**For research article**

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| Response to Reviewer 1 Comments | | |
| **1. Summary** |  |  |
| We appreciate your careful review and insightful comments on our manuscript. Below are our responses to each comment, along with the modifications we have made, which are clearly marked and detailed in the revised manuscript submitted for your consideration. | | |
| **2. Questions for General Evaluation** | **Reviewer’s Evaluation** | **Response and Revisions** |
| Does the introduction provide sufficient background and include all relevant references? | Can be improved |  |
| Are all the cited references relevant to the research? | Yes |  |
| Is the research design appropriate? | Can be improved |  |
| Are the methods adequately described? | Can be improved |  |
| Are the results clearly presented? | Must be improved |  |
| Are the conclusions supported by the results? | Can be improved |  |
| **3. Point-by-point response to Comments and Suggestions for Authors** | | |
| **Comment 1:** *Line 100. It must explain the abbreviation UTT.* | | |
| **Response 1**: Thank you for pointing this out. I agree with this comment. UTT stands for Uniaxial Tensile Test, which is a standard method for assessing the tensile strength of materials. I have now clarified this abbreviation in the manuscript.  *“[updated text in the manuscript (Line 114)]”* | | |
| **Comment 2:** *Line 102. It must explain the abbreviation TPBT.* | | |
| **Response 2:** Agree. TPBT refers to Three-Point Bending Test, a common method for evaluating the flexural strength of materials. I, accordingly, have added this abbreviation in the manuscript  *“[updated text in the manuscript (Line 115)]”* | | |
| **Comment 3:** *Figure 1. A scale must be added to the figure.* | | |
| **Response 3:** Acknowledge the oversight and agree to add a scale to Figure 1 at bottom-most right corner, detailing the specific changes to be made for clarity.  *“[updated scale in the manuscript (Figure1)]”* | | |
| **Comment 4:** *Line 306. Please check the number of cycles.* | | |
| **Response 4:** Thank you for pointing out. We tested samples with load cycles ranging from 1 to 2 million, correcting a previously missing zero. Upon review, I have verified the number of cycles and corrected the data to accurately reflect our findings.  *“[updated text in the manuscript (Line 317)]”* | | |
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| **Comment 5:** *Table 3. How many specimens were used for the test?* | | |
| **Response 5:** We appreciate the feedback. The manuscript has been revised to specify that each test involved six specimens.  *“[updated text in the manuscript (Line 366 and Line 367)]”* | | |
| **Comment 6***: Figure 9. How many specimens were used for the test?* | | |
| **Response 6:** We appreciate the feedback. The manuscript has been revised to specify that each test involved six specimens.  *“[updated text in the manuscript (Line 384 - 386)]”* | | |
| **Comment 7:** *Figure 13. It is not possible to mark zero on the abscissa axis. It can be 1 or ¼ of the cycle. The logarithm of zero is not a number.* | | |
| **Response 7:** Thank you for your observation regarding the use of zero on the X-axis in Figure 13. We understand your concern; however, in our context, marking zero represents specimens failing within one cycle, consistent with the logarithmic scale where log (1) equals zero. Or in other words, zero on X axis represents 1 cycle, 1 represents 101 cycles (10 cycles), 2 represents 102 cycles (100 cycles),3 represents 10 3 cycles (1000 cycles), so on and so forth. This notation aligns with standards demonstrated in the FIB Model Code 2021, specifically referenced in Figure 5.1-7 on page 157, to depict specimens failing immediately under full stress.    *“[updated Figure in the manuscript (Figure13)]”* | | |
| **Comment 8:** *Figure 13. Why, it is only one equation? There are four regression lines, so it should have four equations.* | | |
| **Response 8:** I apologize for any misunderstanding and appreciate the opportunity to clarify. In this scenario, we utilized the high cycle fatigue experimental results from HPC-B, HPC-G, and CM for comparison against the predictions outlined by the FIB Model Code 2010 (Equation 5.1-112, page 158). It is crucial to mention that the equation "log N = 12(1 - Smax)" from the FIB code is used for estimating the number of load cycles under tensile conditions, rather than representing a regression line for the data.  *“[updated Figure in the manuscript (Figure13)]”* | | |
| **Comment 9:** *Chapter 3.4.2. How stress is define by the authors? Is it the stress at the roof of the notch or nominal stress? An equation must be given***.** | | |
| **Response 9:** Thank you for your feedback and highlighting crucial mistake. Since compact tension specimens are associated with fracture toughness tests rather than straightforward tensile stress calculations, stress cannot be calculated in the conventional uniaxial manner (Stress .). For this reason, the average value of the ultimate static tensile load from six specimens under static tensile loading is utilised to determine the stress level for each composition during the fatigue tests. Thank you very much for your feedback. I've revised our terminology based on your insight. Initially, we described using the ultimate static tensile load to define the stress level for each composition. For example, a specimen with a 1000N ultimate static load would have a 100% load ratio equating to 1000N, with subsequent load ratios calculated proportionally (e.g., 0.9 as 900N, 0.8 as 800N). However, this led to a misunderstanding as we actually calculated based on load, not stress. Therefore, we have updated our manuscript to refer to this as "load ratio" instead of "stress ratio," aligning with the true nature of our tests. This change ensures our terminology accurately reflects our methodology. Thank you once again for highlighting this.  *“[replaced all the stress ratio with load ratio in the manuscript (Figure 13 is also updated)]”* | | |
| **Comment 10:** *Lines 464 – 469. The sentence is hard to read. It must be rewritten. In Figure 14 (d) the specimen has been damaged. It does not have a microcrack.* | | |
| **Response 10:** Thank you for the feedback. In figure 14 (d), the specimen is indeed damaged and I have corrected it. I have rewritten the lines 464-469 for improved clarity and readability as follows:  Upon initiating fatigue loading, the specimen remained unchanged through 91,670 load cycles. At the commencement of the 91,671st cycle, early signs of plastic deformation are noted, indicated by a micro-crack opening displacement of 18.5 μm. This early deformation phase is depicted in Figure 14b, correlating with the DIC recording at 100,000 load cycles. As the cyclic loading continued to increase, the specimen exhibited no notable additional deformation, maintaining a crack opening displacement of 20.5 μm as illustrated in Figure 14c. This pattern demonstrates the characteristics of fatigue loading, wherein the surfaces resistant to a microcrack remain in contact, despite the progressive increase in cyclic loading on the specimen, reaching up to 1 million cycles. The mechanism of crack opening and closing continued to remain consistent up to 1.08 million load cycles, and with the further increase in load, crack bridging at the notch tip is observed at 1084297 load cycles (Figure 14d).  *“[updated text in the manuscript (Line 474-484)]”*  Furthermore, based on Editor Ms. Ana Stojkanovic recommendation to add recent references, we have integrated the recent references in the manuscript.  *“[updated text in the manuscript (Line 92 -101)]”*  *“[updated references in the manuscript (Line 747 -759)]”* | | |

We believe these revisions address the concerns raised and enhance the manuscript's clarity and technical accuracy. We thank you for your insightful comments and look forward to further feedback.

**For research article**

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| Response to Reviewer 2 Comments | | |
| **1. Summary** |  |  |
| We appreciate your careful review and insightful comments on our manuscript. Below are our responses to each comment, along with the modifications we have made, which are clearly marked and detailed in the revised manuscript submitted for your consideration. | | |
| **2. Questions for General Evaluation** | **Reviewer’s Evaluation** | **Response and Revisions** |
| Does the introduction provide sufficient background and include all relevant references? | Yes |  |
| Are all the cited references relevant to the research? | Yes |  |
| Is the research design appropriate? | Yes |  |
| Are the methods adequately described? | Yes |  |
| Are the results clearly presented? | Can be improved |  |
| Are the conclusions supported by the results? | Yes |  |
| **3. Point-by-point response to Comments and Suggestions for Authors** | | |
| **Comment 1:** *Line 4. For a better visibility I would suggest to add the corresponding OECID IDs.* | | |
| **Response 1**: Thank you for your suggestion. We have now added the corresponding ORCID IDs for all authors to enhance clarity and ensure proper identification.  *“[updated text in the manuscript (Line 8 - 10)]”* | | |
| **Comment 2:** *Line 27. Please explain quantitatively the originality of your study and the novelty of your results with respect to existing knowledge.* | | |
| **Response 2:** We thank the reviewer for the opportunity to elucidate the quantitative originality and novelty of our research in the context of fatigue behaviour and fracture mechanics of high-performance concrete (HPC) under cyclic loading. Our study diverges from traditional investigations by focusing on high-performance concrete (HPC) at the mesoscale, particularly examining the fatigue behaviour under both low-cycle and high-cycle loading conditions. This nuanced approach is inspired by the need for a deeper understanding of HPC's behaviour under diverse loading scenarios, reflective of modern infrastructure's dynamic operational environments. While previous studies, such as those by Giaccio et al[[1]](#footnote-1). and Wu et al.[[2]](#footnote-2), have explored the influence of aggregate properties on concrete's fracture behavior, our research extends these findings by specifically addressing the dynamic fatigue response of HPC with different aggregate types (basalt and gravel) under cyclic load.  Expanding upon **Colin Loeffler et al.[[3]](#footnote-3)**'s exploration, our study examines a broader range of loading durations on HPC mixtures, yielding new insights into material behaviour under varied loading conditions. This complements and extends Loeffler et al.'s findings on damage initiation due to loading duration.  Building upon **Joseph O. Ukpata et al.**,[[4]](#footnote-4) we provide an extensive analysis of different aggregate types' influence on HPC's fatigue and fracture behaviour, advancing on aggregate impact and offering a deeper understanding of HPC's structural integrity and fatigue endurance compared to Ukpata et al.'s work on laterized concrete.  Complementing **Jinjun Guo et al[[5]](#footnote-5).**, our research explores HPC fracture behaviour under cyclic tensile loading, enriching the understanding of fracture mechanics and extending the scope of research beyond Guo and his team's phase-field method approach.  Additionally, by investigating the impact of aggregate type and specimen configuration, our study provides new insights into optimizing HPC formulations, building upon and enhancing the findings of **Sherif Yehia et al.[[6]](#footnote-6)** on concrete compressive strength.  Our work also expands upon **Kadir Güçlüer**'s[[7]](#footnote-7) discussion by examining the effects of aggregate textural properties on HPC's fatigue resistance and mechanical behaviour under cyclic loading, thus advancing the understanding of textural impacts on HPC.  Moreover, our research addresses some gaps left by **V Mechtcherine and HS Müller[[8]](#footnote-8)** by offering new insights into the fracture behaviour and durability of HPC under cyclic loading conditions, enhancing the existing body of knowledge on concrete's behaviour under stress.  Lastly, our examination of the tensile fatigue behaviour of HPC in supplements the body of knowledge established by **Nadja Oneschkow et al.[[9]](#footnote-9)**, under compressive fatigue behaviour of HPC.   * **Advanced Fracture Mechanics Integration within MDCT Framework**: Our study distinguishes itself by implementing an advanced fracture mechanics approach through a Modified Disc-Shaped Compact Tension (MDCT) method, diverging significantly from conventional wedge split tests (WST) or Compact tensile (CT)-tests. The MDCT approach allows for precise quantification of fracture parameters such as fracture toughness (KIC) and fracture energy (Gf) under. This methodology enhances the accuracy in determining the critical stress intensity factor and energy dissipation mechanisms in HPC, providing a more comprehensive understanding of its fatigue resistance. * **Low and High cycle Fatigue Loading Analysis**: We have systematically categorized fatigue loading into low-cycle (seismic or earthquake-induced) and high-cycle (traffic and wind-induced) domains, applying displacement-controlled and force-controlled fatigue testing respectively. This bifurcated approach allows for the detailed examination of HPC's response under distinct stress-strain cycles, offering novel insights into its behavior under diverse operational conditions. Quantitative results from our study demonstrate differential impacts on the mesostructure and resultant fracture mechanics of HPC compositions, shedding light on their respective fatigue life expectancies. * **Quantitative Evaluation of Aggregate Types**: The research provides a detailed quantitative analysis on the impact of aggregate type (basalt vs. gravel) on the fatigue and fracture behavior of HPC. Our findings indicate that basalt aggregates enhance both the ultimate load capacity and fracture energy of HPC-B compositions, with a quantifiable increase in performance over HPC-G and CM variants. This is a significant advancement in understanding the role of aggregate material properties on the fatigue endurance and structural integrity of HPC. * **Innovative Application of DIC and CT Imaging**: Utilizing Digital Image Correlation (DIC) and Computed Tomography (CT) scans, our study offers a novel quantitative approach to assessing crack propagation and microstructural evolution utilizing novel external trigger mechanism under cyclic loading. These cutting-edge techniques provide high-resolution insights into the crack opening displacement (COD) patterns and internal damage mechanisms, facilitating a deeper understanding of the material’s behavior beyond surface-level observations. * **Implications for Enhanced Structural Design**: The technical findings from our research, particularly relating to the superior fatigue resistance and mechanical robustness of HPC-B, have profound implications for the design and construction of more resilient and durable infrastructure. By integrating our quantitative insights on aggregate selection and cyclic load handling, the study contributes to the development of improved guidelines and standards for HPC applications in dynamic load-bearing structures.   In essence, our research provides a substantial leap in the quantitative understanding of HPC's behavior under cyclic loading conditions, offering new paradigms for its analysis and application in civil engineering and construction. The methodologies and findings presented are poised to influence future investigations and practices in the field.  *“[updated text in the manuscript (Line 28-31)]”* | | |
| **Comment 3:** *Line 101. Replace by Wittmann and al.* | | |
| **Response 3:** Thank you for your suggestion. We have corrected the reference  *“[updated text in the manuscript (Line 106)]”* | | |
| **Comment 4:** *Line 117. Fig. 3.* | | |
| **Response 4:** Thank you for your suggestion. We acknowledge that the figures in our manuscripts are represented as "Figure" in accordance with the MDPI journal template. | | |
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| **Comment 5:** *Line 134. Please explain the GOM acronyms?* | | |
| **Response 5:** We apologize for any confusion caused by the use of acronyms without proper explanation. In the revised manuscript, we have clarified that GOM refers to Gesellschaft für Optische Messtechnik (Society for Optical Measurement Technology), which is the manufacturer of the ARAMIS digital image correlation system used in our experiments.  *“[updated text in the manuscript (Line 147-148)]”* | | |
| **Comment 6***: Line 134. Please a link to ARAMIS software (https://www.gom.com/en/products/3d-testing/aramis-app)* | | |
| **Response 6:** Thank you for your recommendation. We have added the ARAMIS software link, providing direct access to detailed product information and enhancing manuscript transparency.  *“[updated text in the manuscript (Line 147-148)]”* | | |
| **Comment 7:** *Line 153. MDCT acronym was previously explained.* | | |
| **Response 7:** Thank you for pointing out the redundancy. We have revised the text and ensured that the MDCT acronym is only defined once in the manuscript to avoid repetition and maintain clarity  *“[updated text in the manuscript (entire Manuscript)]”* | | |
| **Comment 8:** *Line 171: Could you explain why you chose basalt and not other volcanic rock, such as granite or andesite, dacite, etc..* | | |
| **Response 8:** Thank you for your insightful question regarding our choice of basalt as the aggregate in our research. Basalt is considered for the reference composition for HPC of SPP2020 (Special Priority Program 2020) project. Our choice is aligned with the guidelines and reference compositions outlined in the Special Priority Program 2020 (SPP2020 <https://www.spp2020.uni-hannover.de/en/research/projects-of-the-first-period/de-lorenzis-leusmann> ), where basalt is recommended for its superior mechanical and durability characteristics essential for HPC.. These properties are essential for high-performance concrete, as they contribute significantly to its load-bearing capacity and durability. In contrast, while other volcanic rocks like granite, andesite, and dacite have their advantages, they do not match the combined mechanical and durability properties offered by basalt, particularly in the context of high-performance concrete. Granite, for example, while durable, has a lower modulus of elasticity compared to basalt, making it less suitable for certain structural applications. Andesite and dacite, while sharing some similarities with basalt, do not consistently exhibit the same levels of strength and resistance to environmental factors. | | |
| **Comment 9:** *Line 172: You have once defined them.* | | |
| **Response 9:** Thank you for pointing this out. We have made changes to remove repeated explanations for HPC-B, HPC-G, and CM as per your suggestion.  *“[updated text in the manuscript (Line 184)]”* | | |
| **Comment 10:** *Line 362. Once ITZ acronym explained (pg. 4) is no more necessary to repeat the explanation.* | | |
| **Response 10:** Thank you for the feedback. We've removed the extra explanations of 'ITZ' after the first time we explain it on page 4 to make our paper simpler and clearer.  *“[updated text in the manuscript (Line 375)]”* | | |
| **Comment 11:** *Equation 2 & 3. For the Eq. 2 and 3 there are no references?.* | | |
| **Response 11:** I apologize for this omission and thank you for pointing out this oversight. References for Equations 2 and 3 have now been included in the revised manuscript to provide the necessary citations and to establish the provenance and credibility of these formulation *“[updated text in the manuscript (Line 395 & 396)]”* | | |
| **Comment 12:** *Figure 11. Could be more specific: the crack initially appears in the center (Fig. 11a) and then propagates until the entire sample is split (Fig. 11b).* | | |
| **Response 12:** Thank you for your valuable feedback. We have updated the caption for Figure 11 to more accurately reflect the progression of the crack during the tests. The revised caption reads:  “**Figure 11.** Sequential crack progression under low-cycle fatigue testing. (a) Initial crack appearance at the centre of the specimen, capturing the onset of fracture. (b) Subsequent crack propagation leading to the complete splitting of the sample, illustrating the full extent of specimen failure”  *“[updated figure in the manuscript (Figure 11)]”* | | |
| **Comment 13:** *Figure 13. For a better interpretation please add corresponding error bars !* | | |
| **Response 13:** Thank you for your observation. I apologize for any misunderstanding and appreciate the opportunity to clarify. In this scenario, we utilized the high cycle fatigue experimental results from HPC-B, HPC-G, and CM for comparison against the predictions outlined by the FIB Model Code 2010 (Equation 5.1-112, page 158). Each data point illustrates a direct comparison of the load ratio to the number of load cycles without averaging, hence the omission of error bars. To enhance clarity, we have revised Figure 13 to prevent any misunderstanding.  *“[updated Figure in the manuscript (Figure 13)]”* | | |
| **Comment 14:** *Figure 14. A suggestion: please color cracks in red to be more visible* | | |
| **Response 14:** Thank you for the suggestion to enhance the visibility of cracks in Figure 14. We have taken your advice into consideration and have updated the figure to colour the cracks in red, which will help to distinguish them more clearly against the background. Furthermore, based on your valuable input, we have applied this change to all the figures within the manuscript where crack interpretation plays a crucial role. This modification should facilitate a better interpretation of the crack paths.  *“[updated Figure in the manuscript (Figure 14)]”* | | |
| **Comment 15:** *Line 494. Replace by [25-28]* | | |
| **Response 15:** Thank you for your recommendation to consolidate the references for clarity and conciseness. We have revised line 494 in the manuscript to refer to the collective citations as [25-28], restructuring the text and maintaining consistency in our referencing style.  *“[updated text in the manuscript (499)]”* | | |
| **Comment 16:** *Table 5. Please add the corresponding uncretainties* | | |
| **Response 16:** Thank you for pointing out the necessity of including uncertainties in Table 5. We understand the importance of this information for interpreting the data accurately. Accordingly, we have updated Table 5 to include the corresponding uncertainties for all measured and derived quantities, ensuring a comprehensive and transparent presentation of the experimental results  *“[updated Table in the manuscript (Table 5)]”* | | |
| **Comment 17:** *Figure16. If possible, pleas add error bars* | | |
| **Response 17:** Thank you for your suggestion regarding Figure 16. We have now added error bars to Figure 16 to illustrate the range of uncertainty associated with the experimental data.  *“[updated Figure in the manuscript (Figure17)]”* | | |
| **Comment 18:** *Line 596-597. 0 corresponds to "black" while 255 corresponds to "white"* | | |
| **Response 18:** Thank you for your attention to detail regarding the color scale explanation in lines 596-597. We have updated the manuscript to clearly indicate that in our grayscale images, a value of 0 corresponds to 'black' and a value of 255 corresponds to 'white.' This clarification should help in accurately interpreting the images and their respective grayscale values  *“[updated text in the manuscript (Line 612- 614)]”* | | |
| **Comment 19:** *Figure17. Would be more interesting if you would explain the differences. As I remarked, only a small semicircular crack can be observed on Fig. 17c. It is correct?* | | |
| **Response 19:** Thank you for your insightful observation regarding Figure 17. We have reviewed the figure and your remarks, and agree that a more detailed explanation of the observed differences, including the small semicircular crack visible in Figure 17c, would enhance the understanding of our findings. We have included a detailed analysis in the text surrounding the figure to explain the differences observed among the samples.  *“[updated text in the manuscript (Line 632-647)]”* | | |

Furthermore, based on Editor Ms. Ana Stojkanovic recommendation to add recent references, we have integrated the recent references in the manuscript.

*“[updated text in the manuscript (Line 92 -101)]”*

*“[updated references in the manuscript (Line 747 -759)]”*

We believe these revisions address the concerns raised and enhance the manuscript's clarity and technical accuracy. We thank you for your insightful comments and look forward to further feedback.

1. Giaccio, G., Rocco, C., & Zerbino, R. (1993). The Fracture Energy (G F) of high-strength concretes. Materials and Structures, 725 26(7), 381–386. [↑](#footnote-ref-1)
2. Wu, K.-R., Chen, B., Yao, W., & Zhang, D. (2001). Effect of coarse aggregate type on mechanical properties of high-performance 727 concrete. Cement and Concrete Research, 31(10), 1421–1425. [↑](#footnote-ref-2)
3. Loeffler, C., Sun, Q., Heard, W., Martin, B., Williams, B., & Nie, X. (2020). The effect of loading duration on damage initiation in high-strength concrete. Mechanics of Materials, 140, 103216. [↑](#footnote-ref-3)
4. Ukpata, J. O., Ewa, D. E., Success, N. G., Alaneme, G. U., Otu, O. N., & Olaiya, B. C. (2024). Effects of aggregate sizes on the performance of laterized concrete. *Scientific Reports*, *14*(1). [↑](#footnote-ref-4)
5. Guo, J., Lin, W., Qin, X., Xu, Y., & Dong, K. (2022). Mesoscopic study on fracture behavior of fully graded concrete under uniaxial tension by using the phase-field method. *Engineering Fracture Mechanics*, *272*, 108678 [↑](#footnote-ref-5)
6. Yehia, S., Abdelfatah, A., & Mansour, D. (2020). Effect of aggregate type and specimen configuration on concrete compressive strength. *Crystals*, *10*(7), 625. [↑](#footnote-ref-6)
7. Güçlüer, K. (2020). Investigation of the effects of aggregate textural properties on compressive strength (CS) and ultrasonic pulse velocity (UPV) of concrete. *Journal of Building Engineering*, *27*, 100949. [↑](#footnote-ref-7)
8. Mechtcherine, V., & Müller, H. S. (2021). Fracture behaviour of high-performance concrete. *Finite Elements in Civil Engineering Applications*, 35–43. doi:10.1201/9781003211365-6 [↑](#footnote-ref-8)
9. Scheiden, T., & Oneschkow, N. (2019). Influence of two coarse aggregates on the damage mechanism in high-strength concrete under pure compressive fatigue loading. [↑](#footnote-ref-9)