INSTITUTE OF MACHINE AND INDUSTRIAL DESIGN

FME

Faculty of Mechanical Engineering
Brno University of Technology

Review of Doctoral Thesis

1. PhD candidate
Ing. Ondřej Červinek / Ondrej.Cervinek@vut.cz
2. Name of PhD programme
Design and Process Engineering (Mechanical Engineering Design)
3. Title of PhD thesis
Computational models for non-linear mechanical loading analyses of lattice structures made by powder laser bed fusion

4. Principal supervisor
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7. Overview of the scope of PhD thesis[1]
Very good
This thesis develops and evaluates new methods for predicting the plastic deformation behavior of additively manufactured metal lattice structures under low-to-moderate strain rates via finite element methods (FEM). As the thesis outlines, there is a gap in our understanding of how to model such gross deformation behavior, especially given the complexity of the lattice geometry and variability in the as-built structure. Models of beam lattice structures contain a number of elements and nodes that is far in excess of what a continuum representation of the same volume would contain, which when coupled with the number of degrees of freedom at the nodes, represents a significant computational challenge. Furthermore, it is known that the structural behavior of lattice structures is significantly different from solid structures. The geometric variability of the lattice structure inherent to the manufacturing process adds significant uncertainty. This thesis addresses these issues by introducing new methods for experimentally determining the mechanical properties of thin struts, development of enhanced non-linear models to account for the behavior of the lattice (including geometric imperfections), and verification of the models through experimental testing. As a result of this thesis, our ability to model and predict the deformation of lattice structures with manufacturing variability has been advanced, which may lead to greater adoption of this promising new technology.

[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 thesis outlines the potential applications of energy-absorbing lattice structures quite well. In summary, automotive applications require the inclusion of structures that are capable of absorbing kinetic energy at moderate strain rates while limiting the maximum force and acceleration exerted on the occupants. Such structures are also subject to space and weight requirements, which make open lattice structures an ideal candidate. With improved understanding of how these structures deform, we could design the structure to follow a prescribed force-deformation trajectory for enhanced protection of the vehicle's occupants, payload, and whatever the vehicle collided with. However, prior models of the plastic deformation of metal lattice structures failed to accurately capture this behavior. With the newly developed models, engineers can predict how metal beam lattices would deform despite variabilities in the as-manufactured geometry.

9. Knowledge of existing literature
Very good
The thesis provides a very thorough review of the relevant existing literature. From this, it is clear that many other researchers have been working on this problem for some time, and in particular within the last 15 years. This is likely due to the rapid growth of the additive manufacturing industry. The thesis provides a systematic analysis of the different aspects of the previous modelling approaches and carefully considers the strengths and weaknesses of each approach. In particular, we see that thin struts produced via additive manufacturing behave quite differently than larger bulk structures would predict. The methods that were used to derive mechanical properties of thin struts are flawed, which propagates into mismatched modelled behavior. The models themselves take various approaches to capture the deflection within the structure despite geometric imperfections but show significant room for improvement. In addition, there are gaps with modelling beyond the linear elastic region and within the relevant band of strain rates. Within this thesis, the knowledge gaps are clearly summarized in chapter 3, followed by specific aims, scientific questions, and hypotheses in chapter 4.

10. Choice of methods and technical soundness
Very good
The methods chosen are quite sound. Some of the major shortcoming in previous studies are that they provide either limited or no experimental validation, or that the experimental methods themselves provide limited applicability for interpretation. This thesis focuses heavily on characterization of the as-built structures, which is thought to be the most accurate method for understanding the capabilities of the manufacturing process. These characterizations are used to develop the non-linear models used to predict deformation behavior. Validation is provided through additional compressive plastic deformation testing of lattice structures at low-to-moderate strain rates that are relevant to the intended automotive application.

11. Quality, originality and significance of the results
Very good
The results provided through this thesis (and analysis thereof) are of very good quality. The papers provide excellent documentation of the methods that were used to achieve these results and thorough discussions of their reliability. Alternative models and explanations are provided as necessary to account for unexpected behavior. Limitations and weaknesses of the employed approach are clearly stated. Results are validated using uncertainty margins, alternative models, and through experiments. As such,

the results are thought to be reliable and can serve as a benchmark for future research. The results showed significant improvements in predictability of structural deflection behavior in thin beam lattices, which represents a meaningful advancement in this field.

12. Quality of attached papers
Very good
The papers are well-written and include clear documentation of the employed methods. All figures and results are clearly presented. Most results include uncertainty analysis or comparison with reference models. The discussions are thorough and account for the observed behavior, with alternative explanations provided when necessary. Comparisons with existing literature are provided. The limitations of the individual studies are considered. The conclusions are clearly stated and are supported by the data and analysis of the paper. The grammar and sentence structure, as well as the overall paper structure, are clear and easy to follow. On average, the papers are being cited more frequently than the journals' Impact Factors or CiteScores would suggest. The overall structure of the cumulative thesis is good and tells a coherent story through the course of this research. As such, the thesis provides the reader with much more value than simply reading the three papers separately.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Very good
This thesis represents a significant contribution to the state of the art in this field of research. The problem statement and motivations for conducting this research is clear. The underlying problems and background research are well-understood and clearly laid out. The combination of experimental and model-based methods gives a sense of increased soundness and applicability of the achieved results. The results show significant improvements in the ability to predict plastic deformation behavior in beam lattices under low-to-moderate strain rates, which is highly relevant to the problem at hand. The quality of the attached papers is high, which hopefully translates to a lasting and widespread impact of this research.

14. Questions and comments
Mr. Červinek did great work in this thesis. I have many technical questions for him regarding the methods and results, which I plan to ask him 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

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*