The opinion on Thesis entitled:
"Micromechanical modelling of voided FCC and HCP polycrystals in inelastic regime"
presented by Mr **Saketh Virupakshi**

to obtain the title of *Doctor in "Mechanical Engineering"*

Reviewer: Tomasz Łodygowski, Professor at Poznan University of Technology, Poznań, Poland

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1. Formalities

The basis of this review is the request from the Secretary of the Scientific Council of the Institute of Fundamental Technological Research, Professor Zbigniew Ranachowski, DSc, PhD, Eng., to review the doctoral dissertation of Mr. Saketh Virupakshi, MSc, supervised by Professor Katarzyna Kowalczyk-Gajewska, and co-supervised by dr. Karol Frydrych. Along with the request, I received a printed copy of Mr. Saketh Virupakshi's doctoral dissertation.

2. Introductory remarks

The presented manuscript of PhD thesis is written in English, consists of nine main chapters and incudes Conclusions, the list of References cited in the text of the document (188 entries) and the List of symbols, abbreviations and acronyms, List of Tables and List of Figures; altogether it contains 191 pages.

In his a brief introductory remarks Mr. Saketh Virupakshi presents the main motivations and goals of the thesis. He focuses on metals and alloys with face centered cubic (FCC) and hexagonal closed packed (HCP) lattice symmetry. These materials exhibit high strength and higher durability at elevated temperatures. The Author describes the contents of the thesis, motivation and state of the art of known experimental achievements. In this brief review Author expose the observations regarding ductile failure in materials at macro and micro scales. The fundamental role for fracture resistant of materials under consideration is played by controlling the sizes of inclusions. So it was important to focus on the role of material microstructure on void initiation, growth and coalescence in FCC and HCP lattice structures encompassing both macro and micro levels. Author discusses macroscopic models for porous ductile materials (Gurson, Tvergaard, Needleman type models) and crystal plasticity models for porous crystals. Also with their finite element applications.

The Author defined the main goal of the thesis in the following way:

"To comprehend and elucidate, through numerical analyses and micromechanical modelling, the relationship between crystal anisotropy and the process of void growth and coalescence that result in ductile damage in polycrystalline metals and alloys characterized by FCC and HCP symmetry, especially when they deform by slip and twinning ".

The considered topic is important form the application point of view of certain materials with FCC and HCP lattice symmetry in particular in aviation and aerospace industry, also scientific side of the thesis is not trivial and requires deep understanding of theoretical mechanics and advanced Finite Element (FE) computations.

The following Chapters of the work show the consequent way which Author passed reaching the scientific goals declared at the beginning. Let me mention that it was a pleasure to read this Thesis which clearly presented the following aspects necessary to overcome whole difficulties to achieve finally the description the macroscopic responses of porous crystals and polycrystals through micromechanical mean field models.

To fulfill the review expectations let me briefly summarize the contents of the following Chapters.

3. Contents of the thesis

In Chapters 2 and 3, the Author presented a crystal plasticity model for twin and slip systems. This model is implemented within a FE framework to perform unit cell calculations in 2D as well as 3D cases for FCC and HCP porous single crystals. The FE implementation for the various boundary conditions applied for a unite cell is presented. In computations Author used AceGen code generator which combines the symbolic algebra capabilities of Wolfram Mathematica with automatic differentiation techniques. The unit cell is defined as the smallest microstructural representative volume element (RVE) that captures the effective properties of heterogeneous material.

In Chapter 4, the Author presents the crystal plasticity finite element method (CPFEM) which is employed to investigate cylindrical void growth or collapse in FCC crystals and microstructure evolution for 2D plane strain model. In this study displacement controlled and stress controlled boundary conditions are compared and anisotropic response of porous crystals under different orientations are examined. The results of this Chapter was previously published by the Author and prof. Kowalczyk_Gajewska in Int. Journ. of Solid and Struc. 2023.

Similar analysis is presented in Chapter 5 but for HCP crystals. Chapter 5 also includes 3D unit cell spherical void under uniaxial loading. In the studied cases the crystal orientation is fixed while the loading direction is varied.

A theoretical formulation of micromechanical mean field model for porous polycrystals is presented in Chapter 6. Author, following the concept of Mori-Tanaka the additive scheme is employed to determine the overall response of the single crystal. The additive self-consistent scheme was used to find the overall response of the porous polycrystals. Next, in Chapter 7 the numerical implementation of this model for single and polycrystals is discussed. The mean field model predictions are compared with the FE computations.

In Chapter 8 very interesting discussion of new yield criterion for porous single crystal based on GTN-type formulation is presented. The parameters of the model are calibrated using unit cell FE computations.

In the last part, the Author briefly summarizes the contents of the thesis and formulates final conclusions, as well as possible directions for the future research.

The list of References cited in the thesis concludes the reviewed volume.

4. Remarks concerning the main achievements and the discussion

There are several points that should be emphasized as novel contributions elaborated in the thesis.

a) The Author formulated the extension of the yield criterion enabling its application to crystals deforming by slip and twinning,
b) He introduced a new GTN-type yield criterion based on micromechanical approach for voided elasto-viscoplastic crystals with tuning parameters calibrated using full field FE analyses,
c) Detail discussion on the effect of crystallographic orientation and different boundary conditions on void grows and coalescence has been examined and supported by hundreds of computational jobs for plane strain cell model of FCC as well as HCP crystals,
d) The proposed mean-field model has been validated with respect to the corresponding full-field unit cell CPFEM computations for FCC crystals and polycrystals in terms of the overall and per-grain stress-strain responses.

In general, I found the manuscript very valuable, interesting and well-formulated, and I admire the complexity of the study. It was a real pleasure to study this work and in some parts it was a real challenge to overcome some difficulties of the mathematical expressions.

The thesis is well-structured, logically organized, and written in clear and precise language.

When reviewing the research conducted by a candidate aspiring to obtain a doctoral degree, I usually take into account several key aspects: the level of difficulty the candidate had to overcome, the amount of new knowledge acquired, their familiarity with the current literature in the field, and whether they have published their findings and presented them to the scientific community.

In the case of Mr. Saketh Virupakshi, the answer to all these questions is unequivocally positive. He has met—and even exceeded—all these criteria. Therefore, I strongly recommend that the Candidate be awarded the doctoral degree with distinction.

After reading the manuscript, I would appreciate to hear the comments to my two remarks:

1) ***In Chapter 4 when discussing the material parameters the Author uses the data from Table 4.1. Always the assumed parameters strongly influence the final results and finally the conclusions. What kind of lab experiments have to be done to reproduce the accepted values? I know the data were taken from the work of Potirniche et al. 2006.***
2) ***Usually, when someone is trying to verify the obtained mechanical results compares his achievements with the laboratory results. This is a real proof that the proposed models reflect the reality. In Chapter 7 there is proposed the verification of mean field model (MFM) by numerical results. To which extend this could be treated as a kind of proof that the MFM is correct and describe the real polycrystal material?***

5. Conclusion

The work is a comprehensive study on a scientific problem that is both novel and important from the application perspective. The Candidate has proved his high competences in formulating and solving the scientific problems.

The quality of the presented thesis convinces me that Mr. Saketh Virupakshi is a strong candidate for a Doctor of Science in the field of Mechanical Engineering, awarded by the Scientific Council of the Institute of Fundamental Technological Research. It is my pleasure to recommend the work for oral presentation and open scientific discussion.

Poznań, June 24th, 2025

Signed by / Podpisano przez:

Tomasz Andrzej Łodygowski
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Date / Data: 2025-06-24 13:12

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