TOMASZ G. ZIELIŃSKI, DSc, PhD, MSc, Eng
Professor at IPPT PAN
Institute of Fundamental Technological Research
Polish Academy of Sciences (IPPT PAN)
ul. Pawińskiego 5B, 02-106 Warszawa
email: tzielins@ippt.pan.pl

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Review of the doctoral dissertation of Ms. ISYNA IZZAL MUNA, MSc, entitled:

DEGRADATION OF ADDITIVELY MANUFACTURED POLYMER BASED COMPOSITES UNDER THERMAL CONDITIONS

Legal basis and subject of the evaluation

The legal basis for this review is the letter No. RN-421-4/24, dated 9 December 2024, sent by Prof. GRZEGORZ ŻYWICA, Director for Scientific Research at the Institute of Fluid–Flow Machinery of the Polish Academy of Sciences (IMP PAN), with a request to evaluate the attached doctoral dissertation in accordance with applicable legal regulations (Ustawa z dnia 20 lipca 2018 r., *Prawo o szkolnictwie wyższym i nauce*, Dz.U. 2023, poz. 742 ze zm.) and generally accepted standards.

The subject of the evaluation is the doctoral dissertation by Ms. ISYNA IZZAL MUNA, entitled ***"Degradation of Additively Manufactured Polymer Based Composites under Thermal Conditions"***. The PhD thesis was written at the Department of Mechanics of Intelligent Structures of the Institute of Fluid–Flow Machinery (IMP PAN), under the supervision of Dr. MAGDALENA MIELOSZYK, DSc, PhD, Eng, Professor at IMP PAN.

The dissertation is a stand-alone monograph, although to some extent based on the studies already presented in 10 publications, namely: six articles from peer-reviewed international scientific journals (*Materials*, *Polymers*, *Transactions of the Institute of Fluid-Flow Machinery*, *Procedia Structural Integrity*, *TASK Quarterly*), three conference papers, and a chapter from the scientific monograph "Selected problems in mechanical engineering 2021" published by the Institute of Fluid-Flow Machinery. Ms. ISYNA IZZAL MUNA is the first author in all these articles except two, and the sole author of the chapter.

Structure of the dissertation

The dissertation has one hundred pages including 'front matter' such as Abstract, Table of Contents, etc., as well as Bibliography containing 105 items. The main part of the dissertation is composed of five chapters.

Chapter 1, "*Introduction*", contains two sections: Section 1.1 entitled "*Problem statement*" and Section 1.2 "*Purpose of the Study*". Strangely, the expected outline of the dissertation is missing. However, the reader can find it much later, at the end of the next chapter.

Chapter 2, entitled "*State of the art*", and in particular Section 2.1 provide a comprehensive review of the literature on the following subjects: modern additive manufacturing technologies known as 3D printing with particular emphasis on the FDM technology (Section 2.1.1), 3D printed composites (Section 2.1.2), damage detection in such materials (Section 2.1.3), and material degradation of additively manufactured composites (Section

2.1.4). In Section 2.2, "*Objective and Motivation*", the main thesis of the dissertation is formulated in an honest and clear way, along with two main goals, which the author calls "sub-thesis 1" and "sub-thesis 2". It is clear that the main objective is to show how the thermal degradation of additively manufactured polymer composites reinforced with carbon fibres can be determined based on the results of dedicated experimental tests and numerical simulations. Chapter 2 also contains a very short Section 2.3, entitled "*Thesis Contribution*". In my opinion, this section could be deleted and its content – after the necessary modifications – could be placed in the section describing the organisation of the PhD thesis, and also added – in a different form – to Chapter 5, where the most important achievements are summarised. I have already stated that the final section of Chapter 2, namely Section 2.4, entitled "*Thesis Organization*", should have been included in Chapter 1.

Chapter 3, entitled "*Experimental Method*", discusses the entire experimental work carried out. This includes design and preparation of composite samples (Section 3.1). All experiments on thermal treatment of the composite specimens are presented in Section 3.2, where continuous and cyclic thermal loads with various (subzero and above-zero) temperatures are considered. Section 3.3 discusses destructive testing of the thermally treated and intact (untreated) samples including tensile tests and differential scanning calorimetry (DSC). Nondestructive testing is presented in Section 3.4. These techniques include scanning electron microscopy (SEM) and optical microscopy. The results of destructive testing as well as morphological analyses of the 3D printed samples using SEM and optical microscopy are discussed in Section 3.5 and the entire chapter is concluded in Section 3.6.

Numerical analyses performed by the author are presented in Chapter 4, entitled "*Numerical method*". In Section 4.2, "*Materials*", the relevant mechanical and thermal properties for the polymer composites reinforced with carbon fibres are determined using the rule of mixtures. Unfortunately, the required properties of composite components were not specified. Finite element simulations of various thermal treatments and tensile tests are discussed in Section 4.3, along with various results of these analyses. In particular, the calculated Young's modulus and tensile strength are confronted with the experimentally determined values. In Section 4.4, the classical lamination theory is used for a similar purpose. Main findings and results of Chapter 4 are concluded in Section 4.5.

The final Chapter 5, entitled "*Conclusions and Future works*", contains two sections. The first of them, entitled "*Conclusions*", summarizes the main findings and conclusions, and also presents a list of the main achievements of the work, which – in my opinion – could have been placed in a separate section. More importantly, however, Section 5.2, entitled "*Future Works*" could be reduced significantly and indicate the perspectives on how the obtained results and developed approach can be used, as well as what is their expected impact on composite materials research. In my opinion, the final chapter should rather focus on the main findings and conclusions, as well as the major work achievements, not on possible future investigations.

General assessment

The doctoral dissertation of Ms. Isyna Izzal Muna is dedicated to current research trends in the field of additively manufactured materials. Not long ago, with the popularisation of the well-known 3D printing techniques, scientists and engineers began to introduce technological modifications to obtain additional functionalities. One of the most important steps achieved so far is the possibility to 3D print composites with carbon fibre (or other) reinforcement. Although such modified additive manufacturing techniques are still in the development phase, there is already an obvious need to investigate the properties of composites produced in this way. Ms. Isyna Izzal Muna's work fits very well into this kind of research, going even further, towards studying the degradation of such composite materials under the influence of different thermal loads.

The PhD candidate carried out impressive experimental work. This involved manufacturing of a large number of polymer composite samples reinforced with carbon fibres. The samples were 3D printed using a modified FDM printer[1] during the author's internship at Kaunas University of Technology (KTU) in Lithuania. The experimental tests carried out by the PhD candidate on 3D printed composite samples included: thermal treatment

[1] The FDM printer itself was modified at KTU according to the original design.

under various cyclic and constant temperature conditions, non-destructive testing (using optical and scanning electron microscopes), and destructive testing, namely differential scanning calorimetry and tensile modulus and strength tests. The results obtained during these experimental studies, and in particular the correlated observations of mechanical and morphological changes induced by different thermal treatments, are important and can be very valuable to the scientific communities dealing with additive manufacturing of composites and mechanics of composite materials.

Also commendable is the undertaking (in Chapter 4) of the difficult task of modelling the complex physical phenomena related to the issues studied experimentally. It seems that this attempt was also successful, as the modelling predictions of the key results obtained experimentally (such as tensile strength and Young's modulus) are basically correct. However, the overall presentation and discussion of the simplifying assumptions and models used is not clear and therefore not very convincing. This is only partly due to the poor quality of the English language and style of Chapter 4.

Major critical remarks

• **It is not clear how the influence of thermal loads on the material properties of the composite components is realised in the modelling.** Numerical simulations should replicate the actual experimental routine. In the case of a thermally treated composite, a thermal step (i.e. heat transfer in the representative volume element of the composite) is first performed. The outcome is the temperature distribution, or to be more precise, its change over time in the composite components. If am not mistaken, the mechanical properties of the components and maybe also the composite structure (e.g. the fibre-matrix interface) are to be modified according to that temperature variation, taking into account, for example, whether and how often the glass transition and cold crystallization points were reached in the polymer matrix. These modifications should be performed using some physical models depending on temperature or its cyclic change. What are these models? How are they implemented? The modified properties of components (and/or composite structure) are used for the mechanical simulation to calculate, e.g. the effective Young's modulus for the entire composite (modified by thermal treatment) using the well-known averaging procedures. It should be clearly stated which material properties are changed under the influence of thermal loads. Is it Young's and shear moduli of each component? Or maybe also thermal capacity and conductivity of each material? In the second case, this would obviously have an impact on the thermal analysis itself.

• **What about coupled thermo-mechanical analysis?** Thermal loads induce thermal strains and stresses in the composite that are non-uniform due to the different properties of the components, in particular, different thermal expansions. This may lead to various physical damage such as shrinkage and deformation, cracking, delamination, as discussed by the author in Chapter 3. All this suggests that a thermo-mechanical analysis should possibly be the first step of the entire simulation. It is not clear whether this is the case here. **Has such a thermo-mechanical analysis been considered?** The results of such analysis could additionally include, e.g. the internal deformation of the thermally-treated composite after cooling to the temperature at which the tensile test is performed. Then, a purely mechanical step, i.e. tensile test simulation, could take into account the initial strains and stresses induced in the composite components.

• **Has thermally-induced chemical damage, such as de-polymerisation and de-bonding (on the fibre-matrix interface), been implemented in any way in the modelling?** I realise that this is not an easy task and adopting rational exclusionary assumptions most probably turned out to be the only possible solution. However, this should be clearly stated.

• **A detailed discussion of the issues raised above should appear in Chapter 4 of the thesis.** Even negative answers to questions that I ask are valuable because they indicate what is important and what can be omitted in the modelling. The agreement between the measurement results and numerical simulations given in Table 4.3 (for Young's modulus) and Table 4.4 (for tensile strength), as well as in Table 4.5 (for both) is good. The author also correctly identifies possible causes of discrepancies. **However, all this would be more convincing if all modelling assumptions and procedures were more clearly and comprehensively explained.**

• **The English language and style of the manuscript, as well as the overall quality of the text are poor and significantly reduce the quality of the work. All these elements require significant improvement and corrections to meet publication standards.** Incidentally, Chapters 1 and 5 (i.e. the first and the last) are written in correct English, indicating careful writing and proofreading. Why wasn't this done for the other, main chapters of the dissertation? Due to linguistic deficiencies including grammar and style, it is difficult to read the text in many places in Chapters 2, 3, and 4, or even fully understand the message in several cases. **Moreover, the author seems to have difficulty mastering the entire text of the dissertation; in particular, there are far too many repetitions.** It looks like the author combined the text from various parts prepared earlier, which is of course allowed, but did not remove the repetitive content. There are even entire identical sentences, repeated one after another, or in the same paragraph. **The text and typesetting of the manuscript are in many places sloppy.** There are references to missing sections and figures. A few symbols used in equations or in the text are defined more than once, while others are not defined at all! Abbreviations are constantly and repeatedly introduced instead of being used. Most of the detailed comments below address these linguistic and editorial flaws of the manuscript. However, this is by no means a complete list, but rather a list of representative examples of many similar errors[2].

Minor remarks

The title of the dissertation correctly reflects its content, although it does not mention carbon fibre reinforcement. Certainly for the sake of conciseness, as shorter titles usually sound better. However, the title could start with the term "Thermal degradation" instead of "Degradation", so that the final part of the title, namely "under thermal conditions", could be replaced with the additional information about "carbon fibre reinforcement". Incidentally, in my opinion "degradation under thermal loads" sounds better than "degradation under thermal conditions" although both expressions are commonly used. Finally, the term "polymer based" could be written with a hyphen, as "polymer-based".

I find the use of the word "method" in the titles of Chapters 3 and 4 rather unfortunate, although its plural form would be acceptable in the case of a concise journal article. In Chapter 3, entitled "*Experimental method*", the author does not present a specific experimental method, but the entire experimental research. Of course, this involves a description of the experimental procedures and – what is more important – a discussion of the results obtained using the well-established experimental methods and measurement techniques. Therefore, the correct title for this chapter should be "*Experimental investigations*" or "*Experimental research*", etc. Similarly misleading is the title "*Numerical method*" given to Chapter 4. Keeping with the author's concise style, an appropriate title for this chapter could be, e.g. "*Numerical studies*" or "*Numerical simulations*".

Detailed comments

Pages i-vii and i-vii: The title page, Acknowledgements, Abstract, Publications, and a quote page appear sequentially and are numbered from 'i' to 'vii'. Then, page numbering with Roman numerals restarts, so that Table of Contents, List of Figures, List of Tables, and Abbreviations appear on *new* pages i-vii. This should be corrected to viii-xiv, so that the page numbering with Roman numerals is continuous.

Abbreviations

Page vii, Abbreviations: The acronym CLT is explained as "composite laminate theory", while it should rather be: "classical lamination theory". Incidentally, the correct name is mostly used in the text of the manuscript.

Page vii, Abbreviations: FDM – which stand for "fused deposition modelling" – is a trademarked term introduced by one of the 3D printer manufactures. This term has gained enormous popularity. An alternative, although less popular abbreviation, FFF, which stands for "fused filament manufacturing" is a more general

[2] I provide a PDF document of the manuscript, containing a much larger number of my comments and suggested corrections.

term used to describe the same technological process. Many authors and institutions now propose using FFF and "fused filament fabrication" instead of the popular trademarked term.[3]

Chapter 2

Page 19, Section 2.1.4: Change the word "additive" to "additively" in the title of this section.

Page 19. Quote: "*In section 1.4. it has been briefly described...*"
Comment: There is no Section 1.4!

Page 19. Quote: "*Previously, in section 1.5...*"
Comment: There is no Section 1.5!

Page 21. Quote: "*the material degradation effects on the stress state*"
Comment: Change "effects on" to "affects" or "has an impact on".

Page 22: There are redundant comments on this page.

Page 24. Quote: "*The characterization of the morphological structure will be investigated to reveal the porosity, defects, and damage within these structures by performing NDT methods.*"
Comment: Improve the style, e.g.: "Morphological characterization is performed using NDT methods to detect porosity, defects, and damage in the manufactured composite structures."

Page 25. Quote: "*The 3D model of the CFRP specimens was created in a CAD (computer-aided design) package, which was exported as an STL file*"
Comment: The CAD model was exported, not the CAD package! Correct this sentence.

Page 25. Quote: "*The layer height is set to have four layers for each printed specimen, and an extrusion multiplier is used to control the constant amount of filament content.*"
Comment: Not clear. Correct the grammar and meaning of this sentence.

Page 27. Quote: "*The approximately carbon fiber content in the matrix was calculated by the tool-path length of the specimen and it can be measured as the weight ratio of carbon fiber to composite specimen.*"
Comment: I suppose the fibre content is calculated with respect to the entire composite volume or weight, not that of the matrix alone.

Chapter 3

Page 25, Chapter 3: Change the title "Experimental method" to e.g. "Experimental investigations". See comment in the first part of the review.

Page 29: Unnecessary reintroduction of some definitions and terms (e.g. thermal damage defined in Section 3.2 has already been introduced in Chapter 2). State-of-the-art to thermal degradation is partially repeated at the beginning of Section 3.2.

Page 29: Unnecessary repetitions! Check, for example, the last two paragraphs on this page. The first one could be deleted.

Page 32. Quote: "*Thermal cycling can cause fatigue failure, which is a gradual kind of local damage [71]. The process of thermal cycling can lead to the onset of fatigue failure, which is a sort of gradual local damage.*"
Comment: The second sentence repeats the message of the first sentence. Delete one of them.

Page 30. Quote: "*If a prolonged dwell time is employed, the duration of the test will lengthen until the number of cycles is decreased.*"
Comment: Change "until" to "unless".

[3]Consider using FFF instead of FDM. Personally, I am not against using the abbreviation FDM., however, the currently recommended abbreviation FFF should be preferred.

Page 33: Figure 3.5 is referenced (at the top of page 33) before any reference to Figure 3.4. Perhaps Figure 3.5 should appear before Figure 3.4.

Page 33: There is no reference to discussion taken for the work by Ghasemi et al. Please, add Ref. [71] after "Ghasemi et al."

Page 33: It was reported that the condition of thermal cycling leads to a decrease in the residual stresses and an increase in the failure index. What condition?

Page 33: Add Ref. [71] after "Zhang et al."

Page 33, Figure 3.5: Add "B" over the cooling part of the cycling profile in Figure 3.5.

Page 36. Quote: "*The tensile modulus and strength values of the CFRP specimens were calculated by Equation 3.1 and Equation 3.2, respectively.*"
Comment: Actually, it's the opposite: Eq.(3.1) is used to calculate the tensile strength, while Eq.(3.2) is used for the tensile, i.e. Young's modulus.

Page 37. Quote: "*Tg value difference after the second heating run could be insignificant whereas Tm and Tc value difference could be very distinct difference in their respective values between the two runs.*"
Comment: Improve the style of this sentence.

Page 39. Quote: "*A DSC equipment (TA Instruments Q2000) was used to perform thermal analysis*"
Comment: This has already been said at the beginning of this section!

Page 39. Quote: "*The sample for each thermally treated group was chopped into small pieces to fit inside the pan due to the stiffness of the fiber-reinforced raw filament. There were 5 groups of printed CFRP samples for various thermal treatments as summarized in Table 3.3. The prepared samples were measured with a precision scale. About 10 mg of sample from each treatment group was placed in an alumina hermetic pan and inserted into the DSC cell. A nitrogen atmosphere was supplied to the test chamber at a flow rate of 50mL/min for the cooling process while an electrically heated furnace is used for heating.*"
Comment: Very poor English, but I have already corrected very similar sentences. The same thing has already been mentioned on pages 36-37!

Page 39. Quote: "*The measurement for each sample consisted of two times of the heating process and one time of the cooling process. The following program was used: hold equilibrium at 24C, ramp at 10C/min to 200C, hold isotherm for 2 min, ramp at 10C/min to 40C, hold isotherm for 2 min, and ramp back at 10C/min to 200C.*"
Comment: Another repetition! I think this information has already been provided on page 37 when referring to Table 3.4.

Pages 39-40. Quote: "*The glass transition temperature is commonly abbreviated as Tg.*"
Comment: This symbol appeared already many pages ago and has been used frequently since then. Why repeat this here?

Page 40: The information from the last paragraph of section 3.3.2 should be moved to the beginning of this section.

Page 40, Section 3.4.1: Change the title of this subsection from "Scanning Electron Microscope" to "Scanning Electron Microscopy". In this section the author refers to the NDT technique and what it was used for, rather than to the equipment used for this test.

Page 40. Quote: "*... to evaluate the microstructure of specimens due to thermal treatment.*"
Comment: Improve the style to clarify the message, e.g.: "... to evaluate the microstructure of the specimens and in particular its change due to thermal treatment."

Page 40, Section 3.4.2: Change the title of this subsection from "Optical Microscope" to "Optical Microscopy". In this section the author refers to the NDT technique and what it was used for, rather than to the equipment used for this test.

Page 40. **Quote:** "*... to evaluate the macrostructure of specimens due to thermal treatment.*"
Comment: Improve the style to clarify the message, e.g.: "... to evaluate the macrostructure of the specimens that underwent thermal treatment."

Page 44. **Quote:** "*This mechanical degradation is consistent with the DSC findings, where reduced thermal stability (lower Tg) and altered crystallinity were observed.*"
Comment: I think this will be shown in the next Section 3.5.2. Maybe this conclusion should rather appear there.

Page 48, Figure 3.15: Figure 3.15 from page 48 should rather appear earlier on page 45 or 46.

Page 46: The discussion on page 46 should clearly refer to the specific graphs (a), (b), (c), ..., or (f) in Figure 3.15.

Page 46: There is a lot of repetition here (although written in correct English). I suggest less repetitions and more discussion on DSC curves shown in Figure 3.15 (page 48).

Page 50: The paragraph title "Scanning electron microscopy (SEM)" should be numbered as subsection 3.5.3.

Page 50. **Quote:** "*The effect of thermal treatment with cyclic and prolonged temperature on the 3D-printed CFRP specimens caused morphological changes*"
Comment: To say that "the *effect* of A caused B" is stylistically incorrect. Improve the style, e.g.: "Thermal treatment caused morphological changes..." or "The effect of thermal treatment is morphological changes...".

Page 50. **Quote:** "*The polymer structure of the untreated sample structure displays an intact and undamaged structure.*"
Comment: Improve the style of this sentence.

Page 51, Caption to Figure 3.17: **Quote:** "*SEM photos of the untreated and treated specimen group following destructive tensile testing.*"
Comment: Improve the language, style and message of this caption. I suggest the following modification of this caption: "SEM micrographs of the untreated and treated composite samples before (left) and after (right) tensile testing. The micrograph of the intact sample is shown in the middle."

Page 52. **Quote:** "*the prolonged temperature at -20C (CS-B) created some noticeable gaps in the fibers*"
Comment: I think the author means "gaps *between* the fibres" (not *in* the fibres).

Page 54, Table 3.7: Table 3.7 appears on page 54 but is not mentioned anywhere in the text. It should be referred to in one of the last paragraphs of Section 3.5.

Page 56, Section 3.6: **Quote:** "*In these conclusions, the contents of some of the graphs and Figure 3.16 are revisited, though they have been discussed earlier.*"
Comment: The author tends to repeat (almost *in extenso*) many observations discussed in the previous sections of this chapter, while the main conclusions drawn from these observations are rather expected here. The main findings can also be recalled, but should be stated in a much concise manner.

Page 54. **Quote:** "*Compared to the homogenization methods where the elastic properties of the microstructure are obtained solving the microstructural problem.*"
Comment: I think that "the elastic properties of the *microstructure*" are in fact "the effective elastic properties at the *macro*-scale level".

Chapter 4

Page 56, Chapter 4: Change the title "Numerical method" to e.g. "Numerical studies" or "Numerical simulations", etc. See my comment in the first part of the review.

Page 56: There is a reference to Figure "??" The figure (or its number) is missing.

Page 56: The first paragraph on page 56 compares some numerical and experimental results referring to the non-existent Figure. It looks like this discussion should appear later in this Chapter and was only accidentally placed in Section 4.1 "Introduction". Maybe it was simply copied from the cited works and the mentioned "Figure ??" is simply a figure from the cited work.

Page 56: The second paragraph on page 56 repeats very general information about AM techniques and their impact on the development and production of carbon-reinforced composites. This paragraph seems to have been taken from the beginning of the previous chapter. I see no reason to repeat these general statements here! A similar thing can be said about the third paragraph on page 56.

Page 58. Quote: "*Based on the iso-stress model...*"
Comment: Consider changing this to: "Based on the iso-stress assumption..." (or "condition").

Page 58. Quote: "*uniform fiber dispersion*"
Comment: Replace the word "dispersion" with "distribution".

Page 58, Table 4.1: The material properties of the composite components (polymer and fibres) should also be provided in this table. Check the density value. Incidentally, the unit should rather be [kg/m^3].

Page 59: It seems that "the basic assumptions considered in the thermal case" are rather for mechanical (or thermo-mechanical) analyses.

Page 59, Table 4.2: The material properties of the composite components (polymer and fibres) should also be provided in this table. The coefficients α_{11} and α_{22} are not explained in the text nor in the table caption. Only from the unit it can be concluded that these are thermal expansions.

Page 59, Section 5.9: The first paragraph is an unnecessary repetition of information from previous sections and chapters!

Page 60: I believe that the label "[meiro2016]" that appears at the end of the second sentence on this page is a reference to a work in the Bibliography. This should be a number. Please, correct this.

Page 61, Equation (4.4): The undefined symbol N appears in this equation. I think that N can be eliminated if $N = 1$. If $N \geq 1$, it should be clarified – either below or above equation (4.4) – that N is (as I suppose) the number of fibres in the unit cell.

Page 61: Correct the font and spacing in the last sentence on this page Incidentally, in this case when $f = \pi/4$, the fibres touch each other.

Page 62. Quote: "*The meshes generated with the size of 14.3 are all converged.*"
Comment: The size of what? What unit?

Page 64. Quote: "*The sample model's boundary conditions are determined by how it interacts with its external surroundings in order to accurately represent the physical phenomena of the experimental setup, which may insulate the edges.*"
Comment: It's very difficult to understand this sentence. I think it should be as follows: "The boundary conditions of the specimen model were set to accurately represent the physical phenomena of the experimental setup, which may require thermal insulation at the specified boundaries." Am I right about the thermal insulation? On what surfaces (boundaries) is it applied?

Page 65, Caption to Figure 4.4: Change "(left)" to "(top)" and "(right)" to "(bottom)".

Page 65. Quote: "*The boundary conditions for tensile test simulation are set to be fixed or clamped (encastred) in all directions in the lower grip, and free in the direction of the applied load in the upper grip (unconstrained in the longitudinal direction).*"
Comment: Improve the style and correct this sentence. The surface load is a boundary condition of the Neumann type. When it is applied, the Dirichlet boundary condition, such as constrained displacement in this direction, cannot be applied at the same time. On the other hand, if the load is not zero, it is not the same as the so-called free boundary condition.

Page 65. Quote: "*When a simple structure, such as a composite plate, breaks due to applied forces, it fails fast because the load increases as the structure's load carrying capacity falls. When a mechanical force applied to a thin composite plate causes it to break, the structure fails relatively quickly because the load increases as the structure's load-carrying capacity decrease.*"
Comment: These are two sentences conveying the same information!

Page 68, Caption to Table 4.3. Quote: "*Young's modulus with FEM modeling.*"
Comment: I suggest to change it to: "Young's modulus: experimental results compared to FEM modelling."

Page 68, Caption to Table 4.4. Quote: "*Tensile strength with FEM modeling.*"
Comment: I suggest to change it to: "Tensile strength: experimental results compared to FEM modelling."

Page 68. Quote: "*The mechanical properties from both microscale and macroscale overestimate the experimental result.*"
Comment: In general, but not always. Note that macro-scale calculations underestimate the Young's modulus in the HS-B and CC-A cases, see Table 4.3.

Page 69, Section 4.4: I suggest changing the title of this section from "Classical Laminate Theory" to "Analysis using Classical Lamination Theory".

Page 69, Equations in Section 4.4: Number the equations in this section. Explain the symbols "κ" (curvature), "z" (distance from the midplane), etc.

Page 71. Quote: "*The stress and strain values obtained from CLT computation at global and local coordinates are the same since the laminate consists of unidirectional plies (0/0)s. Thermal stress induced after the thermal loading was calculated by subtracting the final temperature of the sample from the curing temperature (where the room temperature occurred). The stress and strain values obtained from CLT computation at global and local coordinates are the same since the laminate consists of unidirectional plies (0/0)s*"
Comment: The first and third sentences in this quote are identical!

Page 71. Quote: "*. . . between numerical and experimental results (Young's Modulus)*"
Comment: Change to ". . . between numerical and experimental results (Young's modulus and tensile strength)".

Chapter 5

Page 73, Chapter 5: I suggest to change the title "Conclusions and Future work" to (simply) "Conclusions". It can also be called "Conclusions and perspectives" or (after creating a separate section with major work achievements): "Conclusions, major achievements and perspectives". The final chapter should focus on the main findings and conclusions, as well as the major work achievements, not on possible future investigations.

Page 75, Section 5.2: I strongly suggest shortening this section. The title could also be changed from "Future works" to e.g. "Perspectives" or "Research impact and perspectives". Furthermore, the reduced version of this section should rather indicate how the obtained results and developed approach can be used and what is their impact on composites research. See the previous comment.

Conclusions

In the reviewed doctoral dissertation, an original approach combining extensive experimental studies with numerical simulations was used to assess thermal degradation of additively manufactured polymer composites reinforced with carbon fibres. This is a very timely scientific problem in the field of composite materials and modern manufacturing technologies that can be used to produce them. The results and scientific discussions presented by Ms. ISYNA IZZAL MUNA in her dissertation show that she is capable of conducting complex scientific research independently, albeit experimental work seems to be her speciality. They also demonstrate the PhD candidate's general knowledge in the field of mechanical engineering.

The main achievement of the work is the consistently conducted experimental research, which allowed to achieve many valuable results through original studies combining experiments with theoretical considerations. This original research included in particular:

- construction of the measurement stands for analyses of the impact of thermal loads on additively manufactured polymer composites with carbon-fibre reinforcements;
- modification of the existing test stand for tensile testing to accommodate additively manufactured composite samples, ensuring reliable and precise measurements;
- comprehensive analyses of thermal degradation processes in additively manufactured composite samples using non-destructive testing techniques as well as destructive methods. These analyses provided detailed information on the effect of thermal treatments on changes in structural integrity and mechanical properties of the tested composites. They revealed important information about morphological modifications and the onset of damage mechanisms.

The experimental investigations allowed to successfully identify the dominant types of degradation processes, as well as the main degradation mechanisms (such as increased embrittlement and matrix cracking) that occur in additively manufactured composites following specific thermal treatments, leading to significant changes in their material properties. This was achieved by correlating the observed mechanical and morphological changes with different thermal conditions.

Taking on the ambitious task of numerical analyses aimed at simulating the complex phenomena of composite material degradation under thermal loads is also praiseworthy, even though the main critical remarks raised in this review are specific to that part of research and should be addressed.

I conclude that the work by Ms. Isyna Izzal Muna meets the formal and customary requirements for doctoral dissertations, in particular, those specified by the applicable law (Ustawa z dnia 20 lipca 2018 r. *Prawo o szkolnictwie wyższym i nauce*, Dz.U. 2023, poz. 742 ze zm.). Therefore, I recommend its admission to subsequent stages of the doctoral-degree procedure, including a public defence.

Dokument podpisany przez
Tomasz Gracjan Zieliński
Data: 2025.02.11 15:43:41
CET

Tomasz G. Zieliński