Dr hab. inż. Grzegorz Lesiuk, prof. uczelni
Politechnika Wrocławska we Wrocławiu
Wydział Mechaniczny
Katedra Mechaniki, Inżynierii Materiałowej
i Biomedycznej ul. Smoluchowskiego 25,
50-370 Wrocław

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REVIEW

of the doctoral dissertation **by Benard Kiptoo Kipsang, M.Sc.**
entitled "*Assessment of fracture development in thick-walled elements of power boilers after long-time operation*"

Identification description: computer printout with the rights of a manuscript, 146 pages, 183 references.
Doctoral thesis supervisor: Krzysztof Wacławik, PhD. DSc., Prof. Pol.Śl.
Co-supervisor: Prof. Wim De Waele, PhD
Contractor: Chairman of the Discipline "Materials Engineering" at the Silesian University of Technology - Prof. Adam Grajcar, PhD DSc., Eng., letter-resolution dated July 1, 2025.

GENERAL ASSESSMENT OF THE DISSERTATION: TOPIC, PURPOSE, AND SCOPE OF WORK

The doctoral student Benard Kiptoo Kipsang set the goal of researching degradation phenomena in metallic materials used in the energy sector. One of the most important issues addressed by the doctoral student is to explain the phenomena occurring during the exposure of the material to various environmental and temperature conditions including creep phenomenon. The subject of the doctoral student's research was materials from existing pressurized structures and components, i.e., the research was conducted on actual steel parts with over 100,000 hours of operation in order to assess their resistance to cracking. As a Reviewer, I consider the selection of this topic to be appropriate and scientifically important. It should be noted that this topic is important not only from a scientific point of view, but also from an industrial one. The author of the dissertation set the research goal of investigating and understanding the impact of aging caused by long-term operation on the fracture resistance of low-alloy steel in power boilers. A valuable contribution (generally in doctoral dissertations) would be to formulate a research hypothesis that would allow the author's scientific arguments to be organized logically. This is not a criticism, but a suggestion for the future. Nevertheless, given the generally formulated objective of the dissertation, I consider the selection of research methods and tools described in the subsequent chapters of the dissertation to be appropriate. In my opinion, this dissertation tackles a difficult and complex topic and is an important bibliographic reference for other researchers. The structure of the dissertation is correct and typical for this type of study. The work consists of seven chapters and a bibliography of 183 items.

In *Chapter 1*, entitled ***"Introduction, Aims and Objectives and Scope,"*** the author outlines the origins and purpose of the work, presenting the main themes of the dissertation. What is missing here is a clear research hypothesis, which should be the guiding theme of the dissertation. I consider the purpose of the work to be appropriately chosen and ambitiously defined.

Chapter 2 describes the current state of knowledge. In my opinion, this chapter is important and organizes the state of the issue, presenting the theoretical framework used in the dissertation. The history, theoretical basis, and experimental methodology used in research on fracture resistance under flat constraint conditions are discussed. A brief overview of ferritic-bainitic (pearlitic), martensitic, and austenitic steels used in pressure components of power boilers is presented, including an overview of their properties and historical development.

Chapter 3 presents an analysis of the relationships between fracture resistance, steel aging, and geometry, describing changes in fracture resistance in two parts with different operating parameters and geometric dimensions (valve and pipe sections). Both experimental and numerical methods were used.

Chapter 4 presents a comprehensive experimental program investigating the behavior of steel under complex load conditions (mode I+III in the sense of fracture mechanics nomenclature). The influence of the crack inclination angle on fracture toughness was investigated, and the sensitivity of the crack inclination angle to fracture under complex mechanical loading conditions was analyzed.

Chapter 5 presents the results of fracture toughness tests using the CTOD parameter to investigate the effect of short-term thermal creep on fracture toughness. In addition, mechanical tests were conducted and the results discussed, taking into account, among other things, the effect of aging on the results obtained in the impact test on Charpy V-notched specimens, and a microstructure analysis was performed.

Chapter 6 examines the relationship between fracture toughness and steel aging. Accelerated isothermal aging and accelerated creep aging techniques are presented. The effect of material degradation on plastic tear resistance is described.

Chapter 7 summarizes the work, presenting key conclusions and recommendations for future research.

In the reviewer's opinion, the issues raised are important and scientifically relevant. The work is written in correct language using appropriate research methods. However, reading the work raises a number of ambiguities and questions of a scientific nature that should be clarified. These issues will be discussed in detail in the next section of this review.

COMMENTS ON THE DISSERTATION, CRITICAL QUESTIONS, AND DISCUSSION ISSUES

The dissertation is written in correct, understandable language and shows a decent level of editing—no major flaws were found, and some of them are presented later in this review. The rich graphic documentation deserves special mention.

The doctoral student deserves praise for the selection of literature – it includes not only the latest publications, but also earlier publications that are important for this area of research. Of the 183 items, the vast majority are publications in English. This reflects the current requirement to publish in English.

In the reviewer's opinion, the dissertation stands out due to its difficult subject matter and the use of modern interdisciplinary research and analytical tools.

The dissertation presents an original and comprehensive approach to the subject, which is undoubtedly a scientific achievement of the doctoral student. Reading the doctoral dissertation also raises a number of questions and issues for discussion, which are presented below.

Critical remarks and comments:

1. The aim of the work is too general; it might have been worth specifying it in more detail—presenting and indicating what specific physical properties the author has in mind. The lack of a thesis statement increases the feeling that the subject matter and aim are too general.
2. On page 1, there is information that until 1960 (and Irwin's work), there was no explicitly formulated criterion for fracture analysis. This is not true – the author has ignored the important and fundamental role of A.A. Griffith (***Griffith, A.A. (1920)*** *The Phenomena of Rupture and Flow in Solids. Philosophical Transactions: Royal Society, London, Series A, 221, 163-19*), who introduced important energy considerations and initiated the science known as fracture mechanics. This may not be the most important comment in this review,

but out of respect for this researcher, it should have been mentioned and correctly described.

3. Whenever the author presents the results of materials in a post-service condition, the question arises as to whether any non-destructive testing (NDT) was performed to rule out any defects resulting from service that could affect the results obtained.
4. Why did the author, despite his well-informed knowledge of the literature and fracture mechanics, decide in Chapter 3 to use the force criterion, i.e., K_{IC} , for fracture resistance instead of CTOD or the J-integral? For such a ductile material, it was easy to predict from the outset that it would be difficult to meet all the requirements of the standard, especially in terms of ensuring a plane strain conditions, and the results obtained confirmed that this was not the case.
5. Did the material data used in the simulations (such as Table 9) come from your own research? If so, why are there no results? If not, what is their source?
6. What is the purpose of the simulation results presented in Figures 27 and 28? The values of stress intensity factors are well known and described for the geometries presented, as the author also mentions in the dissertation.
7. I am not convinced about the correctness of the K_{IC} nomenclature (Table 13) derived from numerical analyses. K_{IC} is determined experimentally under strictly defined conditions. Therefore, arbitrary use of this concept leads to a number of inaccuracies. I would suggest calling this quantity the "*critical stress intensity factor.*" Please comment on these results and explain their purpose. Was the aim to match the results to the experimental data or vice versa? What role were these results supposed to play in assessing fracture resistance?
8. Page 57 – the presented results of fractographic tests require (this is a general comment on the entire work) improvement and more extensive discussion. Namely: fracture analyses should be conducted with an indication of the locations/areas of analysis. In the notch zone, fracture initiation, propagation, and static tearing (for example). Only then can we draw the appropriate conclusions. In the analyzed case, the author selectively chose locations for his own purposes and discussed these results in relation to the data obtained. Page 57 – Why were fracture studies not performed using scanning electron microscopy?
9. On page 61, there is the statement "*The average K_Q from all the specimens is very consistent with 3.75 and 4.38 MPa$\sqrt{m}$ for the pipe and valve samples, respectively.*" Isn't this a mistake? Much higher K_Q results were obtained. Unless the author meant something else – please clarify this to avoid misunderstanding.
10. Why were the tests in a complex stress state limited only to I+III fracture modes? Why were no tests (in my opinion, much better recognized) in the I+II range undertaken?
11. Could the lack of a physical pre-cracking procedure in the I+III test have had any significance

for the test results obtained? Did the author consider discussing the impact of notch sharpness on fracture resistance results? What is the relationship between the radius of the notch bottom and the destructive forces obtained?

12. Why did the author decide to evaluate the stress intensity factor using the DIC method instead of, for example, the (much easier) FEM method?
13. The author used the equation (4.1) known in the literature as δ_5. Were other criteria considered, such as the possibility of calculating the equivalent CTOD for complex stress states?
14. Why did the author not analyze the crack path – the fracture initiation angle under complex stress conditions? Did the results obtained follow any theory? Would they be consistent with the fracture trajectory predicted by FEM?
15. Statistics are undoubtedly the weak point of the work. Perhaps one of the reasons is the limited availability of materials, and as such, I can consider this reason to be important. Nevertheless, it is not acceptable in a scientific sense to make judgments and prove theses about differences between groups. The author refers to this repeatedly. An example of this is the impact strength measurement results – Fig. 65 with the error bar marked for 2 (!) samples – as evidence, I quote: "*From the results, it is notable that the total impact energy (impact toughness) increases slightly compared to new material and is maximum for 240 hours of aging, while there is no difference in average values of new material and 120 hours of aging.*" Certainly, these differences are not statistically significant, although they are observable. I recommend a great deal of caution and a broader statistical discussion in the future – also in the context of the research results obtained – e.g., Table 32 – no reported R^2 coefficient describing the fit of the presented power curve parameters to the test results.
16. Why did the author not present the results of metallographic analyses (Chapter 5) of the material after creep degradation after 12, 240, and 480 hours? This would allow for a better assessment of the changes occurring in the material and a potential analysis of their impact on mechanical properties.

<u>Editorial comments</u>:

Overall, the dissertation is "readable," but it contains a number of editorial and proofreading errors that detract from its aesthetic value. Here are some examples:

1. List of important symbols – Q – should be "constraint" instead of "constrain"
2. Fig. 2 – the unit is missing – x-axis.
3. Care in writing mathematical formulas – e.g., page 14 – formula 2.5 – it is b0, it should be b_0
4. Lack of references and bibliographical references in some cases – e.g., Table 3 – standards

should be cited, further on page 20 "Wallin proposed..." no reference immediately after mentioning its author.

5. Errors in citation and inconsistent bibliography style resulting from a lack of care. An example is work [66] and its citation on page 25 – Boroski et al. [66] – should be Boroński et al.
6. Carefulness of drawings. Unfortunately, most of the drawings are blurred and of poor quality – more care should be taken with the graphic design. A striking example are the "hand-drawn" figures, e.g., 10-11. Such things should not occur in a dissertation at this level. It would be appropriate to redraw them and provide an appropriate reference indicating the source of origin.
7. Frequent use of the zero symbol in the superscript – example on p. 42. 535^0C instead of 535°C
8. Lack of dimensions in the drawings – e.g., fig. 18, 85.
9. The graphs should be adjusted to the measurement data (this comment applies to the entire dissertation) – examples can be seen in fig. 26, 59, 65, 76, 77, etc.
10. Careful mathematical notation – e.g., in formula 3.1, the dot after 1.1 is unnecessary, 4.2 – unnecessary empty rectangular fields symbolizing the degree of the root.
11. In the microscopic image markings, the markers are almost invisible and blurred, as well as stretched – Fig. 34, Fig. 39 – no marker.

Once again, it should be emphasized that the above comments are only for discussion and in no way detract from the positive reception of the results of the work and the goals achieved by the doctoral student, and have been presented by me in accordance with the maxim *nemo sine vitiis est.*

SUMMARY

The significant and creative contribution **of Benard Kiptoo Kipsang, M.Sc.,** to the development of materials engineering lies in the fact that he presented a solution to the research problem, i.e., ***Assessment of fracture development in thick-walled elements of power boilers after long-time operation***, on the basis of which the following achievements can be identified:

1. Presentation and comparison of the results of fracture resistance tests and analysis of the strength properties of selected materials used in the power industry in a post-operational state (after 100,000 hours).
2. Description of degradation phenomena and the creation of cognitive knowledge for selected alloys, which makes them reliable reference studies for other researchers.
3. Introduction of fracture mechanics approach in testing of materials used in the energy

sector under complex stress conditions. Author concluded that the introduction of shear loading in mode III does not significantly change the basic fracture behavior. Moreover, it appears (regarding statistical issue) that the effect of creep on samples with a straight notch (mode I) resulted in a 33.02% reduction in $CTOD_5$ at maximum load, compared to a 4.7% reduction for samples with a 45° - angled notch (I+III).

4. Development of a test methodology using artificial aging and creep techniques to reliably reproduce and predict future material degradation trends and determine the direction of changes in selected mechanical properties.

FINAL CONCLUSION

for admission to public defense

Taking into account the entirety of the dissertation and the achievements of the author of the thesis, I conclude that **the doctoral dissertation of Benard Kiptoo Kipsang, M.Sc., meets** the requirements of article 13 ust 1. – „Ustawa o stopniach naukowych i tytule naukowym oraz o stopniach i tytule w zakresie sztuki z dnia 14 marca 2003 roku (Dz. U. z 2017 r. poz. 1789 z pozn. zm.)" in connection with art. 179 ust. 1." Ustawa z dnia 3 lipca 2018 r. Przepisy wprowadzające ustawę – Prawo o szkolnictwie wyższym i nauce (Dz. U. z 2018 r., poz.1669 z późniejszymi zmianami)". In view of the above, I hereby submit a request for the admission **of Benard Kiptoo Kipsang, M.Sc., Eng.,** to the public defense of his reviewed thesis as a doctoral dissertation representing the discipline of Materials Engineering.

Wrocław, 7th September, 2025

prof. Grzegorz Lesiuk

/podpis odręczny/

*wyłączenie jawności w zakresie danych osobowych oraz ochrony prywatności osoby fizycznej na podstawie art. 5 ust. 2 ustawy z dnia 6 września 2001 r. o dostępie do informacji publicznej (tj. Dz.U. z 2016 r., poz. 1764)