UDC 620
DOI: 10.15587/1729-4061.2023.273974

FATIGUE DETERMINATION OF THE KENAF/PLA COMPOSITE STRUCTURE USING FATIGUE SPECIMEN (ASTM D7791): A COMPUTATIONAL ANALYSIS

Muthana Adil Najim Abbu*
Duaa Talib Hashim*
Corresponding Author
E-mail: douaa.talb@ntu.edu.iq
Hasan Mohammed Ahmed Albegmprli*
Mustafa Ridha Mezaal*
*Department of Building & Construction Technology Engineering
Engineering Technical College
Northern Technical University
AlMinsaa str., Mosul, Iraq, 41002

In this investigation, a kenaf/PLA composite specimen was subjected to the fatigue load, and the results were analyzed numerically. Some of the most significant fatigue tool aspects that were looked into were life expectancy, damage, alternative stress, and biaxiality indication. The static structural tool was utilized in order to predict the numerical analysis, and the calculations were performed with the GoodMan theory of fatigue. The loading was completely reversed so that it was equal to 30 kN. When it was discovered that the system could continue to function even after 1e6 cycles had been completed. After applying the alternative load of 30 kN, the biaxiality indication was found to be 0.425, with a minimum value of 0.9. It has been determined how much damage has occurred. The minimum amount of cycles necessary to reach the maximum damage potential is 1000, while the maximum amount of cycles necessary to reach the maximum damage potential is 1.7662·10^6. It has been established that there is another stress that is comparable to this one. Based on the findings of the investigation, it was determined that the fillet regions of the specimen were subjected to a maximum alternative stress of 716.4 MPa. The alternative stress cannot drop below 31.276 MPa under any circumstances. It has been determined that 10^6 cycles have been spent living in total by the calculation. It has been found out that there is not going to be any damage regardless of the number of cycles that pass due to the fact that that number is 1. It was found that the alternative stress could reach a maximum value of 716.4 MPa, so that was the value that was used for the alternative stress

Keywords: static structural, FEM, Fatigue analysis, kenaf/PLA composite, ASTM D7791

Received date 22.11.2022
Accepted date 13.02.2023
Published date 28.02.2023

How to Cite: *Abbu, M. A. N., Hashim, D. T., Albegmprli, H. M. A., Mezaal, M. R. (2023). Fatigue determination of the kenaf/PLA composite structure using fatigue specimen (ASTM D7791): a computational analysis. Eastern-European Journal of Enterprise Technologies, 1 (7 (121)), 14–20. doi: https://doi.org/10.15587/1729-4061.2023.273974*

1. Introduction

Composite stiffened panels are widely used in today's thin-walled aeronautical components, including the fuselage and wing structures. It is common practice in such buildings to use adhesive bonding or co-curing to secure the stringers to the skin. In most cases, the failure loads of these structures are far higher than the buckling loads [1]. This is the case in the majority of cases. Nevertheless, the out-of-plane displacements that can occur in the post-buckling regime have the potential to become quite considerable. Furthermore, the cyclic nature of these displacements can lead to a separation in the interface that is formed between the skin and the stringer. During the design process for aerospace stiffened panels, it is necessary to include the buckling load as the limit load because there are no reliable numerical algorithms available that are able to precisely forecast this phenomenon. If the structure were allowed to buckle under certain well-defined service conditions, the effect would either be an increase in the load carrying capability of the structure or a reduction in the weight of the structure when subjected to the same limit load. To prevent the panel from breaking down before its time, however, it is necessary to pay extra attention to the process of fatigue delamination initiation and spread.

Despite extensive coupon-level study, the issue of predicting the spread of fatigue delamination in post-buckled strengthened composite panels remains unanswered. In fatigue loading settings, the rate of delamination growth is commonly defined by applying the power law established by [2, 3], which relates the crack growth rate to the stress intensity factor or, equivalently, to the energy release rate.

Two major categories characterize the numerical methods: damage mechanics and fracture mechanics [4]. This is carried out in accordance with the numerical representation of the delamination and the implementation of the Paris law. Interface elements with an incorporated cohesive law are widely used in damage mechanics simulations of delamination onset and propagation under quasi-static and impact stress conditions [5, 6]. As a result of the positive findings gained for these issues, a select group of writers has extended the cohesive formulation in order to mimic the growth of fatigue cracks. However, the energy release rate is not directly described within the cohesive law. This has led to the development of many models that attempt to establish a connection between the cohesive damage variable and the crack growth rate established by the Paris law [7].

The plastic activity at the crack tip and the possibility of closure effects are significant factors in determining whether or not a fatigue crack will continue to spread. The use of tensile overload in a material reduces the speed at which the crack propagates [8]. Because of the overload, there is a significantly larger region of plasticity near the tip of the crack. This region of flexibility is more extensive than the cyclic plasticity region. The rest of the structure is applying a lot of force to this just discovered plastic zone. This causes the crack front to generate residual compressive stresses, which strengthens the fracture closure action. Multiple studies have found that when an overload is applied, significant deformations occur, resulting in a ductile rip that blunts the fracture tip. As the initial loading state spreads outward, the grain boundaries become cohesive due to the blunting effect; this cohesion can be observed at a relatively large depth behind the point at where the overload was applied [9]. Finding the sharp edge of a fracture typically requires specialized equipment, such as a microscope or binocular magnifier (SEM). It is a potential technology, notably in the field of aeronautics, to repair damaged metal structures with composite patches instead of welding them. This method involves gluing a plate made of composite material to the damaged area of the metal structure, which is often subjected to fatigue loading. The goal of this technique is to repair the damage caused by fatigue loading. Through the adhesive layer, the composite patch is able to take on some of the stresses that are being placed on the damaged structure [10, 11].

In this study, numerical analysis has been performed using static structural tool to investigate fatigue behavior of the Kenaf/PLA composite structure in accordance with ASTM D7791.

2. Literature review and problem statement

The fatigue of metal materials is an essential element that affects both the service life of steel bridge structures and the operation safety of these structures [12]. Due to the influence of material qualities and the quality of the welding, the initiation and growth of small cracks under cyclic stress is an intractable problem [13]. The engineering world has shown that in the early stages of fatigue cracking, it is difficult to see the minute cracks with the naked eye. It takes a long time for fatigue cracking to develop. The concept of a stress amplitude-fatigue frequency curve was first proposed by August Wohler [14]. The standard was utilized to categorize the various fatigue strengths of welded joints, and the subsequent fatigue design comprises keeping the nominal stress amplitude of the structure within an appropriate range [15]. Keeping the stress amplitude below the point where microcracks can propagate is the key to successfully imposing a stress threshold..

Because of its exceptional performance and convenient construction, the steel-concrete composite structure is frequently used in the construction of bridges [16]. Researchers have conducted a significant amount of research on the effectiveness of it. Technology based on neural networks was utilized by [17] in order to maximize the composite beams' embodied energy. In a similar manner, [18] proposed a life-cycle modelling approach for temperature field and temperature effect of steel-concrete composite bridge deck system based on the BP-LSTM algorithm. The temperature field and its impact were modeled using this technique. The fatigue behaviour of welded connections in steel-concrete composite beams with full depth transverse stiffeners was evaluated by [19] using repeated loading tests. There is a large range of possible types and quantities of welded joints in steel-concrete composite constructions, making them a crucial component. Nonetheless, fatigue cracking can occur in welding details with eccentric loads or residual pressures [20].

Previous research has shown that predicting the fatigue life of stud connectors under different situations is possible through a process of fitting the nominal shear stress amplitude and the fatigue action durations. However, the stud is subjected to not only shear stress but also tension when the bridge is in use, as shown by the multi-axis composite stress mode. This is particularly true for the short studs that are located in the steel-UHPC composite structure. As a result, the conventional S-N technique has significant restrictions when it comes to analyzing the fatigue performance of stud connections that come in a variety of types and can be used in a variety of settings. The experimental fitting formulas are challenging to apply to different types and materials of studs, especially in light of new materials and novel structures in the growing use of steel-concrete composite buildings [21]. This is due to the fact that new materials and new structures are being introduced. The fatigue test conducted by [22] discovered that the fatigue life of big diameter studs with diameters greater than 30 millimeters had a value that was lower than the value that was predicted by the existing requirements. In [23], it was shown that a rubber sleeve would reduce the stud's shear stiffness, leading to a lower fatigue life. The push-out test conducted on the steel-UHPC composite structure's short stud revealed that it had somewhat superior fatigue performance than the stud in conventional concrete. The finite element method's advancement over the years has led to widespread adoption of linear elastic fracture mechanics (LEFM) for fatigue performance evaluation in the engineering field. [24] utilized the fracture mechanics approach in order to conduct research on the mechanical properties of the column top plate and the asymmetric fracture circumstances that were present in the shallowly buried coal seam. Using the LFEM approach, [25] examined the studs' fatigue resistance in the composite beam. It is possible to find their research results on this page. However, the fatigue performance of the studs is significantly impacted by the start life of fatigue cracks, and more investigation of studs in composite structures using the fracture mechanics technique is still warranted.

Therefore, fatigue analysis of the kenaf/PLA composite structure has been carried out using fatigue specimen (ASTM D7791) computationally. It has been carried out by depending on the fatigue life, biaxiality indication, damage indicator as well as equivalent alternative stress.

3. The aim and objectives of the study

The aim of the study is to fatigue determination the behavior of the kenaf/PLA composite structure using a fatigue specimen (ASTM d7791). This will function to validate the findings of the experiment method involving the composite sample. To achieve this aim, the following objectives are accomplished:

– to predict life fatigue;
– to investigate biaxiality indication;
– to analysis damage indicator;
– to investigate the equivalent alternative stress.

4. Materials and methods of research

4. 1. Object and hypothesis of the study

Object of study is the behavior of the kenaf/PLA composite structure when subjected to fatigue. The fatigue specimen, which is based on the ASTM D7791 standard, has been used. The GoodMan theory has been accounted for in the calculations that have been taken. The simulation process has been carried out using ANSYS software, which is dependent on the static structural modeling.

4. 2. Mechanical properties

Before the simulation technique can be carried out, the mechanical parameters of the model need to be given. The following properties of a PLA/Knaf blend with a weight percentage of 3 % have been taken into consideration: Variations in Ultimate Tensile Strength, Expressed as a Percentage of Pascals Maximum Stress, Expressed in Megapascals (MPa) [12]. The mechanical properties of the materials that are currently available are listed in Table 1, which may be found here.

Table 1

Mechanical engineering of composite Kenaf/PLA

Material	Maximum tensile stress (MPA)	Passion ratio	Density (g/cm^3)
3 wt.% Kenaf/PLA	55	0.31	0.369

The density, the modulus of elasticity, and the passion ratio were used as the basis for defining the material's mechanical properties in the Ansys software. Fig. 1 showing the prototype of the fatigue sample that is will modeled based on the ASTM D7791 accordingly.

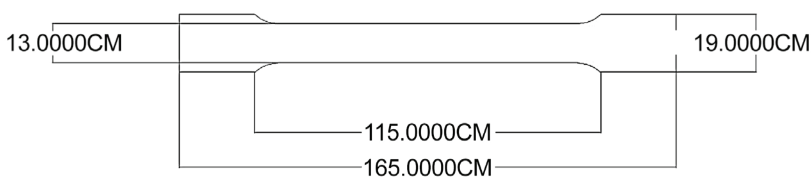

Fig. 1. Geometry of fatigue sample

4. 3. Boundary conditions

Experimentally, a uniaxial fatigue test was carried out with the assistance of a Universal Testing Machine (model 8874 by INSTRON). The load that was applied was 30 kN. The approach for the fatigue tests that were utilized in this investigation was based on ASTM D7791, and the specimens were loaded while subjected to tension-compression stress during the testing phase [13]. The experiment was carried out using a sinusoidal wave with a frequency of 5 Hz at a variety of different levels of applied stress. Failure due to fatigue occurs when a material has been subjected to a series of load cycles with amplitudes that are less than the material's ultimate static strength [14]. In the course of this investigation, fatigue tests on specimens made of plain PLA and kenaf/PLA were carried out in a laboratory.

4. 4. Meshing and modeling

ANSYS The meshing process was carried out with the assistance of meshing, which was utilized in order to carry out the meshing for the problem in question. The process of meshing involves reducing the number of particles in a model that originally contained an unlimited number of particles to a more manageable number of particles. In order to acquire precise answers, fine mesh was created using a structured mesh grid. This allowed for the production of the mesh. The intended outcome of a tiny mesh was achieved with the help of controlling the sizing by applying the curvature size with a coarse mesh and the element size with face meshing. The production of binary nodes for the wedge across all of its zones has resulted in a total of 44536 nodes being produced and the elements are equal to 10834. Fig. 2 presents a representation of the type of mesh in a two-dimensional space. As a result of the fact that the 3D wedge is symmetric, the only aspect of the model that has been constructed and modeled so far is the symmetric aspect. In this particular piece of research, three distinct kinds of boundary conditions were utilized: wedge, symmetry, and far field. This set of conditions was determined by selecting edges from the model.

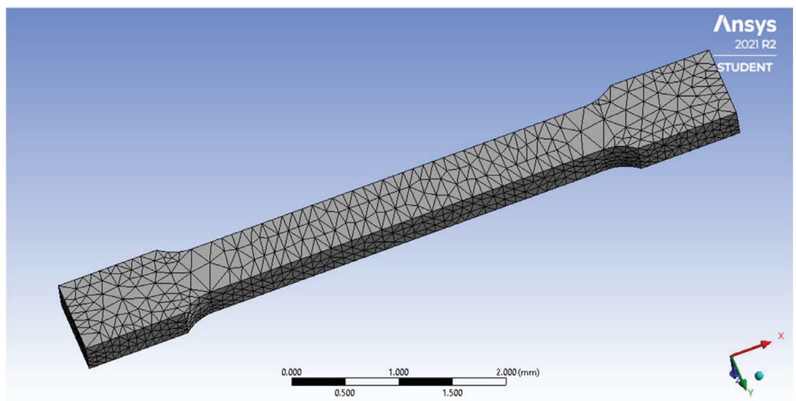

Fig. 2. Finite element model of the prototype

The existing model for this investigation has been meshed, and the structural analysis tool in Ansys software has been used to conduct tests on it.

4. 5. Convergence analysis

In the empirical studies on the relationship, the method for carrying out the results of the numerical analysis that has been chosen is a convergence test. This test compares two sets of results that have been calculated numerically. It has been agreed that the major indicator for convergency will be the life forecast that is provided in the fatigue tool. The technique for reaching convergence has been completed by taking into consideration two distinct solutions as shown in Fig. 3. The initial cycle count for the first solution was 566.17, whereas the initial cycle count for the second solution was 451.29. The mesh that is used in the current model has been improved so that it more correctly represents the second solution.

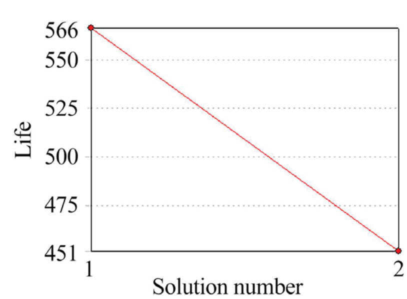

Fig. 3. Convergence analysis of the current model

As can be seen in Fig. 2, two different approaches have been tried out until the convergence status was reached in order to carry out the simulation process confidentially.

5. Results of the fatigue analysis of the kenaf/PLA composite structure using fatigue specimen (ASTM D7791)

5. 1. Life prediction

For the purpose of the present investigation, a prediction was made regarding the amount of time that fatigue spacemen made from PLA reinforced with kenaf particles would be functional under an alternate load. Due to the imposed amplitude of fatigue load of 30 kN, the investigation into the life expectancy projection was carried out as shown in Fig. 4.

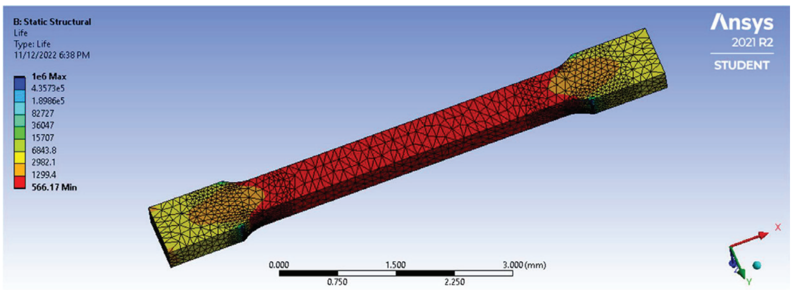

Fig. 4. Graphical analysis of the life prediction for the current model

The ANSYS software's tool referred to as the Static structural tool was utilized throughout the process of simulation. According to the computational findings, the maximum number of cycles that may be applied to the PLA composite structure specimen that is reinforced with kenaf particles is close to one e6. Therefore, it is advised that the current analysis fail somewhere between the range of 1e6 cycle.

Fig. 5 has demonstrated fatigue sensitivity as a result of the alternative amplitude that was applied 30 kN. After that, the numerical results demonstrated that the maximum availability of the stress sensitivity is reaching 3900 cycles while the minimum availability reached 196.4 cycles. It has been determined that the loading history is the primary parameter for determining the life-threatening nature of the current situation.

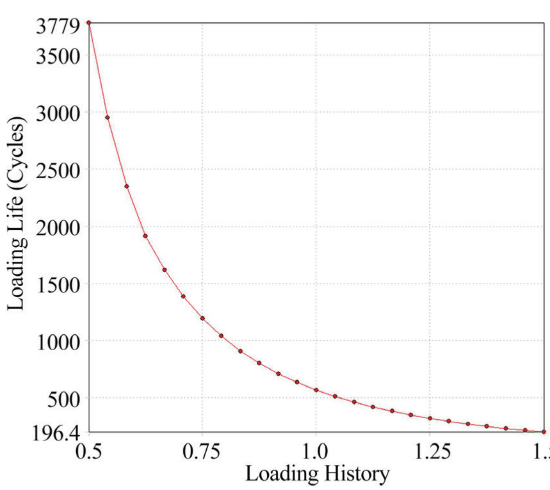

Fig. 5. Fatigue sensitivity of the current fatigue situation

Within 3779 cycles, fatigue sensitivity can be applied using organized steps every 0.25 while in the loading phase (available life).

5. 2. Biaxiality indication

In this research, the biaxiality indication gives information on the stress condition that was experienced over the model and how the results should be understood. This information can be found in both the results and the biaxiality indication.

In this particular situation, the biaxiality indication is computed by dividing the principal stress with the smaller magnitude by the principal stress with the bigger magnitude, while ignoring the principal stress that is closest to zeroas shown in Fig. 5. This particular calculation is done in order to determine whether or not the material exhibits biaxiality. A stress that is exclusively uniaxial is equivalent to a stress with a biaxiality of zero. The biaxiality indicator is 0.425 as a result of the application of the alternative amplitude load 30 kN, and it reached a minimum of –0.9 before reaching that value. The outcome of the simulation, which was presented in Fig. 6, revealed that the tips were the locations where the maximum case biaxiality indication occurred.

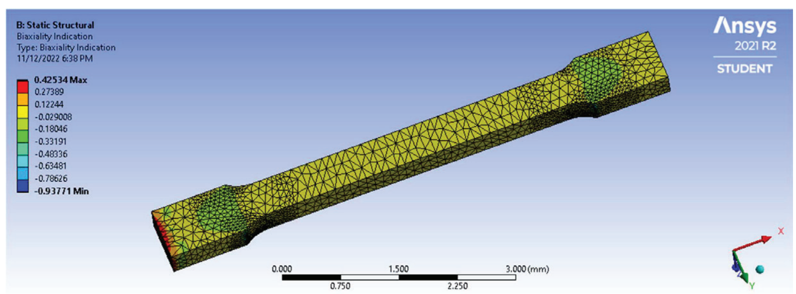

Fig. 6. Graphical explanation of biaxiality indication of the current model

Fig. 6 provides a graphical explanation of the biaxiality indication of the current model. This explanation demonstrates that the highest level of biaxiality indication can be found at the end tips of the specimen.

5. 3. Analysis of damage indicator

Fig. 7 illustrates the likelihood that loading will result in damage being sustained by the structure. This possibility was demonstrated to have become a reality. Specimens have been subjected to an alternative load that is equivalent amplitude to 30 kN as part of the computational modeling of the 3D fatigue spacemen. They have been given the responsibility of carrying this load.

The number of cycles that must be completed before the potential for maximum damage is reached is a minimum of 1000, whereas the number of cycles that must be completed before reaching the potential for maximum damage is 1.7662e6. The results of the simulation indicate that the damage will most likely become apparent sometime in the middle of the fatigue specimen.

The findings of the simulation indicate that the damaged region is located in the middle of the specimen between its head and its body. It is possible that it will fail at 1.7662e6 cycles.

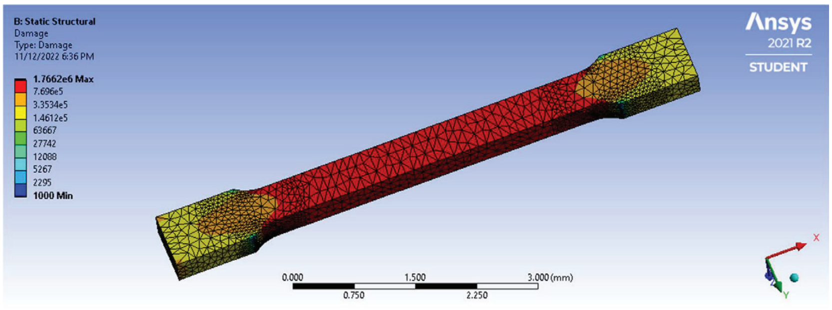

Fig. 7. Analysis of Damage Indicator

5. 4. Equivalent alternative stress

The findings of the simulation have made it feasible to pinpoint the areas of the composite specimen that were influenced by the alternative load 30 kN that was applied thanks to the fact that these results have made it conceivable. The strain is applied along a uniaxial axis throughout the entirety of the body of the specimen that is being investigated. The composite fatigue sample's fillet body was subjected to alternate stresses that were focused there. These stresses were concentrated there. The results of the investigation indicate that the fillet parts of the specimen are subjected to a maximum alternative stress of 716.4 MPa. 31.276 MPa is the minimum alternative stress that can be achieved as shown in Fig. 8.

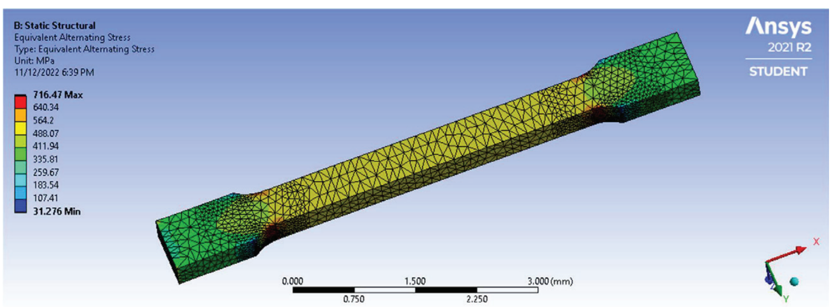

Fig. 8. Explanation of equivalent alternative stress

An explanation of the corresponding alternative stress that was applied to the composite spaceman during the fatigue test was displayed in Fig. 7. The corner of the fillet has borne the lion's share of the total stress that has been applied.

6. Discussion of the results of the fatigue analysis of the kenaf/pla composite structure using fatigue specimen (ASTM D7791)

The prediction of the life of fatigue has been obtained as shown in figure 3 that is reached to 1e6 cycle with dynamic load 30 KN. The biaxiality indication has been investigated to be represented in the figure 6 which reach to the 0.4. Damage indicator was analyzed for the proposed sample in Fig. 7 and it is supposed to be fail at 1.7662e6 cycles. The equivalent alternative stress also has been done as shown in figure 8 and it has been reached to the 716 MPa. The finite element method has been conducted to investigate the mechanical behavior of the kenaf/PLA composite structure using Ansys software.

The results have been calculated, and the characterization procedure of the fatigue sample of the kenaf/PLA composite structure will now be carried out. Finite element method has been compared to previous studies accordingly [26].

The current study is collected for the purpose of studying the kenaf/PLA composite's fatigue behaviour using fatigue specimen (ASTM D7791). Based on the analysis of the conduct, the life predictions suggested that it had entered the 1e6th cycle. Analysis of damage indicator and equivalent alternative stress are added to the biaxiality indication. The data has been validated by a comparison of the proposed approach and the study of tired behaviour. To model the behaviour accurately, the finite element technique was employed.

The limitations of this research are that it can only investigate fatigue behaviour using four parameters: life prediction, biaxiality indication, analysis of damage indicator, and equivalent alternative stress. In addition, the applied dynamic force is 30 KN in magnitude. A composite structure made of kenaf and PLA will be used as the material to be evaluated.

When using this method, there are a few drawbacks that can be observed, one of which is the use of expensive materials in the fabrication of the specimen test. This is one of the drawbacks that can be observed. In addition to this, let's use the ANSYS software to simulate the dynamic behaviour of the structural tool while it is in its static state. This is done while the tool is in its original state. It is possible that in the future, the ACP model will be used to simplify things. This would be beneficial.

There is a possibility of encountering a number of difficulties, one of which is the meshing model of the fatigue spacemen. Among the other potential difficulties are: Convergence analysis of the mesh and the model can be difficult to properly set. In the event that the mathematical model used by the Ansys software is not correctly defined, the results will not be reliable.

7. Conclusions

1. The fatigue life of the composite specimen has been predicted by using the computational method, and the finding stated that it is still able to work within 1e6 cycles.

2. The biaxiality indication has been investigated, and the results of the analysis have been compiled. The application of the alternative load of 30 kN caused the biaxiality indicator to reach a minimum of 0.9 before it reached its current value of 0.425. Prior to reaching that value, it had reached a minimum of 0.9.

3. A calculation has been made regarding the damage indicator. A minimum of 1000 cycles need to be finished before the potential for maximum damage can be reached, while the number of cycles that need to be finished before reaching the potential for maximum damage is 1.7662e6.

4. An investigation was conducted to determine the equivalent alternative stress. According to the findings of the study, the fillet portions of the specimen are subjected to a maximum alternative stress of 716.4 MPa. This was determined by analyzing the specimen. The alternative stress must be at least 31.276 MPa in order to be considered acceptable.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

References

1. Shahar, F. S., Hameed Sultan, M. T., Safri, S. N. A., Jawaid, M., Abu Talib, Abd. R., Basri, A. A., Md Shah, A. U. (2022). Fatigue and impact properties of 3D printed PLA reinforced with kenaf particles. Journal of Materials Research and Technology, 16, 461–470. doi: https://doi.org/10.1016/j.jmrt.2021.12.023
2. Travieso-Rodriguez, J. A., Zandi, M. D., Jerez-Mesa, R., Lluma-Fuentes, J. (2020). Fatigue behavior of PLA-wood composite manufactured by fused filament fabrication. Journal of Materials Research and Technology, 9 (4), 8507–8516. doi: https://doi.org/10.1016/j.jmrt.2020.06.003
3. Shahar, F. S., Hameed Sultan, M. T., Safri, S. N. A., Jawaid, M., Abu Talib, Abd. R., Basri, A. A., Md Shah, A. U. (2022). Physical, thermal and tensile behaviour of 3D printed kenaf/PLA to suggest its usability for ankle–foot orthosis – a preliminary study. Rapid Prototyping Journal, 28 (8), 1573–1588. doi: https://doi.org/10.1108/rpj-08-2021-0207
4. Beigpour, R., Shokrollahi, H., Khalili, S. M. R. (2021). Experimental and numerical analysis of a biodegradable hybrid composite under tensile and three-point bending tests. Composite Structures, 273, 114255. doi: https://doi.org/10.1016/j.compstruct.2021.114255
5. Azlin, M. N. M., Sapuan, S. M., Zuhri, M. Y. M., Zainudin, E. S. (2022). Effect of stacking sequence and fiber content on mechanical and morphological properties of woven kenaf/polyester fiber reinforced polylactic acid (PLA) hybrid laminated composites. Journal of Materials Research and Technology, 16, 1190–1201. doi: https://doi.org/10.1016/j.jmrt.2021.12.046
6. Nurazzi, N. M., Shazleen, S. S., Aisyah, H. A., Asyraf, M. R. M., Sabaruddin, F. A., Mohidem, N. A. et al. (2021). Effect of silane treatments on mechanical performance of kenaf fibre reinforced polymer composites: a review. Functional Composites and Structures, 3 (4), 045003. doi: https://doi.org/10.1088/2631-6331/ac351b
7. Samat, N., Sulaiman, M. A., Ahmad, Z., Anuar, H. (2021). A comparative study on the desiccant effect of polypropylene and polylactic acid composites reinforced with different lignocellulosic fibres. Journal of Applied Science and Engineering, 24 (2), 223–231. doi: https://doi.org/10.6180/jase.202104_24(2).0011
8. Lee, C. H., Padzil, F. N. B. M., Lee, S. H., Ainun, Z. M. A., Abdullah, L. C. (2021). Potential for Natural Fiber Reinforcement in PLA Polymer Filaments for Fused Deposition Modeling (FDM) Additive Manufacturing: A Review. Polymers, 13 (9), 1407. doi: https://doi.org/10.3390/polym13091407
9. Radzuan, N. A. M., Tholibon, D., Sulong, A. B., Muhamad, N., Haron, C. H. C. (2020). New processing technique for biodegradable kenaf composites: A simple alternative to commercial automotive parts. Composites Part B: Engineering, 184, 107644. doi: https://doi.org/10.1016/j.compositesb.2019.107644
10. Nor Arman, N. S., Chen, R. S., Ahmad, S. (2021). Review of state-of-the-art studies on the water absorption capacity of agricultural fiber-reinforced polymer composites for sustainable construction. Construction and Building Materials, 302, 124174. doi: https://doi.org/10.1016/j.conbuildmat.2021.124174
11. Asim, M., Paridah, M. T., Chandrasekar, M., Shahroze, R. M., Jawaid, M., Nasir, M., Siakeng, R. (2020). Thermal stability of natural fibers and their polymer composites. Iranian Polymer Journal, 29 (7), 625–648. doi: https://doi.org/10.1007/s13726-020-00824-6
12. Chandgude, S., Salunkhe, S. (2021). In state of art: Mechanical behavior of natural fiber-based hybrid polymeric composites for application of automobile components. Polymer Composites, 42 (6), 2678–2703. doi: https://doi.org/10.1002/pc.26045
13. Ilyas, R. A., Zuhri, M. Y. M., Aisyah, H. A., Asyraf, M. R. M., Hassan, S. A., Zainudin, E. S. et al. (2022). Natural Fiber-Reinforced Polylactic Acid, Polylactic Acid Blends and Their Composites for Advanced Applications. Polymers, 14 (1), 202. doi: https://doi.org/10.3390/polym14010202
14. Senthil Muthu Kumar, T., Senthilkumar, K., Chandrasekar, M., Subramaniam, S., Mavinkere Rangappa, S., Siengchin, S., Rajini, N. (2020). Influence of Fillers on the Thermal and Mechanical Properties of Biocomposites: An Overview. Biofibers and Biopolymers for Biocomposites, 111–133. doi: https://doi.org/10.1007/978-3-030-40301-0_5
15. Whitworth, A. H., Tsavdaridis, K. D. (2020). Genetic Algorithm for Embodied Energy Optimisation of Steel-Concrete Composite Beams. Sustainability, 12 (8), 3102. doi: https://doi.org/10.3390/su12083102
16. Xiang, S., Wang, D., Yang, L., Tan, B. (2021). Study on the life cycle simulation method of the temperature field and temperature effect of a steel–concrete composite bridge deck system. Measurement and Control, 54 (5-6), 1068–1081. doi: https://doi.org/10.1177/00202940211020343

17. Cheng, Z., Zhang, Q., Bao, Y., Deng, P., Wei, C., Li, M. (2021). Flexural behavior of corrugated steel-UHPC composite bridge decks. Engineering Structures, 246, 113066. doi: https://doi.org/10.1016/j.engstruct.2021.113066
18. Ovuoba, B., Prinz, G. S. (2018). Investigation of residual fatigue life in shear studs of existing composite bridge girders following decades of traffic loading. Engineering Structures, 161, 134–145. doi: https://doi.org/10.1016/j.engstruct.2018.02.018
19. Ferreira, F. P. V., Tsavdaridis, K. D., Martins, C. H., De Nardin, S. (2021). Steel-Concrete Composite Beams with Precast Hollow-Core Slabs: A Sustainable Solution. Sustainability, 13 (8), 4230. doi: https://doi.org/10.3390/su13084230
20. Li, C., Lei, Z., Feng, Z., He, W., Tan, L. (2021). Research on static performance of lightweight STC-steel composite deck. J. Transp. Sci. Eng., 37, 26–33. doi: https://doi.org/10.16544/j.cnki.cn43-1494/u.2021.01.005
21. Lee, P.-G., Shim, C.-S., Chang, S.-P. (2005). Static and fatigue behavior of large stud shear connectors for steel–concrete composite bridges. Journal of Constructional Steel Research, 61 (9), 1270–1285. doi: https://doi.org/10.1016/j.jcsr.2005.01.007
22. Xu, X., Zhou, X., Liu, Y. (2020). Behavior of rubber-sleeved stud shear connectors under fatigue loading. Construction and Building Materials, 244, 118386. doi: https://doi.org/10.1016/j.conbuildmat.2020.118386
23. Cao, J., Shao, X., Deng, L., Gan, Y. (2017). Static and Fatigue Behavior of Short-Headed Studs Embedded in a Thin Ultrahigh-Performance Concrete Layer. Journal of Bridge Engineering, 22 (5). doi: https://doi.org/10.1061/(asce)be.1943-5592.0001031
24. Yang, D. (2021). Analysis of Fracture Mechanics Theory of the First Fracture Mechanism of Main Roof and Support Resistance with Large Mining Height in a Shallow Coal Seam. Sustainability, 13 (4), 1678. doi: https://doi.org/10.3390/su13041678
25. Wang, Y., Nie, J. (2009). Fatigue behavior of studs in a composite beam based on fracture mechanics. Qinghua Daxue Xuebao/Journal of Tsinghua University, 49 (9), 1467–1470.
26. Wu, X., Yu, H., Guo, L., Zhang, L., Sun, X., Chai, Z. (2019). Experimental and numerical investigation of static and fatigue behaviors of composites honeycomb sandwich structure. Composite Structures, 213, 165–172. doi: https://doi.org/10.1016/j.compstruct.2019.01.081