CZECH TECHNICAL UNIVERSITY IN PRAGUE
Faculty of Transportation Sciences
Dean's Office - Department of Science and Research
Konviktská 20, 110 00 Prague 1

Opponent opinion on the doctoral thesis

I. Identification data

Title of dissertation:	Numerical modelling of auxetic structures
Author's name:	Ing. Petr Koudelka
Training workplace:	Czech Technical University in Prague
Opponent of the thesis:	Prof. Matej Vesenjak
Opponent's workplace:	Faculty of Mechanical Engineering, University of Maribor, Slovenia

II. Evaluation based on individual criteria

Actuality of the dissertation topic	
The dissertation combines two very important research fields: i) materials science and ii) computational and experimental mechanics. It focuses on computational modelling and on quasi-static and dynamic mechanical characterisation of advanced metamaterials with negative Poisson's ratio (auxetic materials). Besides the up-to-date topic of the doctoral thesis, it is also based on modern research methods and equipment, which allows to obtain important, valuable and justified results and conclusions. The chosen topic and presented results are also suitable for publication in high-ranking international scientific journals.	
evaluation	**Excellent**

Fulfillment of the goals of the doctoral thesis	
The main aim of the doctoral thesis was to investigate the mechanical behaviour of auxetic materials based on experimental and numerical testing. Although the thesis also presents the quasi-static response of selected auxetic structures, it is primary focused on their dynamic response (at very high strain rates). To reproduce the experimental results, Mr. Koudelka developed appropriate numerical models, which are able to precisely describe the response and behaviour of different auxetic structure types. To achieve the goals and objectives of the doctoral thesis (realistically also considering the limitations of analysed structures and methods), several sub-tasks were performed within two main groups: i) quasi-static loading and ii) dynamic loading. The sub-tasks are written clearly and give an excellent overview of the performed research work. Based on the aims and objectives on one hand and the performed extensive experimental and numerical tests with obtained results on the other hand, it can be concluded that Mr. Koudelka completely fulfilled the goals of the doctoral thesis. The results are also properly documented and systematically described.	
evaluation	**Excellent**

Methods and procedures of solution	
The obtained results are based on experimental and numerical methods. The mechanical behaviour of three auxetic structures (2D missing-rib, 2D and 3D re-entrant honeycomb) made of polymer and steel were initially tested under quasi-static loading conditions, which allowed the validation of the finite element (FE) models. In addition to the stress-strain diagrams, special care was taken to follow the displacement (strain) field distribution to acquire the variation of the Poisson's ratio during the loading. This was enabled by applying the Digital Image Correlation (DIC). In the second phase the auxetic steel structures (specimens with different number of unit cells) were subjected to dynamic tests using the Split-Hopkinson Pressure Bar (SHPB) device. The dynamic tests allowed capturing the mechanical response up to very high strain rates and presented the basis for development of FE models. The numerical models consisted of the testing device and represented auxetic metamaterials discretised in a detail. The thesis reports on proper validation of the FE models and provides an extensive comparison between the experimental and numerical result. Additionally, micrographs of fabricated specimens were taken and studied to account for the influence of the fabrication procedure (e.g. SLS) on the mechanical behaviour of the specimens. It should also be noted that theoretical backgrounds of the performed research work are thoroughly described within the thesis. The candidate managed to successfully apply the up-to-date methods (FE analysis, SPHB and DIC) to obtain reliable and representative results.	
evaluation	**Excellent**

Výsledky disertace – konkrétní přínosy disertanta	
The results of the thesis are addressed in a consistent and thorough way, supported by extensive discussion, diagrams and figures. The candidate provides a broad overview of the obtained results focusing on the Poisson's ratio and strain-rate dependency, as well. However, to better explain the stress-strain responses and the concept of the deformation mechanisms it would be helpful if images showing the deformation sequence during loading would be provided. In overall, the following original conclusions were drawn: the SPHB is a suitable method for investigation of dynamic behaviour of SLS auxetic structures; the used base material is strain rate sensitive (thus, the strain rate influences the macroscopic behaviour of the auxetic structures); loading velocity changes the deformation behaviour; unit-cell number and strain rate influence the Poisson's ratio; fabrication of the structures must be closely controlled. Furthermore, some disadvantages of the developed numerical models (mesh density, material model, time-history of the strain rate in the virtual SHPB) have been also given. The obtained conclusions are based and appropriately supported by experimental measurements and numerical results. They provide insight into the behaviour of novel auxetic metamaterials (different types and unit-cell numbers) subjected to different loading scenarios.	
evaluation	**Above average**

Significance for practice and for the development of the scientific field
The justified results obtained within the submitted thesis present various benefits and are significant from the: i) scientific point of view for the material science, to better and in a more detail predict the behaviour of auxetic metamaterials (the use of appropriate research methods SHPB and DIC is also very important). Furthermore, the developed and validated numerical model of the SHPB device will allow

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for future testing of similar novel materials, while the developed FE models of the auxetic structures presents the basis for a broad parametric study of different types of cellular materials subjected to dynamic loading conditions (at various strain rates); ii) applicative point of view, where the knowledge about the mechanical response and behaviour of auxetic metamaterials will allow for their broader use in general engineering, military, medical and transport applications.	
evaluation	**Excellent**

Formal arrangement of the doctoral thesis and its language level	
The thesis consists of 200 pages in total and is divided into 5 chapters and 2 attachments (bibliography and SEM micrographs). The thesis is well organized and structured. The literature is properly referenced and up-to-date. Although I am not a native speaker, I would rate the English level of the thesis as very good.	
evaluation	**Excellent**

Reminders:

Although the candidate was very thorough, please find below a few minor amendments, nothing significant, consequently none of them merits any kind of discussion about the research work performed and presented:

- Page 15, Section 1.1, Line 1: "...to investigate of the..." → "...to investigate the...";
- Page 15, Section 1.1, Line 11: "...are also shown also for..." → "... are also shown for...";
- Page 25, Line 8: missing parenthesis (brackets);
- Eq. 4.28: is there any particular reason for the expression to be equal to zero;
- Eq. 4.41 and subsequent equations: if f is the body force, please check the correctness of the following article ρf_i.

III. Final evaluation

Final evaluation of the doctoral thesis:

According to the thesis entitled "Numerical modelling of auxetic structures" submitted by the candidate Ing. Petr Koudelka and above statements, I fully recommend the thesis to be accepted for the award of the Ph.D. after a successful final defence.

In Maribor, 16th October 2020

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Signature of the opponent