Vol. 6, No. 1, 2025, page 152-158
JTTM: Jurnal Terapan Teknik Mesin
p ISSN 2721-5377| e ISSN 2721-7825
http://jurnal.sttmcileungsi.ac.id/index.php/jttm

Numerical simulation and flexural strength analysis of jute/epoxy laminated composites using ANSYS workbench

M. Abdi Ruanda[1], Achmad Jusuf Zulfikar[1*], Suardi[2], Mulia[2], Din Aswan A. Ritonga[3]

[1*] Universitas Medan Area, Indonesia. Jl. Kolam no. 1, Medan Estate, Medan, Indonesia
[2] Universitas Tjut Nyak Dhien, Indonesia. Gg. Official No.28, Sei Sikambing C. II, Medan, Indonesia
[3] Universitas Harapan Medan, Indonesia. Jl. HM Joni No 70 C, Medan, Indonesia

* zulfikar@staff.uma.ac.id

Submitted: 21/03/2025 Revised: 16/04/2025 Accepted: 23/04/2025

Abstract: The increasing demand for environmentally sustainable yet mechanically efficient materials has driven interest in natural fiber-reinforced composites, particularly jute-based laminates. While jute fibers offer biodegradability and cost-effectiveness, their limited mechanical performance necessitates further study for structural applications. This research aims to evaluate the flexural behavior of jute/epoxy laminated composites using numerical simulation with ANSYS Workbench 2022 and validate the findings through experimental testing. The primary objectives are to (1) analyze the impact of jute fiber layer configurations on stress distribution and deformation behavior, (2) determine the correlation between the number of fiber layers and flexural strength, and (3) verify the accuracy of the numerical model using experimental data. The composite specimens were fabricated with one to four woven jute layers, following ASTM D790 standards, and tested using a three-point bending setup. Finite Element Method (FEM) simulations were conducted to evaluate stress distribution and identify optimal configurations. Results showed that increasing the number of jute layers significantly reduced stress concentrations and enhanced load-bearing capacity. A four-layer composite exhibited a 31.5% improvement in flexural strength compared to a single-layer configuration. Furthermore, numerical predictions closely matched experimental values, with deviation margins between 1.63% and 2.16%, confirming the model's reliability. These findings highlight the potential of jute/epoxy laminates as sustainable structural materials and demonstrate the effectiveness of FEM-based simulations in optimizing composite designs. Future research should explore hybridization strategies and environmental durability to further enhance performance for industrial applications.

Keywords: Jute fiber; laminated composites; flexural strength; numerical simulation; ANSYS Workbench

1. INTRODUCTION

The demand for sustainable and high-performance materials in engineering applications has led to the exploration of natural fiber-reinforced composites. Conventional materials such as metals and synthetic fiber composites have been widely used due to their high mechanical strength and durability [1], [2]. However, their production and disposal raise environmental concerns, including high energy consumption and non-biodegradability [3], [4]. Natural fibers, particularly jute, have emerged as a viable alternative due to their eco-friendly properties, lightweight nature, and cost-effectiveness. Jute fibers possess excellent tensile strength and stiffness, making them suitable for reinforcement in polymer matrix composites [5], [6]. However, challenges such as moisture absorption and limited mechanical performance compared to synthetic fibers necessitate hybridization with stronger reinforcements like E-glass [7], [8].

Hybrid laminated composites, combining natural and synthetic fibers, offer improved mechanical properties while maintaining environmental benefits [9], [10]. In flexural applications, such as structural components in automotive and construction industries, optimizing fiber composition and layer configuration is critical to achieving superior strength and durability [11]. While experimental studies provide valuable insights, numerical simulation using Finite Element Method (FEM) allows a detailed analysis of stress distribution and failure mechanisms, facilitating material optimization. ANSYS Workbench 2022, a powerful FEM-based software, enables the precise prediction of flexural behavior

p ISSN 2721-5377 | e ISSN 2721-7825
DOI 10.37373/jttm.v6i1.1563

in composite materials [12]–[14]. Therefore, this study employs numerical simulation to evaluate the flexural strength of jute/epoxy laminated composites and validate the results with experimental data [15]. Understanding the stress distribution and deformation behavior of these composites will contribute to the development of sustainable and high-performance materials for industrial applications.

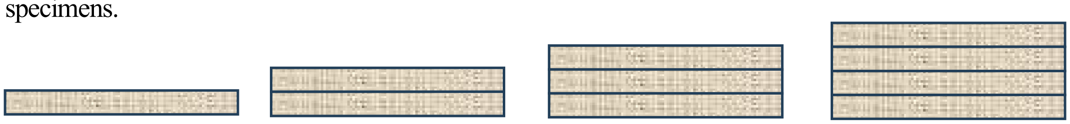
Several studies have investigated the mechanical performance of jute-reinforced composites, highlighting their potential as sustainable engineering materials. Studied the flexural strength of hybrid jute/hemp/flax composites and observed significant improvements with the addition of synthetic fibers [16]. Analyzed the impact and inter-laminar shear strength of jute/E-glass epoxy composites, demonstrating that hybridization enhances mechanical performance [17]. Conducted experimental testing on jute and glass fiber-reinforced composites, reporting that the inclusion of glass fibers increased flexural strength by up to 40%. These findings confirm the viability of jute-based hybrid composites for structural applications [18].

Finite Element Method (FEM) simulations have been widely used to predict composite behavior and optimize material configurations. Performed numerical analysis on hybrid composites under flexural loading and validated the results with experimental data, achieving high accuracy in stress distribution predictions [19]. Explored the bending behavior of hybrid composites and emphasized the effectiveness of FEM in identifying optimal layer arrangements [9]. Despite these advancements, limited studies have specifically examined the flexural strength of jute/epoxy laminated composites using numerical simulation. Additionally, there is a need to validate FEM predictions with experimental data to ensure modeling accuracy. This study addresses this gap by analyzing the flexural performance of jute/epoxy laminated composites through ANSYS Workbench 2022 simulations and comparing the results with experimental measurements. The research aims to establish a reliable numerical model for predicting the mechanical behavior of hybrid laminated composites, contributing to material optimization and sustainable engineering practices.

This study aims to investigate the flexural strength of jute/epoxy laminated composites using numerical simulation and validate the findings with experimental data. The specific objectives of this research are: (1) to analyze the effect of jute fiber layer configuration on stress distribution and deformation behavior in jute/epoxy laminated composites through numerical simulation using ANSYS Workbench 2022. This objective focuses on evaluating how different stacking sequences of jute fibers influence flexural stress and strain distribution under applied loads. The numerical approach will help identify the most effective layering arrangement for improved mechanical performance. Secondly, to assess the relationship between the number of jute fiber layers and the flexural strength of laminated composites, determining the optimal configuration for maximum load resistance. By systematically varying the number of jute layers, the study seeks to establish a correlation between fiber content and flexural properties. The results will provide insights into the structural integrity of jute-based composites for real-world applications. Finally, to validate the numerical simulation results by comparing them with experimental data, ensuring the accuracy of the FEM model in predicting flexural performance. This objective involves conducting a comparative analysis between simulated and experimental flexural test results. A minimal deviation between these datasets will confirm the reliability of the numerical model, making it a valuable tool for composite material design and optimization. By achieving these objectives, this study will contribute to the advancement of natural fiber composites and their application in sustainable engineering solutions. The findings will offer practical guidelines for optimizing laminated composite configurations to enhance flexural strength and durability while maintaining environmental benefits.

2. METHOD

The materials used in this study include woven jute fiber sheets as reinforcement and epoxy resin as the matrix. Jute fibers were selected due to their lightweight, biodegradability, and relatively high tensile strength, making them a viable alternative for composite applications. The composite specimens were designed with varying jute fiber layers, ranging from one to four layers, to evaluate the influence of fiber stacking on flexural strength. Each layer was arranged in a laminated structure, ensuring uniform resin distribution and adhesion. The composite laminates were modeled with standard dimensions of 120 mm in length, 20 mm in width, and 5 mm in thickness, following the specifications of ASTM D790 for flexural testing. This configuration allows for consistent stress distribution analysis and facilitates direct comparison with experimental results. The laminated structure is illustrated in Figure 1, depicting the jute fiber and epoxy matrix arrangement in the composite specimens.



(a) (b) (c) (d)

Figure 1. Schematic representation of jute/epoxy laminate composite configurations: (a) 1-ply, (b) 2-ply, (c) 3-ply, and (d) 4-ply woven jute fabric.

The flexural behavior of jute/epoxy laminated composites was analyzed using Finite Element Method (FEM) simulations in ANSYS Workbench 2022. A three-point bending test setup, as per ASTM D790, was modeled to simulate real-world loading conditions. The simulation process involved creating a 3D finite element model of the composite specimen, applying appropriate boundary conditions, and performing stress analysis. A tetrahedral mesh structure was used to ensure precise stress distribution calculations, with finer mesh regions around areas expected to experience high-stress concentrations.

The boundary conditions included fixed supports at both ends of the specimen while applying a downward load at the midpoint. Material properties, such as Young's modulus, Poisson's ratio, and tensile strength of jute and epoxy, were assigned based on literature values and experimental measurements. Figure 2 presents the three-point bending test setup used in the simulation.

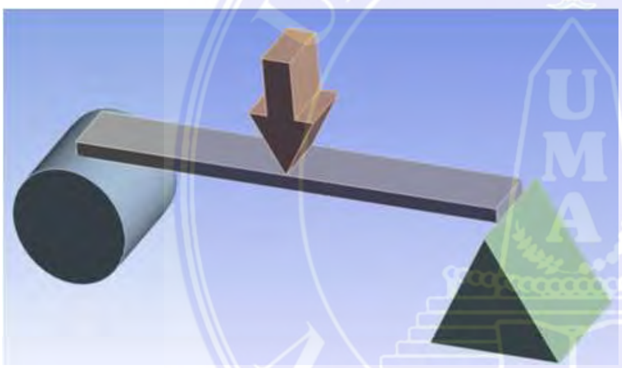


Figure 2. Three-point bending test setup in ANSYS Workbench 2022 (Simulation model showing loading conditions and boundary constraints).

To ensure the accuracy of the numerical simulation, the results were validated against experimental flexural test data. The experimental setup consisted of a universal testing machine (UTM) equipped with a three-point bending fixture, following ASTM D790 testing procedures. The numerical results were compared to experimental values for flexural strength, maximum stress distribution, and deformation behavior. The percentage error between the simulated and experimental results was calculated to assess model accuracy.

Validation was performed by plotting the stress-strain curves of both datasets and analyzing the deviation between them. A close match between the numerical and experimental results would indicate that the FEM model accurately represents the physical behavior of jute/epoxy laminated composites under flexural loading.

3. RESULTS AND DISCUSSION

The stress distribution analysis was conducted using Finite Element Method (FEM) simulation in ANSYS Workbench 2022 to evaluate the flexural behavior of jute/epoxy laminated composites. The simulation results revealed that the maximum von Mises stress was concentrated on the outermost layers of the composite, particularly on the top and bottom surfaces, due to the effects of tensile and compressive loading. As the number of jute layers increased, the maximum stress values decreased, indicating enhanced flexural resistance. This improvement is attributed to the additional fiber layers, which effectively distribute the applied load and mitigate local stress concentrations. The single-layer jute composite exhibited a peak stress of 1834.7 MPa, whereas the

p ISSN 2721-5377 | e ISSN 2721-7825
DOI 10.37373/jttm.v6i1.1563

four-layer composite demonstrated a reduced stress value of 1257.3 MPa—corresponding to a 31.5% increase in flexural strength. These findings suggest that increasing the number of fiber layers enhances the mechanical integrity of the composite by minimizing stress concentrations and associated deformations. The results align with the findings of the report that fiber orientation and layer quantity significantly influence stress distribution in FEM simulations using ANSYS [12], [20]. Figure *3* presents the stress distribution for various composite configurations.

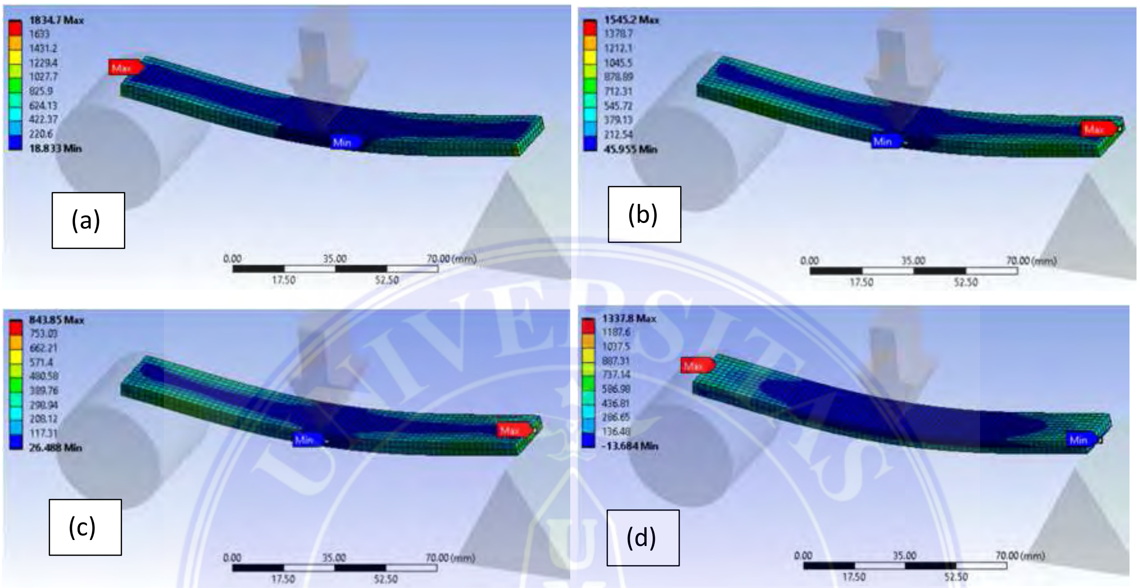


Figure 3. Stress distribution of jute/epoxy laminated composites under flexural loading: (a) 1-ply, (b) 2-ply, (c) 3-ply, and (d) 4-ply woven jute fabric

The configuration of layers plays a pivotal role in influencing the flexural performance of laminated composite specimens. Both experimental observations and numerical simulations underscore the significant effect that the number and sequence of jute fiber layers have on stress behavior and load-bearing capacity. Results from finite element method (FEM) simulations reveal a clear trend: increasing the number of jute layers within the composite tends to reduce the peak stress values while simultaneously enhancing the specimen's ability to withstand applied loads. This behavior is particularly noticeable under a three-point bending test setup, where specimens with a single jute layer often display greater deflections and pronounced stress concentrations, suggesting a higher susceptibility to early-stage failure. In contrast, specimens with multiple jute layers demonstrate improved stress dispersion, which contributes to enhanced structural resilience and reduced likelihood of crack initiation or propagation. Furthermore, the increase in jute layers correlates with a noticeable rise in the elastic modulus, suggesting that the stiffness of the composite is significantly improved as more jute sheets are added. However, this benefit must be carefully balanced, as excessive layering can introduce drawbacks such as increased material weight and complexity during the fabrication process. Achieving an optimal configuration that balances mechanical performance with practical manufacturability is therefore essential. The FEM simulation results show strong agreement with experimental data, with only minor deviations observed, thereby confirming the reliability of the numerical model. These findings are consistent with prior research. Who reported that increasing the number of composite layers from four to six more than doubled the maximum bending moment [21]. Demonstrated through FEM-based studies on sandwich structures that increasing the number of layers and adjusting their properties significantly enhanced stress distribution and bending resistance [22]. These trends support the present study's conclusions regarding jute/epoxy laminated composites. Figure *4* illustrates the comparative stress distribution across various layer configurations.

Validate the accuracy of the numerical simulation, the simulated flexural strength values were compared with experimental results obtained using a universal testing machine (UTM) by the ASTM D790 standard. The comparison demonstrated a strong correlation, with percentage deviations ranging from 1.63% to 2.16%. These results indicate that the FEM model accurately predicts the actual mechanical behavior of jute/epoxy laminated composites under flexural loading. The stress–strain curves derived from both experimental and simulation tests exhibited similar trends, further confirming the validity of the numerical model.

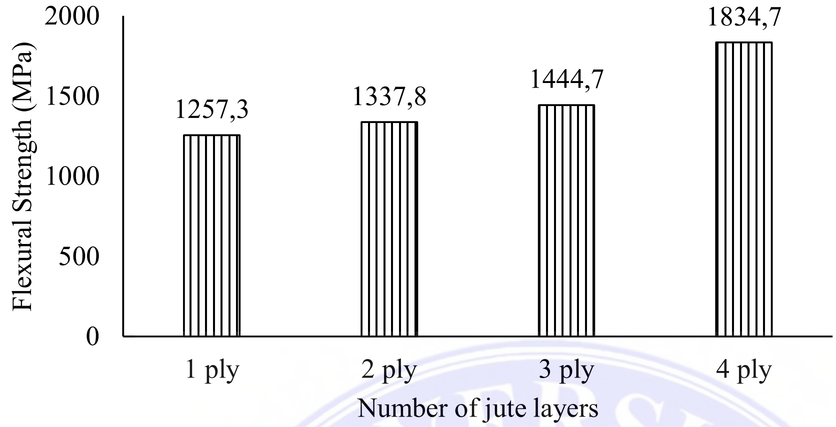


Figure 4. Effect of jute layer configuration on stress distribution.

The high level of agreement between the two datasets suggests that FEM is a reliable tool for optimizing laminated composite configurations without the need for extensive physical testing. Moreover, the findings underscore the potential of hybrid natural fiber composites for structural applications, particularly in the automotive and construction sectors. These results are consistent with the study which reported a deviation of approximately 10% between experimental and theoretical analyses, reinforcing the reliability of FEM in predicting flexural strength [23]. The present findings also align with those, who compared experimental data based on ASTM D790 with FEM-based ANSYS simulations and reported minimal differences, supporting the application of FEM for structural optimization in composite design [24]. *Figure 5* illustrates the comparison between experimental and simulated results.

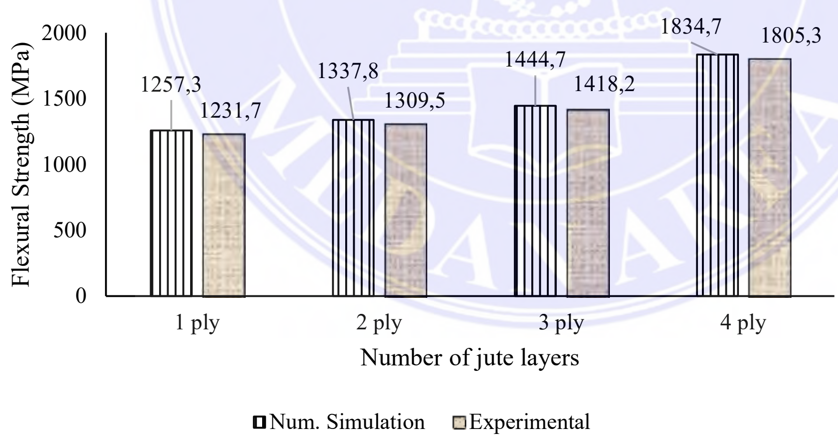


Figure 5. Comparison between experimental and simulated

These results demonstrate the effectiveness of jute fiber reinforcement in enhancing composite performance and validate the applicability of FEM simulations for structural material analysis. Future research should explore additional factors such as fiber orientation and environmental effects to further optimize composite properties.

4. CONCLUSIONS

This study successfully analyzed the flexural behavior of jute/epoxy laminated composites through numerical simulation using ANSYS Workbench 2022 and validated the results with experimental data. The findings provide critical insights into the effect of fiber layer configuration on stress distribution, deformation behavior, and overall flexural strength. First, the numerical simulation results demonstrated that increasing the

p ISSN 2721-5377 | e ISSN 2721-7825
DOI 10.37373/jttm.v6i1.1563

number of jute fiber layers significantly improved the stress distribution and load-bearing capacity of the composites. The stress concentration was primarily observed at the outermost layers, with higher stress values in single-layer configurations. As the number of layers increased from one to four, the maximum von Mises stress decreased by approximately 31.5%, confirming the role of multi-layer reinforcement in enhancing mechanical integrity. The stress distribution analysis also highlighted that additional layers contributed to reduced material deformation, thereby increasing the composite's resistance to bending loads. Second, the relationship between fiber layer configuration and flexural strength was established through numerical and experimental evaluations. The simulation results showed that higher fiber content resulted in improved flexural properties, with reduced stress accumulation and enhanced structural stiffness. However, excessive layering could lead to increased material weight and fabrication challenges, emphasizing the need for optimal layer configurations. The study confirmed that three to four layers of jute fiber provided an effective balance between mechanical performance and manufacturability for laminated composites. Third, the validation process demonstrated the high accuracy of the numerical model in predicting flexural behavior, with an error margin between 1.63% and 2.16% when compared to experimental data. The stress-strain curves from both simulation and experimental tests showed strong agreement, confirming the reliability of the FEM approach for composite analysis. These results suggest that numerical simulation can be a valuable tool in composite material optimization, reducing the need for extensive physical testing while ensuring precise mechanical performance predictions. In conclusion, this study reinforces the feasibility of using jute/epoxy laminated composites as sustainable alternatives in structural applications. Future research should explore fiber orientation, hybrid reinforcements, and environmental durability to further optimize material properties for industrial use.

ACKNOWLEDGEMENT

The authors express their sincere appreciation to Universitas Medan Area for its support throughout the completion of this research.

REFERENCE

[1] B. Praveena *et al.*, “Influence of Nanoclay Filler Material on the Tensile, Flexural, Impact, and Morphological Characteristics of Jute/E-Glass Fiber-Reinforced Polyester-Based Hybrid Composites: Experimental, Modeling, and Optimization Study,” *J. Nanomater.*, vol. 2022, no. 1, p. 17, 2022. https://doi.org/10.1155/2022/1653449

[2] A. J. Zulfikar and M. Y. Yakoob, “Hybrid Laminated Composite Casing As Concrete Reinforcement,” *Suranaree J. Sci. Technol.*, vol. 30, no. 5, pp. 1–10, 2023, doi: 10.55766/sujst-2023-05-e0870. https://doi.org/10.55766/sujst-2023-05-e0870

[3] A. Nayab-Ul-Hossain, S. K. Sela, M. A. Hasib, M. Alam, and H. R. Shetu, “Preparation of graphene based natural fiber (Jute)-synthetic fiber (Glass) composite and evaluation of its multifunctional properties,” *Compos. Part C Open Access*, 2022, doi: 10.1016/j.jcomc.2022.100308. https://doi.org/10.1016/j.jcomc.2022.100308

[4] A. J. Zulfikar, Y. Yaakob, H. M. Umarfaruq, and R. Syah, “Natural Jute Laminate for the Improvement of Strength Properties of Concrete Specimen,” *Eng. Trans.*, vol. 71, no. 1, pp. 507–518, 2023, doi: 10.24423/EngTrans.3120.20231017.

[5] N. Mostafa and M. B. Hunain, “Mechanical Performance and Vibration Characteristics of Glass/Jute Fibre-Reinforced Polyester Hybrid Composites,” 2019.

[6] A. J. Zulfikar, M. Y. Yaakob, and R. Syah, “Application of E-Glass Jute Hybrid Laminate Composite With Curved Shape on Compressive Strength of Cylindrical Column Concrete,” *J. Appl. Eng. Technol. Sci.*, vol. 5, no. 1, pp. 184–196, 2023, doi: 10.37385/jaets.v5i1.2072. https://doi.org/10.37385/jaets.v5i1.2072

[7] S. H. Mahmud *et al.*, “Fabrication and mechanical performance investigation of jute/glass fiber hybridized polymer composites: Effect of stacking sequences,” *Next Mater.*, 2024, doi: 10.1016/j.nxmate.2024.100236. https://doi.org/10.1016/j.nxmate.2024.100236

[8] A. J. Zulfikar, D. A. A. Ritonga, A. Purnomo, and T. Erdiansyah, “The Influence of e-glass epoxy composite laminate material application on the crack pattern of cylinder concrete column cross-section,” *J. Terap. Tek. Mesin*, vol. 5, no. 1, pp. 97–104, 2024. https://doi.org/10.37373/jttm.v5i1.889

[9] S. Margabandu and S. Subramaniam, “Experimental evaluation and numerical validation of

bending and impact behaviours of hybrid composites with various stacking arrangements," *Mater. Res. Express*, vol. 6, no. 1, pp. 33–43, 2019. https://doi.org/10.1088/2053-1591/ab54e7

[10] M. Y. Yuhazri, A. J. Zulfikar, and A. Ginting, "Fiber Reinforced Polymer Composite as a Strengthening of Concrete Structures: A Review," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1003, no. 1, 2020, doi: 10.1088/1757-899X/1003/1/012135. https://doi.org/10.1088/1757-899X/1003/1/012135

[11] A. J. Zulfikar, S. Pranoto, D. A. A. Ritonga, J. J. B. B. Butar, and B. O. Simanjuntak, "Efficacy of jute-glass hybrid laminate composite wrapping under flexural loading," *JTTM J. Terap. Tek. Mesin*, vol. 5, no. 2, 2024. https://doi.org/10.37373/jttm.v5i2.1214

[12] S. Shahriar, L. Jiang, J. Park, M. S. Islam, B. Perez, and X. Peng, "Experimental and FEA Simulations Using ANSYS on the Mechanical Properties of Laminated Object Manufacturing (LOM) 3D-Printed Woven Jute Fiber-Reinforced PLA Laminates," *J. Manuf. Mater. Process.*, 2024, doi: 10.3390/jmmp8040152. https://doi.org/10.3390/jmmp8040152

[13] A. J. Zulfikar, "The Flexural Strength of Artificial Laminate Composite Boards made from Banana Stems," *Budapest Int. Res. Exact Sci. J.*, vol. 2, no. 3, pp. 334–340, 2020.

[14] N. Johri, G. Agarwal, R. Mishra, and H. Thakur, "FEM analysis of polymeric hybrid composites," *Mater. Today Proc.*, 2021, doi: 10.1016/j.matpr.2021.12.248. https://doi.org/10.1016/j.matpr.2021.12.248

[15] H. A. Guangul, M. Prabhakar, D. W. Lee, and J. Song, "Development of hybrid green composites by dual natural fibers (jute/bamboo) reinforcement and investigation of their mechanical behavior," *Polym. Compos.*, 2024, doi: 10.1002/pc.28336. https://doi.org/10.1002/pc.28336

[16] V. Chaudhary, P. Bajpai, and S. Maheshwari, "Studies on Mechanical and Morphological Characterization of Developed Jute/Hemp/Flax Reinforced Hybrid Composites for Structural Applications," *J. Nat. Fibers*, vol. 15, no. 2, pp. 80–97, 2018. https://doi.org/10.1080/15440478.2017.1320260

[17] M. Sanjay, G. Arpitha, P. Senthamaraikannan, M. Kathiresan, M. Saibalaji, and B. Yogesha, "The Hybrid Effect of Jute/Kenaf/E-Glass Woven Fabric Epoxy Composites for Medium Load Applications: Impact, Inter-Laminar Strength, and Failure Surface Characterization," *J. Nat. Fibers*, vol. 16, no. 2, pp. 600–612, 2019. https://doi.org/10.1080/15440478.2018.1431828

[18] M. Y. Khalid, A. Al Rashid, Z. U. Arif, W. Ahmed, H. Arshad, and A. A. Zaidi, "Natural fiber reinforced composites: Sustainable materials for emerging applications," *Results in Engineering*, vol. 11. Elsevier B.V., Sep. 01, 2021. doi: 10.1016/j.rineng.2021.100263. https://doi.org/10.1016/j.rineng.2021.100263

[19] C. Dong, "Numerical study of hybrid composites containing basalt fibres under flexural loading," *SN Appl. Sci.*, vol. 1, no. 1, p. 287, 2019. https://doi.org/10.1007/s42452-019-0310-1

[20] J. M. Said, A. Jumahat, S. Kushairi, I. I. S. Azhar, and N. F. Azlan, "Maximum Bending Stress Analysis of Jute/Epoxy and Glass/Epoxy Polymer Composites," *Int. J. Integr. Eng.*, 2022, doi: 10.30880/ijie.2022.14.05.026. https://doi.org/10.30880/ijie.2022.14.05.026

[21] M. Bambach, "Experimental and numerical study of the bending strength of natural fibre composite structural channel sections," *Compos. Struct.*, 2019, doi: 10.1016/J.COMPSTRUCT.2018.11.031. https://doi.org/10.1016/j.compstruct.2018.11.031

[22] H. Mobark, M. T. M. F. Agha, L. Hammed, and S. A. Ameen, "Sandwich Structure Bending Analysis Using Finite Element Analysis," *J. Mech. Eng.*, 2024, doi: 10.47134/jme.v1i4.3396. https://doi.org/10.47134/jme.v1i4.3396

[23] S. K. K. Sharif, S. B. Shikkeri, and K. Rajanikanth, "Mechanical characterization of Jute/Banana/Epoxy reinforced laminate composite," *Mater. Today Proc.*, vol. 27, no. xxxx, pp. 835–839, 2020, doi: 10.1016/j.matpr.2019.12.379. https://doi.org/10.1016/j.matpr.2019.12.379

[24] F. Dorčiak, M. Vaško, F. Bárnik, and J. Majko, "Comparison of experimental flexural test with FE analysis for specimen with different size and shape of internal structure created by 3D printing's," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 776, no. 1, p. 12078, Feb. 2020, doi: 10.1088/1757-899X/776/1/012078. https://doi.org/10.1088/1757-899X/776/1/012078