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Revision of the Ph.D. dissertation of M.Sc. Torkan Shafighfard

The basis for reviewing the doctoral thesis is: the Act of July 20, 2018, *Law on Higher Education and Science* (Journal of Laws of 2023, item 742), as amended, and the letter of Grzegorz Żywica, Ph.D., Eng., prof. IMP PAN, Deputy Director for Scientific Affairs of the Institute of Fluid Power Machinery No. RN-421-5/24 of January 8, 2024.

1. Layout of work and general remarks

Ph.D. dissertation of M.Sc. Torkan Shafighfard entitled "Diagnostic Methods for Fiber Reinforce Composite Structures with Imperfections" was published as a monograph in English. It contains a summary in this language, a list of publications and conference presentations with the Author's participation, a table of contents, a list of figures and tables and the main substantive part. It has a total of 109 pages, including 101 pages of the main part of the work and a list of 122 publications cited in the text of the dissertation.

Dissertation consists of 6 chapters. In the first Author explains the reason for interest in composite materials. Second chapter presents background for his study and literature review. In the end M.Sc. Shafighfard formulates the thesis of his work. The third chapter presents the method of producing test specimens and their basic experimental tests. The fourth chapter presents the results of the main experimental studies, and the fifth chapter presents the numerical analyses. In the last chapter, the author summarized the results of his research and gave directions for further research.

The problem of diagnostic of composites, especially fiber reinforced is very important and all the time needs new investigations. Scientists and engineers use a lot of methods for detect, localise, and measure imperfections like delaminations, fibre breaking et cetera.

The Author used a few experimental methods – Digital Image Correlation, thermography, and Bragg's gratings. All of these methods have been known for a long time, but they are still very willingly used in complex mechanical tests. During investigations very simple – flat rectangular specimens – have been used, but described methods can be used in different – much more complicated shapes. In analytical-numerical part of the work Finite Elements Method and Machine Learning methods have been used. In my opinion this part of the work is the most important. The problem addressed in the work has not only scientific but also practical applications, which makes it all the more interesting and valuable.

The candidate is also a co-author of numerous articles, which indicates his predispositions to scientific work.

Taking into account the degree of complexity and topicality of the subject matter, I believe that this dissertation may be the basis for applying for a doctoral degree in the discipline of mechanical engineering.

2. Comments on the work

The arrangement of the dissertation is typical and correct, and whole the issue is generally described correctly.

The work does not contain any significant substantive errors, although attention should be paid to some inaccuracies or doubts. Some of these comments are debatable, others may result from too superficial description of some phenomena. Below I present my main comments and questions.

a. General remarks

- In my opinion, the title of the work is too general. It does not indicate the scientific potential of the work, or the complexity of the research performed.
- The main thesis of the dissertation: "It is possible to perform continuous monitoring of loadings and degradation process of FRP composites using SHM and NDT diagnostic methods" is obvious, because such research has been carried out in practice for years. In my opinion, it should be focused on the use of machine learning to predict the possibility of damage.

b. Editorial comments

The work is written in a simple and understandable language with a small number of linguistic errors. Some of the errors related to editing the work are presented below:

- Page 5_9: what does it mean: "totally different s."?
- Fig. 2.9 (page 18): The sensor is completely invisible in the photograph; the connector is dominant. It is a pity that no photograph of the sensor used in the research was included.
- 31_6: The abbreviation for millimetres is mm, not MM.
- 33^4: 1.75 mm is probably the bundle diameter, not a single fibre.
- 33^5: What filament was used? DR3D is the name of a company, not a filament. What was its diameter, probably not 1.75 μm as written in the work?
- Table 3.2, page 33: the fibre density is probably 1.76 g/cm^3, not 176 g/cm^3.
- Table 3.3, page 34: What does it mean "temperature -75°C±180°C"? Prabably should be: "temperature -75°C ÷ +180°C". Similar mistakes below.
- Table 3.4, page 41: no units specified.
- Table 3.5 and 3.6 (page 43 and 45): no error sign (plus or minus).

- Table 4.1, page 53: For unnotched sample HD should be probably "-", not 6 mm. Lack of units in whole table.
- Table 5.1, page 73: Probably an error in the "Length" column. The mean value is less than the minimum, and the std (standard deviation?) is 3 times greater.
- Point "h" below Table 5.1 (page 73): is the 3rd sequence [0, 45, 0, -45, 90, 0] good? It is not symmetrical.
- Equation 5.3, page 76: No limits in the first sum.
- Fig. 5.7, page 91: Different scales in the charts make the analysis of the results very difficult.
- Page 99_1: The title of the chapter should be moved to the beginning of the next page.

c. *Substantive comments*

The comments below have different levels of importance. I have marked in the text which of them the Candidate should refer to during his defence.

- Page 15^{5-7}: The Author writes that such methods as acoustic emission, ultrasonic, eddy current, x-ray can be used for detecting surface-level defects, what is not true. Some of the mentioned methods do not require any surface preparation. The great advantage of many of them is the possibility of obtaining field results. The main disadvantage is the need to place the equipment close to the object under examination.
- Page 19^{9-11}: The quantities mentioned by the author are not physical, but material constants, and may be slightly different for different Bragg gratings.
- Page 32_{2-3}: The Author writes that after integrating the sensor into the sample, the signal amplitude decreased by 50%, and the spectrum shape was not affected. The attached graph shows that there has been a shift in the signal maximum. Please explain this shift and decrease in amplitude (*question to be answered during defence*).
- Page 39_5: Please show in defence presentation what was the layer thickness and whether the sensor was placed in the symmetry plane of the specimen.
- Page 47^{14-15}: The Candidate writes that "It was conducted that the sensors influence on the AM CFRP material is very limited". Graphs on Fig. 3.16 are intended as proof, but they show the results for specimens with the sensor installed. I have not seen any tensile test results for a sample without a sensor anywhere in the manuscript.
- Fig. 3.16, page 47: The Author performed measurements on 5 specimens and there is only one curve on the graphs. Is this a result for one of the samples or an average result? If so, how was the averaging done? Please show the results for all specimens during the defence (the same applies to the results shown later in the thesis). How was strain measured? Using an extensometer or FBG?
- Fig. 3.16, page 47: How will the Author explain such a large difference between the tensile curve for the specimen without and after thermal treatment (*question to be answered during defence*)?
- Tab. 4.1, page 53: The dimensions L, W, T are given with very small measurement uncertainties. Are they correct? How were they measured? It is hard to believe that the

length dimension is maintained with an accuracy of 0.04%. Entering the third digit after the decimal point (dimension T) with uncertainty up to 0.05 makes no sense.

- Page 53, last paragraph: How are holes made in the samples? The technology of making holes in fibre composites has a large impact on their strength.
- Table 4.2, page 55: How were the values of the given parameters measured? Especially in the case of Kirchhoff modules (*question to be answered during defence*)?
- Fig. 4.8, page 63: What were the stress values far from the holes?
- Fig. 4.9, page 64: How were the strains and stresses given in the graphs measured? Using DIC or otherwise? The work lacks maps obtained from DIC. Please include them in your presentation during the defence.
- Thermograms, pages 66-69: An increase of temperature that reaches 20 degrees centigrade during static loading of a carbon composite (a good thermal conductor), seems too high. Is the Author sure that there was no error in the measurements?
- Fig. 4.15, page 71: Figures a and b show different regions of the specimens, so it is difficult to judge whether both types of damage occurred in both cases.
- Fig. 5.1, page 80: The presented diagrams should be explained. Without this, showing them makes no sense.
- Page 55 last paragraph: Analysing the stress range of 6000-8000 MPa does not make sense from a practical point of view. This exceeds significantly the strength of the composite.

3. Conclusions

M.Sc. Torkan Shafighfard carried out research work consisting of an experimental and analytical-numerical part. The obtained results are correct, which confirms the ability to conduct scientific activities. The literature used is relevant and up to date. The submitted dissertation demonstrates the Author's ability to conduct research.

Taking into account the general quality of the dissertation, its current topic, novelty, and the Author's ability to solve an important scientific problem, I declare that the work titled: "Diagnostic Methods for Fiber Reinforce Composite Structures with Imperfections" meets the conditions set out in the Act of July 20, 2018, *Law on Higher Education and Science* (Journal of Laws of 2023, item 742), as amended, and I request that it could be admitted to public defence.