INSTITUTE OF **MACHINE** AND **INDUSTRIAL DESIGN**

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Faculty of Mechanical Engineering
Brno University of Technology

Review of Doctoral Thesis

1. PhD candidate
Ing. Martin Malý / Martin.Maly2@vut.cz
2. Name of PhD programme
Design and Process Engineering (Mechanical Engineering Design)
3. Title of PhD thesis
Processing of metal materials using Selective Laser Melting technology at elevated temperatures

4. Principal supervisor
doc. Ing. Daniel Koutný, Ph.D. / Daniel.Koutny@vut.cz
5. Co-supervisor
doc. Ing. Libor Pantělejev, Ph.D. / pantelejev@fme.vutbr.cz

6. Reviewer
Dr. Michael R. Tucker/ mtucker@ethz.ch
ETH Zurich

7. Overview of the scope of PhD thesis[1]
Very good
This thesis evaluated the effects of moderate-to-high build plate preheating on residual stress and defect formation in various materials in laser powder bed fusion (LBPF). Three classes of materials were experimentally tested: a titanium alloy (Ti6Al4V), a nickel alloy (IN919), and pure copper. Parameter development studies were conducted on each of the materials under varying preheat settings. The printed specimens were evaluated optically (microscopy, optical scanning), mechanically (tensile, hardness, bridge curvature method (BCM), and/or using various imaging techniques (SEM, XRD, EDS). Statistical methods were used to evaluate the relative contributions of the preheat temperature and various processing parameters to the residual stress and density. The results defied expectations in some cases, but are well-addressed in the ensuing discussions. The thesis summarizes whether and under what conditions preheating is advantageous for processing of these materials. In particular, it is shown that preheating of Ti6Al4V can reduce, but not eliminate residual stress. However, the feedstock rapidly oxidizes, which limits the economic utility of this approach. Preheating of IN919 to 400C unexpectedly increased residual stresses, which was attributed to the enhanced formation of the carbide phase. As such, preheating is not recommended for this material. Finally, preheating of pure copper to 400C successfully increased the part density to 99%, but at the expense of highly oxidized feedstock. The choice of whether to preheat copper is therefore a question of feasibility (i.e. is LPBF the only way to

[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.

produce this part?) vs business case (i.e. is the value of the part greater than the value of the oxidized powder?)

8. Significance of the topic and clarity of problem statement
Very good
As the field of additive manufacturing grows, so does the menu of different material options. Certain materials have limited weldability, as evidenced by the formation of cracks due to the residual stresses arising from the process. This would be the case for Ti6Al4V and IN919. One approach to reducing the stress is to preheat the build plate, which in turn reduces the thermal gradient between the melt pool and the solidified material. Secondly, it is of interest to efficiently process highly reflective materials, such as copper. Copper reflects a significant amount of the incident light at typical LPBF laser wavelengths, and as such requires a high amount of laser input power. Preheating the build plate is thought to reduce the amount of laser energy to melt the material in multiple regards, as outlined in the thesis. A wider range of processable materials will increase adoption and applicability of LPBF as an industrial manufacturing process. This is all clearly outlined within the thesis.

9. Knowledge of existing literature
Very good
The thesis begins with a thorough review of the sources of residual stress within LPBF. It continues with process parameter studies that have been done with preheating for various material systems (beyond the three mentioned above). These reviews are fairly comprehensive. Based on these, the thesis identifies gaps in the existing literature regarding the effects of high-temperature preheat on certain materials. The thesis aims, scientific questions, and hypotheses are all derived from these previous studies. Thus, the thesis is well-motivated and the author appears to understand the methods and key mechanisms to expect to observe through these experiments.

10. Choice of methods and technical soundness
Good
The studies themselves are a very straightforward replication of other studies that have been done. As such, it is believe that the methods are sound, but don't represent a contribution in and of themselves. The experiments were designed and conducted in a systematic way, and the characterizations are in line with standard practices. The statistical methods of papers 1 and 3 are a nice feature that is typically absent from most publications in this field. The characterization and measurement techniques support the discussion and conclusions. Some additional modelling (e.g. thermal history, grain refinement, precipitate formation) would have enhanced the results and made these studies more transferrable and impactful.

11. Quality, originality and significance of the results
Good
The methods were based on well-established techniques for running parameter development experiments and doing mechanical and image-based characterizations, so the quality of the results is high. The results of these studies can also be regarded as original. As outlined in the literature review, no one has done these studies with these parameters and these materials in the past. The significance is also good, since now other researchers/manufacturers who want to use these materials will know which processing conditions to target for these materials, as well as the tradeoffs they would face by using preheating. The

main limitation of these studies is that there is no general model proposed for predicting how preheat would affect other materials. As such, these methods would need to be repeated in their entirety to see how another material would behave, which limits its scalability.

12. Quality of attached papers
Very good
The papers are well-written and are already receiving more citations than the impact factor or CiteScore would predict. The studies are all well-described in terms of their methods. The results and analysis are sound. The discussions include consideration of the limitations of the technique, comparison with other studies, and proposals for mechanisms that come into play when the results were not as expected. Interestingly, these studies contained what some may consider to be "negative" results, but for sure add value to the overall field of research. I will for sure be introducing these papers to my students as examples of how to present such results. One (minor) shortcoming is that the grammar and sentence structure of these papers is less clear than the rest of the thesis.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Very good
This is a very good thesis that advances our knowledge of how moderate-to-high build plate preheat influences the residual stress and porosity in three distinct materials. The results challenge the "common wisdom" that preheating is good, and more preheating is better. The candidate has a thorough grasp of the state of the art, which he then applies directly in conducting this study. The results are reliable and of good utility to other researchers and industrial manufacturers. The main limitation of this work is its limited applicability to other materials due to a lack of a new model or other method to predict which materials would benefit from a heated build plate and by how much. As such, the main contribution is limited to the new knowledge that we have about the specific parameters and materials that were tested.

14. Questions and comments
Well done. I will have further technical questions at the defense.

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	
Date: 20.02.2023	

Please note

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Review of Doctoral Thesis

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6. Reviewer
Univ.-Prof. Dr.-Ing. Sergio de Traglia Amancio Filho/ sergio.amancio@tugraz.at
TU Graz (Austria)

7. Overview of the scope of PhD thesis[1]
Very good
Engineers and scientists are continuously driven to develop new materials and manufacturing technologies to fulfill the crescent demand for efficient, high-performance and cost effective cars and airplanes. Additive manufacturing (AM) of metals offers the possibility of using a wide range of high strength and lightweight alloys, which can help decrease vehicle structural weight and fuel consumption. 3D-structures with complex internal geometries and improved topology can be created via AM, such as honeycomb cores, internal lattice structures and complex channels. However, there are still several engineering and scientific knowledge gaps hindering a smooth and long-term successful transfer of AM metal process from the laboratory to the industrial environment. An example is the lack of understanding regarding the correlation between processing, microstructure, and as-print mechanical performance of engineering alloys such as titanium and nickel-based and copper alloys. This PhD thesis aims to investigate the effect of pre-heating in combination with other process parameters on the residual stresses of Ti6Al4V, Inconel 939 and pure copper alloys additively manufactured by Laser Powder Bed Fusion (LPBF). The main hypothesis stated by Mr. Martin Malý was that – through the application of preheating – residual stress would be thereby reduced, whereby less support structures would be required, which in turn could lead to lower manufacturing costs. Moreover this approach could potentially also lead to highly denser AM structure, such as in the case of highly reflective alloys such as copper. The scope of this thesis is to evaluate and try to answer these detected scientific-engineering knowledge gaps.

[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.

8. Significance of the topic and clarity of problem statement
Very good
The chosen topic is highly actual and of high relevance for the transportation and medical industries, where L-PBF is under consideration. The selected powder materials were reported in the literature to be of complicated laser-powder-bed-printability. The thesis' scientific-engineering problem was well stated by the PhD candidate, who clearly devised his objectives with a holistic view based on very good balance between materials science and mechanical engineering. By investigating Ti6Al4V, Inconel 939 and copper alloys, Mr. Malý has selected highly relevant industrial engineering materials, which are challenging to be additively manufactured by LPBF and whose detailed description of their metallurgical behavior and process-related residual stress distributions is still largely missing in the literature. The PhD candidate investigated the application of high-temperature preheating and its influence on residual stress, relative density, microstructure, and mechanical properties of these alloys to address these knowledge gaps.

9. Knowledge of existing literature
Good
The PhD candidate starts his literature review by concisely reviewing the main theories of residual stresses in metals and more specifically in LPBF. After that, the author continues his good literature survey by analyzing the state of the art on pre-heating methodologies and their influence on as-built quasi-static mechanical resistance, relative density and residual stresses. He revises the behaviour and properties - in a good way - of the following family of alloys produced by LPBF: Ti, Ni-based, Intermetallic, steel and Al alloys. After a good critical discussion on the main finds from the literature, Mr. Malý summarizes his literature review, whereby he concludes this chapter identifying the knowledge gaps in the literature. These were wisely used by him to devise the main scientific questions (i.e. goals) of his PhD thesis, as follow: (1) Understand the correlation between process parameters and preheating on the residual stresses of LPBF-Ti6Al4V alloy; (2) Study the influence of preheating on the residual stresses of the LPBF-IN939 nickel-based alloy; (3) Evaluate the application of high-temperature preheating on the relative density of Cu. All in all, Mr. Martin Malý has successfully provided the reader with the fundamental information needed for the interpretation and discussion of his results. He was able to achieve a good and balanced mixing of text-book theory and up-to-date information from peer-reviewed manuscripts.

10. Choice of methods and technical soundness
Very good
The PhD candidate selected an appropriate amount of methods adequate for the testing, characterization and analysis of his results. A very good amount of advanced analytical techniques were used; they were introduced in the thesis document and thoroughly described in the individual papers. Mr. Malý properly described all materials and methods in the respective chapter. This has been accomplished in very well elaborated manner, proper for a cumulative PhD thesis.

11. Quality, originality and significance of the results
Very good
Mr. Malý has successfully provided the reader with the well-written publication [I] "Effect of Process Parameters and High-Temperature Preheating on Residual Stress and Relative Density of Ti6Al4V Processed by Selective Laser" where he tackles the issues identified in PhD thesis Goal (1). The PhD

candidate used the surface response design method and analysis of variance to determine the optimized process parameters set to decrease residual stress and increase relative density. In the paper, the lowest distortions were accomplished with the application of the highest laser power, the lowest laser velocity, the shortest dwell time, and maximum preheating. The PhD candidate explained this observation by the slower cooling speeds and longer exposure times of Ti6Al4V in the ductile state, which allowed for relieving of internal stresses. Furthermore, the evaluation of the relative density showed that main process parameters influencing this response are the hatch laser power and velocity, as well as preheating temperature. Regardless of the positive observations, when working with preheating, oxygen and hydrogen take-up increases to values above the allowable established by ASTM for this alloy. This is because the diffusion rate of these atoms from residual oxygen content in the inert atmosphere increases along with the H-diffusion from residual moisture contained in the powder when preheating at 550 °C. This may be an issue as Oxygen in Ti6Al4V increases as-built ultimate and yield strength, while decreasing ductility. Moreover, the ductility of this alloy decreases with increasing hydrogen content, which may further impair mechanical performance of AM-parts. Therefore he concludes that thermally-affected, unmolten Ti6Al4V powder after printing with 550 °C preheating cannot be reutilized in subsequent printing jobs. On the other hand, specimens produced with 200 °C displayed no changes in H-content, but a small amount of oxygen was absorbed (nonetheless, at permitted percent in accordance with ASTM standard). Therefore, he concludes that these powders produced at 200 °C preheating may be reused in subsequent printing jobs. However, the PhD candidate does not present any experimental evidence to support this hypothesis. All in all the PhD candidate concludes that the combination of process optimization tools and preheating was unable to fully eliminate residual stresses in L-PBF Ti6Al4V. Moreover, the elevated absorption of O and H by the preheated powder may restrict its reuse in further printing jobs. Therefore the Mr. Malý concluded that this approach is not cost effective for printing titanium powders via L-PBF.
In his second publication [II], "Effect of Preheating on the Residual Stress and Material Properties of Inconel 939 Processed by Laser Powder Bed Fusion" the author addresses PhD thesis Goal (2). He investigated the influence of preheating IN939 powder on the resulting residual stresses, mechanical properties and microstructure of as-built specimens. The study shows that preheating increased quasi-static tensile strength and microhardness of produced IN939 specimens. This has been attributed to the formation and increase in density of MC-type carbides at higher preheating temperature of 400 °C. Furthermore, Mr. Malý observed the formation of γ' phase precipitates due to lower cooling rates and thermal gradients taking place during preheating. Carbides and precipitates were identified as the reason for increasing ultimate tensile and yield strength of L-PBF IN939 parts. In opposition to PhD candidate's initial expectations from paper [I], residual stress increased at 400 °C preheating. This has been attributed to the formation of precipitates, which increase inner residual stress leading to higher warpage in the printed parts. Finally, the PhD candidate analyzed the O-absorption in the unmolten Ni-based alloy powder. He detected at 400 °C a slightly increase in oxygen content. Therefore the author concluded that preheating is not an adequate method for decreasing residual stresses in L-PBF IN939 parts, as pre-heating-related microstructural changes induce high internal residual stresses.
The study [III] "Effect of high-temperature preheating on pure copper thick-walled samples processed by laser powder bed fusion" tackles PhD thesis' Goal (3). It addresses the effect of preheating on a pure copper alloy. Another objective of this study was the manufacturing of homogeneous and dense thin-walled specimens (e.g. for future applications in heat exchangers), assuming that relative density would be also increased, as it has been observed in study [I]. The correlation between L-PBF process parameters and preheating was also evaluated by design of experiments and analysis of variance. The author showed in this very good publication, that, a) copper was able to be printed with high densities lager than 99%. This is definitely a very good engineering achievement, which was not previously reported in the literature for this alloy. Optimized processing conditions were established for the first time for the LPBF process carried out with lasers of max. power of 400 W and wavelength of 1064 nm, along with preheating of 400 °C. However, a high amount of oxidation in the powder was measured, which induced poor bonding between adjacent layers and tracks. Moreover, preheating has caused strong oxidation of the non-molten powder, sometimes inducing initial sintering of these powder particles. Therefore, reuse of preheated non-molten powder is not recommended by the author. On the other hand, printed Cu-parts

were not strongly oxidized by preheating. Therefore, the approach of preheating copper powder was successful in producing thin-wall parts with high relative densities, an unique contribution of this PhD thesis to the state of the art of L-PBF of highly reflective metallic alloys.

12. Quality of attached papers

Very good

Two manuscripts in this cumulative PhD thesis were published in a fairly high-impact factor materials science journal (Materials, journal impact factor = 3.748, Quartile Q1, Metallurgy &Metallurgical Engineering) and one in a very good high-impact factor manufacturing journal (J. Man. Processes, journal impact factor = 5.684, Quartile Q2 (Engineering, Manufacturing). Moreover, Mr. Martin Malý's papers have achieved so far an excellent number of citations by a total of 59. The published papers were useful to properly answer the proposed scientific questions in the thesis, as the PhD candidate was able to confirm or refute the proposed hypotheses established in the beginning of his PhD work. In summary Mr. Malý provided the reader with a very good scientific interpretation of the results, being able to apply strong mechanical and material engineering knowledge to explain the experimental observations leading to the main insights and conclusions of his PhD thesis. All in all the attached papers are adequate to support the scientific-engineering approach of this cumulative PhD thesis.

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

Very good

The PhD candidate provided the materials science community with a very good first understanding of the correlations between process parameters and powder preheating affecting as-built microstructure, quasi-static mechanical properties and residual stress of three metals, which are very difficult to be processed via L-PBF. By ingeniously using design of experiments and analysis of variance, coupled with solid physical metallurgy knowledge, the PhD candidate was able to establish robust theories to explain and describe the influencing of the chosen L-PBF processing parameters on the as-built properties. A highlight in this PhD work was the production of Cu thin-wall specimens with very high density and reduced amount of defects, an achievement reported for the first time in the literature. In a nutshell this was a clever approach to visualize and explain the influence of energy input and powder preheating in the selected alloys, which is an engineering knowledge area still scarcely reported in the literature. These very relevant findings will certainly set a solid path for the future developments in L-PBF of Ti, Ni-based and Cu-alloys, as the reduction of structural defects and residual stresses (meaning less support structures) may be better controlled or fully hindered, potentially leading to lower manufacturing costs.

14. Questions and comments

The thesis is well written. However there are a few minor grammatical mistakes and figure formatting issues, which must be corrected in the final thesis version.

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

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16. Date and signature	
28/02/2023	

SIGNATURINFORMATIONEN	Datum/Zeit-UTC	2023-02-28T16:14:30+01:00
	Prüfinformation	Informationen zur Prüfung der elektronischen Signatur finden Sie unter: https://www.signaturpruefung.gv.at
Hinweis	Dieses mit einer qualifizierten elektronischen Signatur versehene Dokument hat gemäß Art. 25 Abs. 2 der Verordnung (EU) Nr. 910/2014 vom 23. Juli 2014 ("eIDAS-VO") die gleiche Rechtswirkung wie ein handschriftlich unterschriebenes Dokument.	

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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Brno University of Technology

Principal supervisor's final report on the PhD study

1. PhD candidate
Name of PhD candidate / E-mail: **Ing. Martin Malý/ Martin.Maly2@vut.cz**
2. Name of PhD programme
Name: Machines and Equipment
3. Title of PhD thesis
Title: Processing of metallic materials by Selective Laser Melting at elevated temperatures

4. Principal supervisor
Title and name of principal supervisor / E-mail: **doc. Ing. Daniel Koutný, Ph.D.**/ Daniel.Koutny@vut.cz
5. Co-supervisor
Title and name of co-supervisor / E-mail: **doc. Ing. David Paloušek, Ph.D./** David.Palousek@one3d.cz **/doc. Ing. Libor Pantělejev, Ph.D./ pantelejev@fme.vutbr.cz**

6. Stays at other institutions (min. 7 days)
Institution / Country / From / To Graz University of Technology/Austria/ 1.5.2018 - 31.10.2018

7. Teaching activities
Course name / Total number of hours Engineering Drawing Fundamentals (1K)/ 208 Engineering Drawing (2K)/ 52 CAD – Basis (3CD)/ 130 Design and CAD (4KC)/ 208 Additive Technologies (ZAT)/ 78 Team Project (ZKP)/ 5 Master Thesis Project - Results and Discusion (ZD5)/ 26

8. List of main publications
Bibliography references cited according to the norm ISO 690. If appropriate, impact factor must be specified. **MALÝ, M.; HÖLLER, C.; SKALON, M.; MEIER, B.; KOUTNÝ, D.; PICHLER, R.; SOMMITSCH, C.; PALOUŠEK, D. Effect of Process Parameters and High**-Temperature Preheating on Residual Stress and Relative Density of Ti6Al4V Processed by Selective Laser Melting. Materials, 2019, 12(6), pp. 1-13. ISSN: 1996-1944. Journal impact factor = 3.623, Quartile Q2, Citations = 50.

MALÝ, M.; KOUTNÝ, D.; PANTĚLEJEV, L.; PAMBAGUIAN, L.; PALOUŠEK, D. Effect of high-temperature preheating on pure copper thick-walled samples processed by laser powder bed fusion. Journal of Manufacturing Processes, 2022, 73, pp. 1-15. ISSN: 1526-6125.
Journal impact factor = 5.01, Quartile Q2, Citations = 6.

MALÝ, M., K. NOPOVÁ, L. KLAKURKOVÁ, ADAM O., L. PANTĚLEJEV and D. KOUTNÝ. Effect of Preheating on the Residual Stress and Material Properties of Inconel 939 Processed by Laser Powder Bed Fusion. *Materials*. 2022, 15(18). ISSN 1996-1944. Available at: doi:10.3390/ma15186360.
Journal impact factor = 3.748, Quartile Q1, Citations = 0.

HERNANDEZ TAPIA, L.; CARRANZA-TREJO, A.; KASHIMBETOVA, A.; TKACHENKO, S.; KOLEDOVÁ, Z.; KOUTNÝ, D.; MALÝ, M.; ČELKO, L.; MONTUFAR JIMENEZ, E. Microstructure of Selective Laser Melted Titanium Lattices and In Vitro Cell Behaviour. In *Proceedings 30th Anniversary International Conference on Metallurgy and Materials.* Tanger, 2021. pp. 1179-1185. ISBN: 978-80-87294-99-4.

MAŠEK, J.; LÖFFELMANN, F.; POPELA, R.; KUBÍK, P.; ŠEBEK, F.; KOUTNÝ, D.; MALÝ, M.; PANTĚLEJEV, L.; PAMBAGUIAN, L. Additive manufacturing capabilities for heat switch technology: Key challenges & knowledge gaps. *9th European Conference for Aerospace Sciences.* Lille, France, EUCASS association, 2022. pp. 1-15.

9. Assessment of the supervision process

Very good

Justification for evaluation: Basic communication with the student focused on the course of doctoral studies took place on a regular weekly basis. More detailed discussions of the topic of the dissertation, including planned experiments, partial results and proposals for further steps, then took place approximately every four to six weeks. In addition to regular meetings, internal reviews of prepared publications and discussions on additional evaluation of results and text modifications took place. The student also actively discussed specific topics of prepared studies with supervisor specialists and other experts in the field of material sciences. Throughout the course of the study, communication went smoothly, and certain disruptions and slowdowns in activities only occurred during the COVID-19 pandemic. The extension of the study beyond the standard time was also due to the effort to publish the results in first-quartile journals, which involved a demanding and lengthy review process in several journals.

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

Very good

Justification for evaluation: The doctoral student worked very actively and independently while solving the thesis topic. From the beginning of his studies, he was successively involved in five applied research projects. Student prepared and solved two faculty internal projects of teaching innovation for the additive technologies course. During the fourth and fifth year, he solved and led his own research project of the TAČR Zeta program for young researchers. During the project, he showed that he is able to independently plan experiments, evaluate the results and prepare final research reports, but also that he is able to coordinate and lead a team including experts from two involved companies. Within his dissertation, he also demonstrated that he is able to identify the research gaps, establish hypotheses, realize appropriate verification methodology and discuss achieved results.

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11. Assessment of the contribution that the research makes to knowledge in the field
Very good
Justification for evaluation: The doctoral student focused the research on the influence of preheating temperature on the residual stress and relative density with aim to minimize the amount of supporting structures and enhance the effectivity of hard-to-process materials by laser powder bed fusion process. The focus was on three materials titanium alloy Ti6Al4V, nickel-based alloy Inconel 939 and pure copper. Three studies were published describing the effects of preheating on individual materials. First study confirms, that the residual stress and potentially the amount of support structures can be minimized by higher preheating temperatures. However, it was shown, that the effect is not as significant as was predicted by previous studies. The study also revealed strong oxidation of powder at higher preheating temperatures, this effect may eliminate recycled material from further use. The second study reveals the reasons for the different development of residual stresses in Inconel 939 and shows that the preheating effect cannot be generalized across materials. The third study proves that with an increased preheating temperature, a better quality of pure copper material can be achieved even with a standard laser. The significance of the results is confirmed by the high number of citations.

12. Other comments
Project on which student participated or led during his PhD studies: 2021 – 2022, TAČR FW03010160 – TREND, Surface treatment of very thin structures realized by 3D metal additive manufacturing, team member 2020 – 2022, TAČR Zéta TJ04000314, Additive Manufacturing of Turbine Engine Components from Heat-Resistant Alloy Inconel 939, project leader 2020, FV 20-21, Innovation of the subject Additive Technologies in the application of design rules for components for 3D printing, project leader 2017-2020, ESA Contract no. 4000123317/18/NL/GLC/hh, Additive Design for Aerospace Applications Capabilities (ADAAC), team member 2019, FV 19-19, Innovation of the subject Additive Technologies in methods for the design of experiment, project leader 2017-2019, MPO FV20232, Structural biodegradable implants processing by means of direct metal laser sintering, team member

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	
27/02/2023	

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*