INSTITUTE OF MACHINE AND INDUSTRIAL DESIGN

Faculty of Mechanical Engineering
Brno University of Technology

Review of Doctoral Thesis

1. PhD candidate
Ing. Daniel Kvarda / Daniel.Kvarda@vut.cz
2. Name of PhD programme
Design and Process Engineering (Mechanical Engineering Design)
3. Title of PhD thesis
Experimental investigation and numerical modelling of top of rail products

4. Principal supervisor
prof. Ing. Martin Hartl, Ph.D. / Martin.Hartl@vut.cz
5. Co-supervisor
Ing. Milan Omasta, Ph.D. / omasta@fme.vutbr.cz

6. Reviewer
Prof. Roger Lewis/ Roger.Lewis@sheffield.ac.uk
University of Sheffield

7. Overview of the scope of PhD thesis[1]
Very good
The work described in the thesis was focussed on developing a greater understanding of the function of friction modifiers in the wheel/rail interface. A largely unexplored area of wheel/rail interface tribology despite the benefits top-of-rail products can provide. A model that can be used to establish film thickness of a third body material in an interface was developed; a high pressure torsion test and MTM tests were carried out and a creep force modelling approach was presented. This gives a frame work for testing of products and determining characteristics of the friction behaviour that can be fed int, for example, multi-body dynamics models of train performance. The testing approaches were sued to study the impact of varying product amount and constituents. A focus mentioned in the thesis was possible low adhesion with over application. I would have liked to see more about how big a problem this is and some discussion around how much product ends up in the contact and how this varies as product is carried down the track. Thresholds amounts were identified though above which there could be a problem. Effect of particles in the products was seen to play a possible role in this behaviour which added some nice fundamental aspects to the work.

8. Significance of the topic and clarity of problem statement

[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.

Very good
As railway infrastructure owners and train operators seek to reduce maintenance and their carbon footprint greater emphasis is being placed on control of friction in the wheel/rail interface which can help reduce energy consumption and wear and rolling contact fatigue. In order for products applied to the top—of-rail to be optimised and for the right amounts to be applied in an effective way more research is needed on their performance. This is a relatively large gap though in terms of wheel/rail tribology research. The literature review in the thesis very nicely laid out the gaps in the knowledge and the work was designed well to start to fill some of these. A good mix of modelling and experiment, with new techniques, was planned to fulfil some well proposed objectives for the work. As mentioned above, I thought it was odd that so much was mentioned about the risk of low adhesion where you have over application of product. With wayside application there is some risk, but it would have been good to see some indication of what problems have been experienced. This does not detract from the work as this aside, the outcomes are very useful for examining the function of top-of-rail products. I would have liked to see some more discussion around how this might effectively ne scaled up to understand the full-scale contact operation given the simplifications around the lab testing and modelling, the outcomes of the project are a great starting point for this.

9. Knowledge of existing literature
Good
The literature review was good and referred to most of the existing work on performance of top-of-rail friction modifiers. I particularly liked the additional chapter which gave a good criticism of what has been done in the past and identified gaps in the knowledge that formed the basis for the aims and objectives of this work. However, I would have liked to see a bit more on; the different types of products and how their properties give quite wide ranging performance; application of the products – how this is achieved (onboard/wayside); the equipment used; what amounts are applied and where and what is understood about the “carry-down” of product by passing wheels and how the amount of product and hence friction varies along the track. Another aspect that could have been included is the various standards (some admittedly still under development) that exist for this type of product and how the research presented here could help inform those.

10. Choice of methods and technical soundness
Very good
A good mix of techniques was applied in the work for the thesis. Different test rigs and modelling approaches were combined to give a good overall analysis of the performance of the top-of-rail products and to provide tools (in the form of models) to perhaps predict behaviour required of future products as they are designed. The simplifications for the small-scale tests – small contact, low roughness etc. mean that is can be difficult to extrapolate to the full-scale contact. I think for the MTM testing, this is particularly difficult. Even if a product gives a film thickness in an MTM test that separates the contacting surfaces resulting in low friction, will this happen in the real case. This needs a bit more thought, but in the first instance it would be a good way to assess a product’s performance and rank different products. It gives really good control over the test conditions though at a high resolution as well as in the data derived from the tests (e.g. friction) which means it is well suited to assess the effects of subtle changes in product formulation as was seen in the testing carried out. The HPT testing and the parameterisation of the creep force model is great and gives data that can be used in other modelling to assess train performance. It would have been good to see if there was some full-scale data to use to validate the model predictions for film-thickness and friction. This would be a good step for the future.

11. Quality, originality and significance of the results
Very good
The outcomes from the work are very good. Results have been achieved that indicate thresholds for safe amounts of product in the interface; how different formulations of product can vary performance; test methods for effectively assessing different formulations; modelling approaches for assessing film thicknesses and friction and allow predictions for the full-scale contacts based on small-scale inputs. These are all really useful for the rail way industry. There is a large amount of novelty in the work and the outcomes will be useful both for other researchers in this field and engineers in industry.

12. Quality of attached papers
Very good
The papers are very good. They are published in good tribology journals that are largely well read by people in the railway industry as well. It is good to see the international collaboration, although perhaps some indication of the roles the different authors played in the work would have been good. As Daniel is the lead I have assumed he drove the work and pulled in advice where needed.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Very good
Overall this work is very good. The methods used and the outcomes are great. I have mentioned a few limitations as I have gone through the answers above. Most could be dealt with a bit more discussion as some may not all be resolved in a research sense very easily. Having access to full-scale facilities or field data is not easy and is usually expensive for example, but some discussion around transfer of outcomes would be possible.

14. Questions and comments
As I have gone through the answers above I have mentioned a few areas where questions could be asked where the work could have been expanded in terms of discussion etc.: for example, the application of the products and issue over possible low adhesion; test limitations and how they affect scaling to the actual contact. There are also some comments in the pdf of the thesis which I have gone through carefully. This can be passed onto Daniel if appropriate. I am looking forward to the viva.

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	
25/07/2023	

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*

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Review of Doctoral Thesis

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6. Reviewer
Dipl.-Ing. Dr.techn. Alexander Meierhofer/ Alexander.Meierhofer@v2c2.at
Virtual Vehicle Research Center

7. Overview of the scope of PhD thesis[1]
Very good
The thesis uses extensive measurements from a variety of different test rigs to develop and validate a mathematical model. This model is supposed to predict the frictional behaviour in the wheel-rail contact under the presence of different friction modification products. Therefore, it includes a normal contact model, a boundary friction model, an elastohydrodynamic model, an asperity contact model and a temperature model. The used test rigs include an optical ball on disc tribometer, a mini traction machine, torsional rheometer, optical profilometer and a high pressure viscosimeter. The experimental results were used to parametrize and calibrate the model, which then was used to proof certain pre-defined hypothesis regarding the effects of the use of friction modification products.

8. Significance of the topic and clarity of problem statement
Very good
The topic of friction modifiers and their behaviour promises very interesting applications. To know the influence of such a product, or even better to explicitly design it for a given application, would be a very cost effective strategy to reduce maintenance cost. However, these products are not

[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.

nearly as well understood as the literature seems to imply. Especially the dependency of its properties on the composition is very poorly understood. In this thesis, it was tried to investigate the properties of such friction modification products and predict their influence on a real track. While similar models exist in the literature and the ideas behind these is not entirely new, their results were so far only compared to a small sample of friction modification products, compared to the large amount presented in this thesis.

9. Knowledge of existing literature
Excellent
The presented literature research is very extensive and combines a multitude of different areas of research: wheel-rail contact mechanics, rheology, friction modification and tribology. All of these research areas are important as an introduction into the topic and very related to the presented work. They are all well presented in language, structure and readability. For each, a very in detail description was given that combines most of the work done on thesis' related topics. The presented literature was easy to grasp and understand, which is especially important when so many different research areas are presented, and it cannot be assumed that the reader is deeply familiar with all of them.

10. Choice of methods and technical soundness
Excellent
For the measurement part, a multitude of experimental devices was used, most importantly a optical ball on glass tribometers, mini-traction machines and a torsion rheometer. The according laboratory setups and the test rigs were explained in sufficient detail as well as their purpose within the presented study. Next, a mathematical model was created. It contains a normal contact model, a boundary friction model, an electrohydrodynamic model, an asperity contact model and a temperature model. Each of these models was described in satisfying detail. The parameters used in the model were calibrated using the experimental results. Thus, it was possible to test certain pre-defined hypothesis regarding the properties of the friction modification products.

11. Quality, originality and significance of the results
Very good
The work presented in the thesis was done very purposefully, structured and was well thought out. This are indicators of research of great quality. The used experimental devices were mostly standard products, however one device, the torsion rheometer, was self-designed and developed. The mathematical modelling was based on existing literature and, as mentioned in the thesis itself, uses many ideas from there, especially Klaus Six et al. However, the were some modifications to the existing ideas and the way, the ideas are connected is definitely novel. This especially extends to the results themselves because even if similar models did exist in the literature, such an extensive comparison for such a variety of friction modifying products is rare if not unheard of. This will be a good steppingstone for future researchers and hopefully lead to solve some more mysteries regarding friction modification products.

12. Quality of attached papers
Very good

Like the thesis itself, the attached papers are very well structured, use a clear language, are well written and are, thus, of high quality. They go into great length to describe the work related to the thesis, regarding numerical modelling as well as experimental set-up. The first paper, called "Asperity-based model for prediction of traction in water-contaminated wheel-rail contact" focuses on the development of the model, while the other two papers ("The effect of top of rail lubricant composition on adhesion and rheological behaviour" and "Shear properties of top-of-rail products in numerical modelling") focus on the calibration of the parameters of the model.

13. Overall assessment, strengths and weaknesses (based upon the above evaluation categories 8–12)
Very good
As mentioned before, the thesis is very well readable, although it combines a huge number of research areas, as well as including testing and modelling. While some of the experimental devise used are standard products, one of the test machines was created by the author as a novel way to measured certain parameters necessary for the calibration of the model. The model itself is based on ideas that can be found in the paper but with enough modifications and put together in such a way that it can be considered an improvement to previous work. However, the introduction of field tests and a comparison of the model results to such tests would elevate the already impressive thesis additionally.

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

16. Date and signature	
28/07/2023	

Please note

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FME

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Principal supervisor's final report on the PhD study

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Ing. Daniel Kvarda / Daniel.Kvarda@vut.cz
2. Name of PhD programme
Design and Process Engineering
3. Title of PhD thesis
Experimental investigation and numerical modelling of top of rail products

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5. Co-supervisor
Ing. Milan Omasta, Ph.D. / omasta@fme.vutbr.cz

6. Stays at other institutions (min. 7 days)
Southwest Jiaotong University / People's Republic of China / 31/03/2018 / 04/08/2018 Railway Technical Research Institute / Japan / 25/07/2019 / 07/11/2019 Virtual Vehicle Research GmbH / Austria / 01/10/2021 / 31/03/2021

7. Teaching activities
3CD - CAD / 78 1K – Engineering Drawing Fundamentals / 104 2K – Engineering Drawing / 78 ZSY-A – Finite Element Method – ANSYS Classic / 78 ZSY-A – Finite Element Method – Structural Analyses / 58 ZAW – Finite Element Method – ANSYS Workbench / 90 ZAW – Finite Element Method – Advanced Analyses / 70 ZBW – Finite Element Method – Advanced Analyses / 32 ZAP – Analytical Project / 147 ZTR – Tribology / 4

8. List of main publications
Publications related to the topic of this thesis: • KVARDA, D., R. GALAS, M. OMASTA, L.B. SHI, H.H. DING, W.J. WANG, I. KRUPKA and M. HARTL. Asperity-based model for prediction of traction in water-contaminated wheel-rail contact. Tribology International, 2021, 157, 1–11. (IF 5.620) • KVARDA, D., S. SKURKA, R. GALAS, M. OMASTA, L.B. SHI, H.H. DING, W.J. WANG, I. KRUPKA and M. HARTL. The effect of top of rail lubricant composition on adhesion and

rheological behaviour. Engineering Science and Technology, an International Journal. 2022, 35, 1–9. (IF 4.36)
- KVARDA, D., R. GALAS, M. OMASTA, M. DZIMKO, I. KRUPKA and M. HARTL. Shear properties of top-of-rail products in numerical modelling. Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit. 2022, 0, 1–10. (IF 1.87)

Other publications

- GALAS, R., D. KVARDA, M. OMASTA, I. KRUPKA and M. HARTL. The role of constituents contained in water–based friction modifiers for top–of–rail application. Tribology International. 2018, 117, 87–97. (IF 5.620)
- SHI, L.B., Q. LI, D. KVARDA, R. GALAS, M. OMASTA, W.J. WANG, J. GUO and Q.Y. LIU. Study on the wheel/rail adhesion restoration and damage evolution in the single application of alumina particles. Wear. 2019, 426-427, 1807–1819. (IF 4.695)
- SHI, L.B., C. WANG, H.H. DING, D. KVARDA, R. GALAS, M. OMASTA, W.J. WANG, Q.Y. LIU and M. HARTL. Laboratory investigation on the particle-size effects in railway sanding: Comparisons between standard sand and its micro fragments. Tribology International. 2020, 146, 1–12. (IF 5.620)
- REMESOVA, M., S. TKACHENKO, D. KVARDA, I. ROCNAKOVA, B. GOLLAS, M. MENELAOU, L. CELKO and J. KAISER. Effects of anodizing conditions and the addition of Al2O3/PTFE particles on the microstructure and the mechanical properties of porous anodic coatings on the AA1050 aluminium alloy. Applied Surface Science. 2020, 513, 1–10. (IF 7.392)
- LI, Q., B.N. WU, H.H DING, R. GALAS, D. KVARDA, Q.Y. LIU, Z.R. ZHOU, M. OMASTA and W.J. WANG. Numerical prediction on the effect of friction modifiers on adhesion behaviours in the wheel-rail starved EHL contact. Tribology International. 2022, 170, 1–11. (IF 5.620)
- NAVRATIL, V., R. GALAS, M. KLAPKA, D. KVARDA, M. OMASTA, L.B. SHI, H.H. DING, W.J. WANG, I. KRUPKA and M. HARTL. Wheel squeal noise in rail transport: the effect of friction modifier composition. Tribology in Industry. 2022, 44, 361–373.
- LI, Q., S.Y. ZHANG, B.N. WU, Q. LIN, H.H DING, R. GALAS, D. KVARDA, M. OMASTA, W.J. WANG and Z.F. Wen. Analysis on the effect of starved elastohydrodynamic lubrication on the adhesion behavior and fatigue index of wheel-rail contact. Wear. 2022, 510-511, 1–12. (IF 4.695)

9. Assessment of the supervision process

Very good

The supervision process was based on regular meetings with the supervisor, co-supervisor and particularly the research team of the Wheel-rail interface research group. Daniel Kvarda always came up with his own ideas and suggestions for solutions. The supervision of the student was seamless, based on his own initiative and acquired knowledge in the field.
The candidate spent more than 13 months on internships at the world's leading workplaces in China, Japan and Austria. The work at these institutes also contributed to the formation of his PhD work, especially staying at Virtual Vehicle Research Center under the supervision of dr. Klaus Six.

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

Excellent

Daniel Kvarda was a very independent and self-motivated student. The development of the model, which is part of the dissertation, was entirely in the student's competence. Similarly, the design and implementation of the experiments included in the main publications were carried out by the student independently.

The candidate was also involved in projects that were more or less related to the thesis topic. These projects were carried out within a broader research team and Daniel was able to participate very well in team projects and activities. In conclusion, I found Daniel Kvarda a very caring, responsible and individually-minded PhD student with a significant contribution to the development of the research group.

11. Assessment of the contribution that the research makes to knowledge in the field
Very good
In his PhD work, Ing. Daniel Kvarda was investigating the frictional behaviour and low adhesion conditions of the top-of-rail products with the use of a mathematical model and experimental data. He prepared and published three papers as the first author in high-quality journals, namely Tribology International (Q1), Engineering Science and Technology, an International Journal (Q2) and Proceedings of the Institution of Mechanical Engineers, Part F: Journal of Rail and Rapid Transit (Q3). This research presents a novel solution that contributes to the development of more general models that may be of use in the management of rolling stock. Besides the main publications, the candidate is a co-author of 7 papers that also contributes to knowledge in the field of wheel-rail tribology significantly.

12. Other comments
Apart from the research activities, Daniel Kvarda contributed significantly to preparing and teaching the course Finite Element Method - Advanced Analyses (ZAW) and Finite Element Method - Structural Analyses (ZSY-A).

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	
Date:	

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*