidate describes precisely the finding for process parameters, the preparation of the machine for safety use, and different microstructural features. In the case of mechanical testing, the obtained results are not bringing any new findings.

8. Significance of the topic and clarity of problem statement
Excellent
The investigated topic is very challenging since the processing of magnesium alloys at elevated temperatures can provoke burning or flame ignition. The use of rare-earth to retard this effect does not reduce completely this problem. For that, the investigation of proper parameters in an almost inert atmosphere seeks to build high-performance components. In this context, the thesis aims to determine the optimal parameters and reduce the typical defects observed during additive processing. The candidate

[1] Overview of the scope of PhD thesis is a short description of objectives of PhD thesis's research and summary of main findings and scientific achievements.

identifies the problems described in the literature (section 3.3) and uses them as starting point to improve the technique.

9. Knowledge of existing literature

Very good

The candidate prepared a very good summary of the existing literature related to the additive manufacturing of magnesium alloys (section 2.2) and the consequence of oxidation on the processing of magnesium (section 2.3). It is a very challenging topic of investigation since there is a lack of information in the literature, having two main consequences: a good preparation of scientific questions to be answered during the study, the possibility to determine the main problems of processing, and the difficulty to find comparable results to validate/confirm the obtained one. Although the corrosion behaviour of the material is not the main topic of investigation, the state of the art (section 2.4) in this field is limited only to some examples in additive manufactured material. It could have helped with a summary of cast conditions of the same material in different environments.

10. Choice of methods and technical soundness

Good

The experimental method selected for this thesis was correct, but there were some techniques not enough exploited and insufficient details in the description of the methodology. Some methods are poor described or unclear, which makes the reproduction of the method difficult for obtaining similar results. The first part to identify the best parameters and improvement of the atmosphere circuit is good explained, and it influences the quality of the results. The microstructural analysis would be right, but the results shown focused mainly on the defects, without a good analysis of the microstructural features and their relationship with the mechanical properties. The selection of the compression test is not well justified, and the results for extruded material are missing in the section of results. Furthermore, there is some inconsistency in the curves shown for the compression test without any explanation.

11. Quality, originality and significance of the results

Very good

Although WE43 is one of the most studied magnesium alloys in the field of additive manufacturing, the thesis attempts to be original by determining open scientific questions from the literature. The preparation of state-of-the-art, the formulation of the hypotheses and the questions led to obtaining research with good quality due to the originality of the investigation. In this case, the thesis presents new insights into the field of manufacturing. The analysis of different parameters affecting the surface quality and the defects (pores, cracks, delamination, lack of fusion, etc.) brings new information to optimize the process for future components and improve the quality of the surface. The modifications carried out in the atmosphere circuit will have a positive impact on further studies, giving an overview of possible problems to be found during the printing of the material (mainly oxygen contamination). In general, the quality of the work is good, with highlights in the technological aspects but with a barely metallographic and mechanical characterization of the material. The candidate did not exploit the possibility to understand the microstructure -mechanical properties relationship and compare in a better way with different processes (casting, extrusion, forming)

12. Quality of attached papers

Very good

The current version of the thesis does not have the original articles annexed. The candidate mentions the articles in the different sections and invites the readers to read the works to understand better the description of his thesis. From this Thesis, at least six articles were submitted and accepted, finding the latest publication online available in March 2022. From these six articles, three bring substantial information and new insights in the studied field. During the review process, I did not have access to article D. Article A focuses on the influence of the process parameter on the weld tracks, with a very good characterization of the surface quality and defects found after the weld track. Article B summarizes, technologically, the relationship between some process parameters, defects formation and mechanical properties, without scientific details. Article C is previous to A and with a different process's technique (it uses a pre-heated plate) shows only a microstructure characterization and the influence of Oxygen on the defects. Article E is well prepared, focusing on the corrosion resistance of a material with low porosity. Interpretation and discussion of the results are clear and bring an interesting conclusion of the post-surface treatment surface of the material to reduce the degradation rate.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)

Very good

In general, the overall performance shown in the thesis is very good. He clearly prepared the problem statement and the scientific questions to determine the major findings through the chosen methodology. The strengths of this work are the conceptual formulation mentioned before and the analysis and interpretation of the results obtained to optimize the process, comparing and correlating with existing literature. The weakest of this work are the presentation of the results in section 6 for the results and the superficial characterization of the as built material by metallography and mechanical testing.

14. Questions and comments

Comments: 1) Some typo mistakes and text formatting were found during the reading. 2) The structure of the result (Section 6) is complicated to follow. I am finding that each sub-section has a mix of results, like process parameters, microstructure characterization, different compression tests, and some bending tests, among other experimental techniques. I would recommend in the future to separate processing optimization (including roughness, porosity, and microstructure of build material) from the property's characterization (corrosion, mechanical testing and metallographic characterization of the best parameter set). 3) One suggestion to be considered in the future is the author's contribution (Autorovo přispění) to the accepted publications, given in Section 4.3. The candidate does not describe his activities in each article and he uses the results in his Thesis, especially those where he meant his contribution was only 20% (printing samples?).Questions: a) Metallography: What is the main goal of only one EBSD measurement in the work? b) Mechanical testing: Are you using average curves? How is the reproducibility of the results? Why tensile and/or Impact test were not included? c) Immersion Test: Why the corrosion rate was not estimated by weight loss? d) Immersion Test: Why the immersion test was not with constant pH?

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15. Conclusion
PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.
YES

16. Date and signature	
21/06/2022	

Please note

A. *Evaluate categories 7 to 13 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent. The qualification of 'excellent' should only be given for a PhD Thesis in the top 3% of the research in your field of expertise.*
B. *E-mail the completed form to:* Klara.Javorcekova@vut.cz

FERNANDO WARCHOMICKA.

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Principal supervisor's final report on the PhD study

1. PhD candidate
Jan Suchý / E-mail: jan.suchy1@vut.cz
2. Name of PhD programme
Design and Process Engineering
3. Title of PhD thesis
Processing of Magnesium Alloys by Selective Laser Melting Method

4. Principal supervisor
doc. Ing. David Paloušek, Ph.D. / E-mail: david.palousek@vut.cz
5. Co-supervisor
doc. Ing. Daniel Koutný, Ph.D. / E-mail: Daniel.koutny@vut.cz doc. Ing. Libor Pantělejev, Ph.D. / E-mail: pantelejev@vutbr.cz

6. Stays at other institutions (min. 7 days)
Institution / Country / From / To

7. Teaching activities
Course name / Total number of hours Engineering Drawing Fundamentals (1K)/52 Machine Design (2K)/26 CAD – Basic (3CD)/208 Design and CAD (4KC/CKC)/104 Digital Technologies and CAD (RS1)/12 CAD Modelling (ZM1)/88 Additive Technology (ZAT)/26

8. List of main publications
IF journals 1. Suchy J, Horynová M, Klakurková L, Palousek D, Koutny D, Celko L. Effect of laser parameters on processing of biodegradable magnesium alloy WE43 via selective laser melting method. Materials (Basel). 2020;13(11). - *Materials, MPDI – IF 3.623, Q2* 2. Suchy J, Pantelejev L, Palousek D, Koutny D, Kaiser J. Processing of AlSi9Cu3 alloy by selective laser melting. Powder Metall. 2020;63(3):197–211. - *Powder Metallurgy, Taylor & Francis – IF 1.911, Q2*

3. Suchý J, Klakurková L, Man O, Remešová M, Horynová M, Vojtěch D, et al. Corrosion behaviour of WE43 magnesium alloy printed using selective laser melting in simulation body fluid solution. 2021;69(June):556–66. - *Journal of Manufacturing Processes, Elsevier – IF 5.01, Q2*

WoS or Scopus

1. Skřivánková, V.; Vlašic, F.; Suchý, J.; Paloušek, D.; Mazal, P. Study of fatigue loading of the SLM and cast material by acoustic emission method. In Metal 2018 - 27th Internation Conference on Metallurgy and Materials, Conference Proceedings. Ostrava-Zabreh: Tanger LTD., 2018. s. 1345-1350. ISBN: 9788087294840.
2. Krištofová P, Roudnická M, Kubásek J, Paloušek D, Suchý J, Vojtěch D. Influence of Production Parameters on the Properties of 3D Printed Magnesium Alloy Mg-4Y-3RE-Zr (WE43). Manuf Technol. 2019 Oct 24;19:613–8. 98
3. Krištofová P, Kubásek J, Vojtěch D, Paloušek D, Suchý J. Microstructure of the Mg-4Y- 3RE-Zr (WE43) magnesium alloy produced by 3D Printing. Manuf Technol [Internet]. 2019;19(1):89–94.
4. Krištofová P, Roudnická M, Kubásek J, Michalcová A, Vojtěch D, Suchý J, et al. Magnesium alloy we43 produced by 3d printing (Slm). Defect Diffus Forum. 2020;405 DDF:345–50.
5. Krištofová P, Kubásek J, Roudnická M, Michalcová A, Suchý J, Paloušek D, et al. Structure and properties of additively manufactured WE43 magnesium alloy. In: 28th International conference on Metallurgy and Materials. Brno; 2019. p. 1578–82.

9. Assessment of the supervision process

Very good

The topic of PhD studies is focused on additive manufacturing from magnesium alloys and freely follows previous Jan's diploma thesis. Jan approached the issue systematically according to the study plan with the support of the national project MPO TRIO. Thanks to the project, Jan established cooperation with a company and university research group. The research activities were conducted to apply the knowledge to a specific product and industrial usage. He had to adapt the manufacturing technology and improve safety to do the experiments because of the high reactivity of the material. During the study, Jan published three scientific IF articles as the main author and five papers as co-author. He had to adapt the manufacturing technology and improve safety to do the experiments.

10. Assessment of the candidate's ability to work independently

Very good

Jan worked on the topic independently. If possible, he followed the schedule and consulted regularly. He carried out laboratory measurements and prepared experiments. The area of magnesium alloys was supported by two projects: INTERREG AT-CZ ReMaP, ATCZ229 (partners LKR Leichtmetallkompetenzzentrum Ranshofen GmbH and FH OO Forschungs & Entwicklungs GmbH) and national project MPO TRIO (FV20232) Structural biodebradable implants processing by means of direct metal laser sintering (Prospon, The University of Chemistry and Technology, Prague). Projects provided a good background for the work, and Jan brought the opportunity to cooperate with other colleagues in the field. He was the main author of three impact articles.

11. Assessment of the contribution that the research makes to knowledge in the field

Good

Jan described the problems associated with the additive manufacturing process of magnesium alloy using laser additive technology. His research revealed some phenomena that fundamentally affect the quality of

the laser melted material. Laser melted magnesium alloys represent a relatively rare topic, unlike, for example, aluminium alloys. Revealing the causes of instability in the process is a basic prerequisite for applicability. An essential part of the work is the assessment of the suitability of the use of AM processed material for medical procedures. Jan dealt with the influence of surface roughness on the corrosion behaviour and corrosion rate. It is possible to estimate how the corrosion rate of the processed material changes with the laser power and scanning speed. This knowledge is essential for real applications in biomedicine.

12. Other comments
Jan was also active in supervising the bachelor these. He cooperated on several commercial projects, for example, for Thermofischer, Honeywell, Hanon Systems, and CEITEC Research Institute.

13. Conclusion
PhD thesis is an independent scientific work that presents a novel solution to a significant problem in the research area and demonstrates the candidate's ability to conduct independent research.
YES

14. Date and signature
18/02/2022

Please note

A. *Evaluate categories 9 to 11 using the following scale: unacceptable, acceptable, satisfactory, good, very good, excellent.*
B. *In each category 9 to 11 explain reasons for evaluation using between 100–200 words.*
C. *E-mail the completed form to: Klara.Javorcekova@vut.cz*