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Review

The doctoral dissertation of MSc Eng Jafar Amraei as a collection of thematically linked publications in scientific journals under the collective title - „Thermomechanical fatigue life assessment of polimer-matrix composites under temperature control and different loading regimes"

The review of the work was commissioned by the Chairwoman of the Discipline Council "Mechanical Engineering" of the Silesian University of Technology, Dr. Hab. Eng. Alicja Piasecka-Belkhayat, from March 27, 2025. The supervisor of the reviewed doctoral dissertation is Dr. Hab. Eng. Andrzej Katunin, and the auxiliary supervisor is Dr. Hab. Eng. Dominik Wachl.

1. Characteristics of the work

The fatigue life of structural elements has been analyzed for many years. Moreover, composites have recently been increasingly used in engineering applications. This material is not as well understood as metallic materials. Therefore, the study of thermomechanical fatigue behavior of polymer matrix composites, taking into account the self-heating phenomenon, is ideally placed in the contemporary problems of the strength of modern materials and their practical application. The reviewed work fits perfectly into this issue and allows for a better understanding of the problem. Therefore, the problem undertaken by the PhD student, Mr. Jafar Amraei, MSc. Eng., fits perfectly into such research and analysis. The title of the work reflects the scope of the doctoral thesis well.

The entire doctoral thesis was prepared carefully and distinguished by its almost perfect graphic design. Thanks to this, the work is very easy to read.

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The reviewed doctoral thesis consists of two parts. The first part is the doctoral student's self-presentation written in English, and the second is eight attached publications that are part of the collection of publications. The self-presentation itself is contained on 81 pages.

The second part consists of copies of the following publications:

I. J. Amraei and A. Katunin. "Recent advances in limiting fatigue damage accumulation induced by self-heating in polymer–matrix composites". *Polymers* 14.24 (Dec. 2022), p. 5384.
II. P. N. B. Reis, A. Katunin, and J. Amraei. "Critical analysis of the systems used to reduce self-heating in polymer composites subjected to very high cycle fatigue regimes". *Fatigue & Fracture of Engineering Materials & Structures* 48 (Jan. 2025), p. 1371–1392.
III. J. Amraei, A. Katunin, and M. Lipińska. "Numerical simulation and experimental validation of self-heating of polymer-matrix composites during low-cycle fatigue loading". *International Journal of Fatigue* 188 (Nov. 2024), p. 108510.
IV. J. Amraei, T. Rogala, A. Katunin, A. Premanand, G. Kokot, D. Wachla, W. Kuś, M. Bilewicz, B. Khatri, and F. Balle. "Thermomechanical fatigue behavior of CF/PEKK composite under low and ultrasonic frequencies". *Composites Part B: Engineering* 281 (July 2024), p. 111539
V. A. Premanand, T. Rogala, D. Wachla, J. Amraei, A. Katunin, B. Khatri, M. Rienks, and F. Balle. "Fatigue strength estimation of a CF/PEKK composite through self-heating temperature analysis using cyclic bending tests at 20 kHz". *Composites Science and Technology* 243 (Oct. 2023), p. 110218.
VI. J. Amraei and A. Katunin. "Thermomechanical fatigue life assessment of polymer-matrix composites via entropy-based damage evolution and stiffness degradation under different frequencies". *Composites Part B: Engineering* 298 (Jun. 2025), p. 112353.
VII. J. Amraei, T. Rogala, A. Katunin, I. Barszczewska-Rybarek, J. M. Parente, and P. N. B. Reis. "Synergistic effects of graphene nanoplatelets and carbon nanofibers on thermomechanical fatigue response of modified glass/epoxy composites". Submitted to *International Journal of Fatigue*, Under Review (Dec. 2024).
VIII. J. Amraei, A. Katunin, D. Wachla, and K. Lis. "Damage assessment in composite plates using extended non-destructive self-heating based vibrothermography technique". *Measurement* 241 (Feb. 2025), p. 115670.

Additionally, statements of co-authors on the substantive contribution to individual works have been attached. Based on the submitted statements, one can distinguish the contribution of the doctoral student to individual works and at the same time his/her achievements, which are the basis for applying for a doctoral degree. These works are evidence of the doctoral student's contribution to the development of science, which contribution was synthetically presented, as mentioned earlier, in the self-presentation. The number of co-authors of individual works ranges from two (in two works) to ten. It should only be noted that work VII should not be attached because it has not been published, and is only in the review.

The self-presentation is divided into 7 numbered chapters. At the beginning, there is an introduction, a list of publications concerning the doctorate, a statement of the author's contribution, and a list of important symbols and designations. The self-presentation ends with an unnumbered chapter, References, which contains a list of literature concerning the discussed issue, numbered 126. After the list of literature, there are summaries in Polish and English at the end, which is a good custom. The only thing missing is the Polish title.

The first chapter, entitled Introduction to the Work, summarizes the literature review with a short description of the work's genesis and the thesis, purpose, and scope of the work. According to the reviewer, it would be better if the thesis, purpose, and scope of the work resulted from the literature review and, in a way, the conclusion of this chapter. However, two works that are the basis of the doctoral dissertation (I and II) concern precisely this problem, i.e., the state of knowledge in this field. The second chapter concerns the modelling of self-heating. The next chapter is the analysis of fatigue in various load conditions. The fourth chapter presents the application of various methods for determining fatigue life. The next fifth chapter analyses the use of nanocarbon to increase fatigue life. The next sixth chapter draws attention to using self-heating in non-destructive damage analysis. It should be noted here that all chapters end with valuable conclusions in the last subchapters of the proper chapters. The last numbered seventh chapter presents a summary. It defines the conclusions from the doctoral dissertation, or more precisely, from the self-report and attached publications, which are the basis for applying for the doctoral degree. This chapter presents a summary analysis, draws many conclusions, and provides conclusions for further research, which is very valuable. The Author could distinguish several fundamental conclusions from the work.

2. Opinion on work regarding fulfillment of statutory conditions

2.1. Assessment of general theoretical knowledge

The review of the state of knowledge contained partly in the self-presentation and the attached works I and II allows us to confirm the great understanding of the PhD student in the problems of thermomechanical fatigue of composite materials. The literature review presented in these works is rich, although this issue is relatively new when applied to real structures.

2.2. Assessment of the ability to conduct independent scientific work

The doctoral student demonstrated independence both in terms of preparation and conducting the actual research on composite materials. Although the scientific publications that are the basis of the doctoral thesis are not independent, this does not undermine independent

research. It only demonstrates the ability to work in a team. Only the work where there are as many as 10 co-authors breaks away from this pattern because there are already too many co-authors. Fortunately, there is only one such work in the body of work.

2.3. Evaluation of an original solution to a scientific problem

The presented achievements within the individual chapters indicate, as demonstrated in the characteristics of the work, the scientific contribution of this doctoral dissertation, its innovativeness, and the validity of the undertaken topic. He was able to solve the problem of self-heating of composites. Analyses were carried out for a wide range of fatigue life, i.e., the range of small and large numbers of cycles, despite the very positive review of the doctoral dissertation of MSc Eng. Jafar Amraci, which was written in the characteristics of the work and the most important achievements of the Doctoral Student, I included several doubts in the characteristics of the work, as well as in the comments and questions regarding the work.

3. Comments and specific questions regarding the work

I have included some of my comments in the previous points. Below, I am citing other errors or questions I have noticed:

- In the second chapter of the self-report, bending stresses were mentioned. It should rather be normal stresses from bending. The term used by the Author is incorrect
- In Figures 2.7, 4.3, and 4.5, stress was mentioned. It should rather be the stress amplitude or the maximum value. It is not known.
- Fatigue characteristics, e.g., Figures 3.1, 3.4, 4.4, 4.8, 4.9, 4.10, are presented in the Wohler S - log (N) system. The Basquin log(S) - log (N) system works better here. Why was such a model adopted?
- On page 33 of the self-report, the dynamic Young's modulus was mentioned. Please explain this better. Because fatigue and dynamics are not the same. Dynamics is the impact strength or the effect of high frequency on fatigue. Traditionally, it is assumed that Young's fatigue modulus is equal to the fatigue modulus. For example, in the Ramber-Osgood model.
- Abbreviations are used too often in the work and in individual publications. The use of these abbreviations makes it difficult to read and understand the work quickly. In the reviewer's opinion, there should be significantly fewer of them.

4. General comments and conclusions

From the presented characteristics of the work and the comments or additional questions concerning it, it follows that the dissertation indicates a very wide understanding of the problem posed in the work in the fatigue life of composite materials. In particular, it should be noted that the PhD student used the acquired knowledge and experience to apply his knowledge to analyze composite elements. The few comments in the review may be the subject of analysis in the PhD student's further research and publication activities. They may also be useful in editing subsequent scientific works. It should be noted here that a significant part of the comments are like questions and suggestions for future use, and not a direct criticism of the reviewed dissertation.

The most important scientific and research achievements of the work include:

- Develop a physical model that considers the effect of self-heating on composites subjected to fatigue loads. This model enables simulation of the temperature distribution throughout the material thickness, which is impossible with direct measurement using a thermal imaging camera.

- Introduction of a new, dimensionless, and scalable coefficient based on the concept of heat dissipation rate. This coefficient transfers fatigue test results from those conducted at controlled temperature using an impulse load scheme with forced air cooling to conditions with natural air cooling.

- The scope of application of the heat dissipation rate concept has been extended to determine critical self-heating temperature ranges in conditions that may constitute a damage criterion in future fatigue tests using the ultrasonic method.

- The S-log N curves were developed and verified concerning the standard S-log N curves corresponding to the final destruction. This approach allowed for continuous monitoring of the fatigue degradation process - from the initial damage initiation to the complete destruction - overcoming the limitations of classical assessments based on the S-log N curves.
- Determination of the ability of high thermal conductivity carbon nanostructures to reduce the thermal effects caused by self-heating. This allowed for effective control of the self-heating temperature.
- Development of a two-stage algorithm based on the effective thermogram limit and the maximum temperature ratio. This algorithm allows for systematically selecting the optimal thermogram from a large set for each damage scenario.

After the analysis of the work, the work can be positively assessed in terms of both general theoretical knowledge, the ability to independently conduct scientific work, and finding an original solution to the scientific problem. In addition, it should be noted that the reviewed doctoral thesis is an interdisciplinary work and could be placed in two currently functioning disciplines: Mechanical Engineering and Materials Engineering. Because material issues are treated in the work as a decidedly secondary issue, the work is best placed in the discipline of Mechanical Engineering, as it was sent for review.

5. Conclusion

The entire assessment of the doctoral dissertation allows for the formulation of a conclusion on the sufficient fulfillment of the conditions specified in the Law on Higher Education and Science of July 20, 2018, as amended, and the admission of the dissertation of M.Sc. Eng. Jafar Amraei entitled "Thermomechanical fatigue life assessment of polymer-matrix composites under temperature control and different loading regimes" for the public defense of the doctoral thesis at the Silesian University of Technology in the Discipline of Mechanical Engineering.

At the same time, I am applying for the distinction of the reviewed dissertation, which I hope to confirm after the defense, which is also very important.

Kind regards