

Review of Doctoral Thesis

1. PhD candidate
Ing. Pavel Čípek / Pavel.Cipek@vut.cz
2. Name of PhD programme
Design and Process Engineering (Mechanical Engineering Design)
3. Title of PhD thesis
The effect of synovial fluid constituents on friction and lubrication of articular cartilage
4. Principal supervisor
doc. Ing. Martin Vrbka, Ph.D. / martin.vrbka@vut.cz
5. Co-supervisor
doc. Ing. David Nečas, Ph.D. / david.necas@vut.cz
6. Reviewer
Anna Neus Igual Muñoz / anna.igualmunoz@epfl.ch
EPFL SCI STI SM
7. Overview of the scope of PhD thesis¹
Evaluate: Very good
The main goal of the PhD thesis is to understand the role of main constituents of the synovial fluid on friction and lubrication of articular cartilage. To do that, an experimental approach was considered by developing a new multi-analytical instrument or tailored biotribology tests. The degradation mechanisms of articular cartilage leading to costly health problems can only be faced by a sound understanding of the involved phenomena during its operation. This requires for a rigorous development of instruments based on the fundamental understanding of the tribological phenomena (in this specific case, friction and lubrication). The candidate took a system approach, considering the whole complexity of the tribological system. The main outcome is the development of an experimental set-up and procedure allowing for testing natural and artificial cartilage under well controlled tribological conditions. The influence of the main synovial fluid constituents on friction and lubrication was described and compared.
8. Significance of the topic and clarity of problem statement
Evaluate: Excellent
The present increase in average age of population leads to variety of health issues, including the mobility ones. In this particular case, the articular joints are a key factor for an appropriate quality of life. A deep

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.

understanding of the involved mechanisms leading the good functioning of those articular joints is a prerequisite for their substitution in case of damage. Friction and lubrication phenomena play a major role in the behaviour of cartilage, guaranteeing the functionality of the joint. This frame is perfectly described in the PhD thesis, highlighting the importance of understanding the influence of the synovial fluid properties (components and concentration) on the biotribological behaviour of the cartilage. The scientific questions to be addressed are clearly stated by the candidate and the methodology rigorously developed to answer them. The relationship between friction and lubrication is clearly stated.

9. Knowledge of existing literature

Evaluate: **Very good**

An extensive knowledge of the existing literature related to the biotribological behaviour of artificial cartilage is shown in the PhD thesis. The state of the art analysing the relationship between the cartilage behaviour and the properties of the surrounding synovial fluid is considered. The in-situ characterization methods are accordingly reviewed. The existing models of friction and lubrication are correctly described. Just the research work carried out by Berthier et al. at INSA Lyon could have been also considered. They have done an interesting work on the interactions between synovial fluid constituents and its tribological behaviour which could be of interest for this PhD thesis. It can be also interesting for the candidate to check the work carried out at AC2T (Wien, Austria) by the group of Manel Ripoll related to the interaction cartilage/metals.

10. Choice of methods and technical soundness

Evaluate: **Excellent**

The complexity of the tribological system considered in this PhD thesis requires for a tailored development of experimental set-ups and methodology which was carried out by the candidate. It consists of an ad-hoc tribometer allowing for an in-situ visualization of the contact area cartilage-synovial fluid through a glass by fluorescence. The whole experimental conception, also includes an image analysis system allowing for the quantification of particles during the tribological tests. The methodology allows for facing the open scientific questions addressed at the beginning of the PhD thesis.

11. Quality, originality and significance of the results

Evaluate: **Very good**

The results show the potentiality of the developed methodology for the deeper understanding the biotribological behaviour of cartilage or other kind of soft materials. They also show the influence of some proteins on the formation of a lubrication film by their influence on the formation of particles within the contact. The set of results also aim at understanding the relationship between the frictional behaviour of the cartilage depending on the lubrication capability of the synovial fluid components. The amount and quality of the results are demonstrated by their publication in international journals.

12. Quality of attached papers

Evaluate: **Very good**

The research work carried out during the thesis was published in one peer-reviewed paper and four papers in journals related to the fields of tribology and materials. The first paper, the most technological one, describes the new experimental set-up, including the description of its validation. In the other papers, the proposed methodology is further developed to understand the role of some components of the

synovial fluid (proteins, hyaluronic acid and phospholipids) on friction and lubrication through the formation of an adsorption film. The results have been also presented in different conferences and other journals.

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

Evaluate: **Very good**

Overall, the work developed in this PhD thesis allows for going one step further in the field of biotribology of artificial cartilage, by the conception of a new experimental methodology including multi-analytical techniques. It is a very relevant work which aims at understanding the influence of specific constituents of the synovial fluid on the friction and lubrication of the cartilage. The complexity of the system requires for a sound development of a new experimental methodology which was set-up in the thesis and appropriately validated. The relationship between the formation of lubrication films, their nature and the presence of particles on friction is studied in a systematic way. Although the considered variables is limited (as must be for a PhD thesis), the potential of the approach is very valuable.

14. Questions and comments

15. Conclusion

PhD thesis is an independent scientific work that presents a novel experimental set-up for in-situ visualization and friction measurements of cartilage contacts allowing for studying tribological systems. The developed instrument and methodology was used for the description of the frictional behaviour and lubrication film formation of artificial cartilage sliding against a glass surface as a function of the lubricant composition (synovial fluid). Influence of synovial fluid constituents on lubrication friction were described in terms of lubrication fluid formation .

YES/NO

16. Date and signature

14/03/2022

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 Prashant K. Sharma / p.k.sharma@umcg.nl
Faculty of Medical Sciences, University of Groningen
7. Overview of the scope of PhD thesis¹
Evaluate:
Justification for evaluation: 100 – 200 words.
8. Significance of the topic and clarity of problem statement
Evaluate:
Justification for evaluation: 100 – 200 words.
9. Knowledge of existing literature
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Evaluate:
Justification for evaluation: 100 – 200 words.

11. Quality, originality and significance of the results
Evaluate:
Justification for evaluation: 100 – 200 words.

12. Quality of attached papers
Evaluate:
Justification for evaluation: 100 – 200 words.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
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Justification for evaluation: 100 – 200 words.

14. Questions and comments

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/NO

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Principal supervisor's final report on the PhD study

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The Effect of Synovial Fluid Constituents on Friction and Lubrication of Articular Cartilage
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5. Co-supervisor
Doc. Ing. David Nečas, Ph.D. / david.necas@vut.cz
6. Stays at other institutions (min. 7 days)
No stays or internships were carried out.
7. Teaching activities
Machine Design – Machine Elements (5KS), Machine Design – Mechanical Drives (6KT), Machine Design Fundamentals (1K), Machine Design (2K).
8. List of main publications
Papers in journals with IF:
ČÍPEK, P.; VRBKA, M.; REBENDA, D.; NEČAS, D.; KŘUPKA, I. Biotribology of Synovial Cartilage: A New Method for Visualization of Lubricating Film and Simultaneous Measurement of the Friction Coefficient. <i>Materials</i> , 2020, 13(9), 1-20. ISSN: 1996-1944.
REBENDA, D.; VRBKA, M.; ČÍPEK, P.; TOROPITSYN, E.; NEČAS, D.; PRAVDA, M.; HARTL, M. On the Dependence of Rheology of Hyaluronic Acid Solutions and Frictional Behavior of Articular Cartilage. <i>Materials</i> , 2020, 13(11), 1-14. ISSN: 1996-1944.
FURMANN, D.; NEČAS, D.; REBENDA, D.; ČÍPEK, P.; VRBKA, M.; KŘUPKA, I.; HARTL, M. The effect of synovial fluid composition, speed and load on frictional behaviour of articular cartilage. <i>Materials</i> , 2020, 13(6), 1-16. ISSN: 1996-1944.

ČÍPEK, P.; VRBKA, M.; REBENDA, D.; NEČAS, D.; KŘUPKA, I. Biotribology of Synovial Cartilage: Role of Albumin in Adsorbed Film Formation. *Engineering Science and Technology, an International Journal*, 2022, 34, 101090. ISSN: 22150986

Papers in SCOPUS indexed journals:

ČÍPEK, P.; REBENDA, D.; NEČAS, D.; VRBKA, M.; KŘUPKA, I.; HARTL, M. Visualization of Lubrication Film in Model of Synovial Joint. *Tribology in Industry*, 2019, 41(3), 387-393. ISSN: 0354-8996.

9. Assessment of the supervision process

Very good

The supervision process followed the pre-set rules for PhD study. The process was based on one-month main meetings and on-demand discussions with supervisor, co-supervisor and colleagues from Biotribology Research Group. The candidate was always well prepared to discuss the issue of the dissertation including reflection of critical comments. The final PhD thesis and research papers were prepared in time and in sufficient quality. The outputs of PhD thesis have been three research papers. The teaching activities of candidate were focused especially on tutorials of courses of Machine Design – Machine Elements, Machine Design – Mechanical Drives and Machine Design Fundamentals. The candidate attended four international conferences where he presented partial results of his research: Engineering Mechanics in Svatka in Czech Republic, 16th International Conference on Tribology - Serbiatrib in Kragujevac in Serbia, 60th International Conference of Machine Design Departments in Hnanice in Czech Republic and 5th International Conference on BioTribology (online - live and on-demand).

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

Very good

The candidate worked independently, based on the discussion with me and my colleagues from the lab and other experts from the field of biotribology, chemistry and orthopaedics. I would like to highlight candidate's efforts in the design and development of a new tribometer that allows for simultaneous measurement of the friction coefficient and visualization of the lubricating film using fluorescence microscopy. The candidate independently designed a methodology of experiments based on the state of the art, performed experiments, and, according to the results analyses, he formulated conclusions. All of the publications, where he is listed as the main author, were prepared by himself. The candidate also supervised three bachelor theses in the field of biotribology and significantly participated in the other research projects of our Biotribological Research Group.

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

Good

The PhD thesis is composed from three papers. One paper was published in the journal in Scopus database ("Tribology in Industry") and the other two were published in the journals with impact factor ("Materials" and "Engineering Science and Technology, an International Journal"). However, the candidate has also co-authored two other biotribological publications in the journal with impact factor ("Materials"). The main scientific output of this thesis is the understanding of tribological behaviour of the model synovial joint. For this purpose, a new simulator has been developed to combine coefficient of friction measurement and visualization of lubricated cartilage contact using fluorescence microscopy. The combination of simultaneous measurement of friction and observation of lubricating film in the model of



synovial joint helps to find answers to some of the scientific questions. E.g.: In which lubrication regime does the synovial joint work? How do the different components of synovial fluid (albumin, gamma-globulin, hyaluronic acid, and phospholipids) affect friction and lubrication of cartilage? I believe that the obtained scientific findings will suite the understanding of cartilage lubrication and the better treatment of osteoarthritis by viscosupplementation. The main weaknesses of the PhD thesis are the lack of a deeper analysis of the results and what it means for up-to-date cartilage lubrication (what lubrication regimes are present) and what it means for cartilage wear (only friction and lubrication were discussed). I also find the thesis lacking a better variability of experiments. Only one component (albumin) of the synovial fluid was fluorescently labelled and observed. Why not gamma-globulin or hyaluronic acid? Is it possible to describe the behaviour of synovial fluid on the basis of labelled albumin alone?

12. Other comments

none

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

16. Date and signature

24/03/2022

Please note

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- 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