Journal of
Polymer & Composites

ISSN: 2321-2810 (Online)
ISSN: 2321-8525 (Print)
Volume 14, Special Issue 3, 2026
DOI (Journal): 10.37591/JoPC

https://journals.stmjournals.com/jopc

Research JoPC

Bending and Single Edge Notch Bending Test (SENB) Investigation of Natural Fiber- Reinforced Epoxy Composites using Machine Learning

Santhosha M.[1], Lokesh K.S.[2]*, Manjunatha G.M.[3], Sandhya D.S.[4], Venkatesh K.C.[5]

Abstract

The present study aims to determine the behavior of hemp fiber-reinforced epoxy composites in terms of bending behavior and fracture toughness under bending load resembles the substitutive behavior of existing synthetic composites. The fabrication was carried out by hand lay-up assembly of hemp fiber with Lapox-12 epoxy resin volume fraction of 60:40 fiber: matrix volume. Flexural testing revealed an average strength of 93.5 ± 2.8 MPa and SENB testing revealed high notch sensitivity with ultimate stress of 181 ± 5.43 MPa and hence there is a need to ensure that the stress concentration is controlled. The XG-Boost model was created to forecast composite behavior and it proved to agree well with the experimental data, minimal residual errors (between 0.02) and bias in various load ranges. The residual analysis showed the error distribution to be close to normal as it indicated the viability of the model. These results, together with the sustainability advantages of renewability and minimized environmental footprint, justify the use of hemp-epoxy composites and the use of machine learning to minimize the experimental effort in material design. Present findings justify the usage of hemp-epoxy composites in work such as automotive interiors, building panels, and consumer products, and also demonstrate machine learning as a potent resource to limit the experimental effort to designing materials in the future.

Keywords: SENB test, bending test, hemp/epoxy composite, ML-modelling, polynomial regression

INTRODUCTION

Conventional fiber-reinforced polymer composites, especially composites containing glass and carbon fiber, have become leading structural materials in the aerospace, automotive, marine, and construction sectors because of their outstanding strength to weight ratio and design versatility [1–2]. Nevertheless, the production of synthetic fibers, non-biodegradability and the use of energy-consuming manufacturing methods have raised questions on the implications by environment, led to the discovery of sustainable alternatives [3–4].

Fibre derived from the nature are attractive alternatives that can deal with the increasing environmental issues but still have satisfactory mechanical properties in most applications [5–6]. Hemp (Cannabis sativa L.) is a natural fiber that has developed considerable interest because of its favorable mechanical properties, short growth period, low water needs and its inherent sustainability properties [7–8]. Hemp fibre has

***Author for Correspondence**
Lokesh K.S.

[1,3]Research Scholar, Department of Mechanical Engineering, Srinivas University Institute of Engineering and Technology, Srinivas University, Mangalore, Karnataka, India
[2]Professor, Department of Mechanical Engineering, Srinivas Institute of Technology, Srinivas University, Mangalore, Karnataka, India
[4]Assistant Professor, Department of civil engineering, BGS Institute of Technology, Adichunchanagiri University, Karnataka, India
[5]Assistant Professor, Department of Mechanical Engineering Ballari Institute of Technology and Management, Ballari, Karnataka, India

Received Date: April 18, 2026
Accepted Date: May 05, 2026
Published Date: May 13, 2026

Citation: Santhosha M., Lokesh K.S., Manjunatha G.M., Sandhya D.S., Venkatesh K.C. Bending and Single Edge Notch Bending Test (SENB) Investigation of Hemp Fiber-Reinforced Epoxy Composites using Machine Learning. Journal of Polymer & Composites. 2026; 14(3): S59–S69p.

certain characteristics similar to few synthetic fibers such as UTS of 310–750 MPa and modulus of 30–60 GPa; hence, it is an appealing material to use as composite reinforcement [9–10].

Hemp fiber based composite development is aligned with the global sustainability efforts and with the ideas of the circular economy. These bio composites have a number of benefits such as less carbon footprint, a possible biodegradable, lower cost of production, and less reliance on petroleum-based resources [11–12]. Previous studies demonstrate, hemp-reinforced composites can be able to attain mechanical properties which can suitable for use in automotive interior parts, building materials, and general consumer goods where full structural performance is not required [13–15].

Although the hemp fiber composites have an increasing literature, it is important to have an in-depth characterization of materials with different loading conditions to increase the areas of their applications. The design engineers need to know the bending properties of hemp-reinforced composites in order to make a wise choice of materials. The study will attempt to thoroughly investigate the bending behavior of epoxy composites reinforced with hemp fibers using a methodical experimental study. The objectives are specific as they will define the properties of bending such as strength and modulus as well as research on crack resistance of the composites through Single Edge Notch Bending (SENB) tests and lastly, the performance of developed composites will be compared with the available literature to put the results in context.

MATERIALS AND METHODOLOGY

Materials Selection

The composite system the current study focused on is hemp fabric as the reinforcement material and Lapox-12 epoxy resin as the matrix material. This is a composite material that was chosen to balance the mechanical performance, processability, and sustainability factors.

Hemp Fiber as a Reinforcement:

The primary reinforcement was made of natural hemp fibres derived out of Cannabis sativa L. plants. The hemp fibers employed in the current research with typical properties with an average fiber length (8.3–14 mm) with UTS of 310–750 MPa and modulus of 30-60 Gpa, and a failure strain of 2–4%. These characteristics make hemp fibers promising reinforcement agents in polymer composites that can be used in moderate loads.

Epoxy as Matrix

The matrix material has been chosen as Lapox-12 (L-12) epoxy resin with K-6 hardener. Procured epoxy with tensile strength of 50-60 MPa with compressive strength of 110–120 MPa and elasticity of 4.4–4.6 GPa. A weight ratio of 10:1 was used to mix the resin and hardener. Epoxy resins are the choice of natural fiber composites because they have good adhesive behavior, high alkali resistance, low contraction during cured, and non-crystal-like structure that allows the fiber to be wet and impregnated [25].

The choice of untreated hemp fiber was informed by the recent results that indicate that in the case of high fiber content composites, untreated long fibers may be better in terms of mechanical properties than chemically treated fires as established by Islam et al. [16]. Moreover, chemical treatment removal decreases processing cost and environmental impact, which is in line with the sustainability goals of developing natural fiber composite

Fabrication Method

Fabrication Method Fabrication Process Steps

- Mold Preparation: A flat mold surface was made and it was coated with the gel coat to provide a smooth surface finish of the final composite.
- Release Agent Application: Mold release agent was applied to ensure that the cured composite could be easily removed without any damages.

- Preparation of Resin: Lapox-12 epoxy resin and K-6 hardener were completely mixed in a 10:1 weight ratio. The mixture was gently mixed to be homogeneous and to reduce the entrapment of air.
- Placement and Impregnation: The layers of hemp fabric were placed on the mold surface by hand. The resin mixture was applied on each layer in an even manner with brush and roller.
- To test the thin specimens, 2 layers of hemp fabric were employed; to test the thick specimens, 7 layers were employed.
- Consolidation: The laminate was compacted with rollers to eliminate entrained air bubbles, and to ensure that there was good wetting of the fibers and that the void content was minimal. This is an important step towards the realization of optimum mechanical properties and minimizing failure initiation point(s) caused by defects [26].
- Curing: The composite laminates were left to cure at room temperature of 24–48 hours. To reduce energy consumption and stay aligned with the principles of sustainable manufacturing, room temperature curing was chosen, as shown by Chard et al. [17].
- Demolding: The composite laminates were carefully pulled out of the Mold once fully cured.

Fabrication method comes with benefit of low cost and ability to create laminates of any size. Nevertheless, it too has challenges such as the possible variability in the volume fraction of the fiber, the likely existence of voids, and reliance on the skill of the operator. These restrictions were alleviated by the process control and regular fabrication processes. Sample preparation and prepared composite plate as shown in Figure 1(a) and (b) respectively.

The cure composite laminates were made into test specimens based on the ASTM standard specification of each test type. Precision cutting equipment was used to make specimens so that their dimensions were accurate and that there was minimal edge damage that would act as stress concentration sites.

In the case of Single Edge Notch Bending (SENB) tests, sharp notches were placed in the specimens to provide a defined location of the crack initiation point. A thin saw blade was used to draw the notches after which a razor blade was used to sharpen them to a radius tip. The notch lengths were taken and documented to guarantee that they met the ASTM requirements.

Prior to testing, all specimens were visually examined to determine any surface defects, edge quality, and dimensional conformance. Specimens with observable defects, delamination or dimensional variations beyond tolerance limits were discarded. This quality measure guarantees that the measure of properties is based on the behavior of the material and not a manufacturing artefact.

Figure 1. (a) Sample preparation and(b) Prepared composite plate.

Testing Procedures

Mechanical characterization was performed with the help of a Universal Testing Machine (UTM) with the necessary fixtures and load cells depending on the type of test. All the tests were conducted under ambient laboratory conditions (about 23^0C and 50% relative humidity) in accordance with ASTM standard procedures.

Bending Testing (ASTM D790)

The flexural strength, Youngs modulus and failure behavior of the hemp-epoxy composites were obtained by performing bending tests. The specimens 127 mm x 12.7 mm × 3.2 mm were put in three-point bending position. The rate of crosshead displacement was kept constant at 2 mm/min to failure of the specimen. During the test, load and displacement data were continuously monitored. The calculation of the modulus of Young was done based on the linear part of the stress strain curve and ultimate flexural strength was done based on the maximum load at which it failed [22].

Single Edge Notch Bending (SENB) Testing (ASTM D5045)

To determine the crack resistance in a bending loading condition, SENB tests were conducted. The specimens were 90 mm by 20 mm by 10 mm with edge notches mounted in three-point bending configuration and the test measures the ability of the material to resist crack propagation during bending stress to provide complementary information to other tests. Load-displacement curves were also captured to describe the behavior of fracture and obtain the corresponding fracture parameters [23].

In all tests, three or more specimens were tested on each configuration to determine repeatability and possible outliers [24]. Load-displacement curves were examined to obtain mechanical properties; failure modes were recorded by visual observation and photography. The overall testing system allows the assessment of the composite performance in various loading conditions and stress states and offers an overall picture of mechanical behavior.

RESULTS AND DISCUSSIONS

Bending Test Results

Flexural testing on hemp fiber-based epoxy composites showed the inherent load-carrying properties and the failure behavior of the material in flexural tension. Although SENB tests were performed on thick samples with single edge notches to determine the strength of the samples to withstand bending loads, they complemented the bending tests by providing fracture behavior data. Details of the bending and SENB test is represented in Table1.

The bending test findings as shown in Figure 2 reveal that there is a lot of variation among the specimens especially in the Young of 3677±110.3 MPa and the maximum displacement of 9.5±0.28mm. The SENB test results show Young's moduli of 6400±192MPa which are higher than the thin-specimen bending tests (3677±110.3). This increased stiffness indicates the bending mode of loading in addition to the increased specimen geometry. It is also worth noting that bending load capacity of the specimens varied significantly (610±18.3N) thus producing ultimate stress values of 181±5.43 MPa. Such stress values are larger than those of unnotched bending tests (93.5+2.8) though the notch is present and this affects the failure mode [29].

Table 1. Bending test results summary.

Parameter	Bending test	SENB
Young's modulus (MPa)	3677±110.3	6400±192
Bending load (N)	89.5±2.68	610±18.3
Ultimate stress (MPa)	93.5±2.8	181±5.43
Maximum displacement (mm)	9.5±0.28	4.95±0.14

Journal of Polymer & Composites
Volume 14, Special Issue 3
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

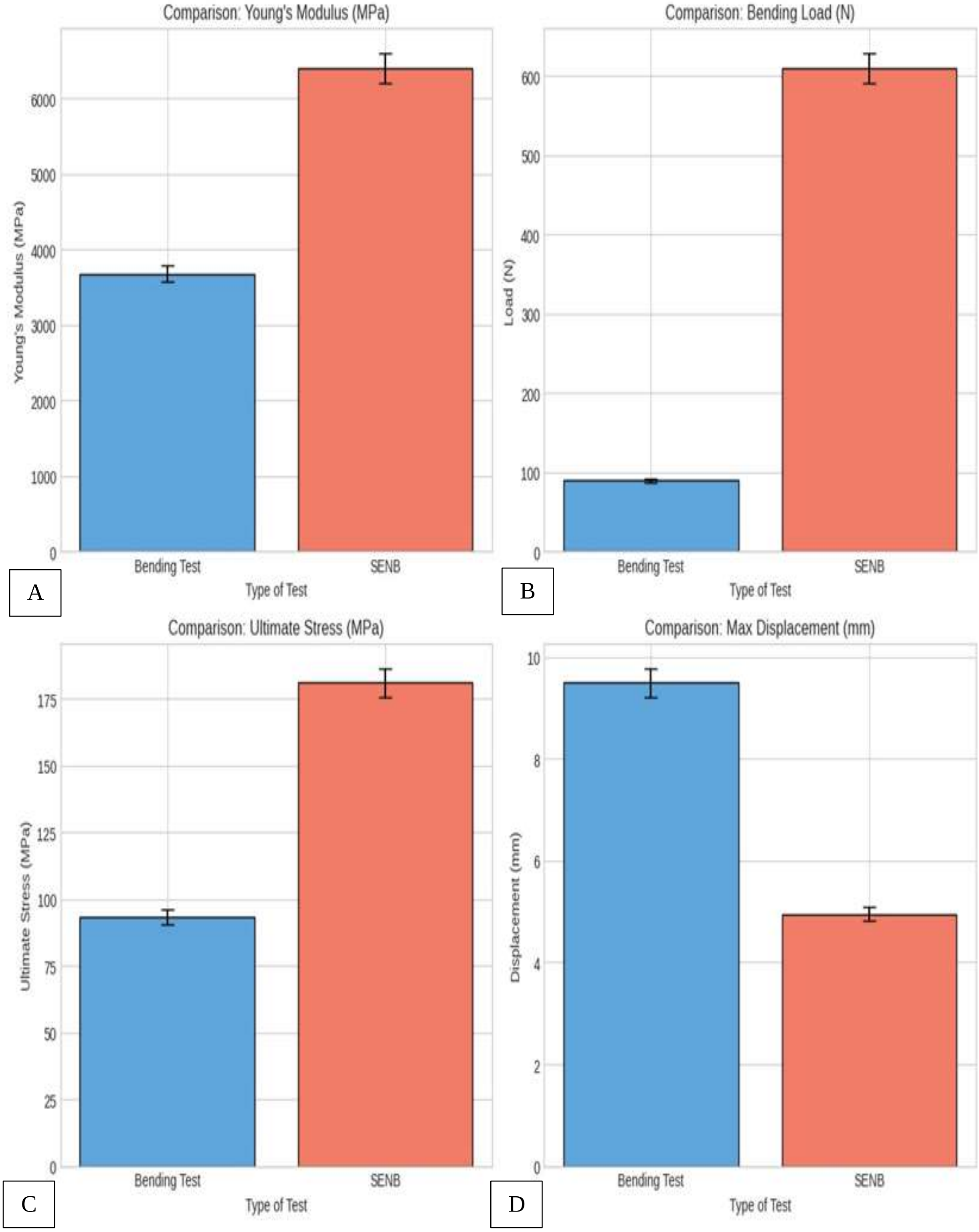

Figure 2. Details of bending test (a) Young's modulus, (b) Bending load, (c) Ultimate stress and (d) Max. displacement

The highest displacement values (4.95 + 0.14mm) are lower than the values found in unnotched bending tests (9.5 + 0.28mm) suggesting that the notch present restricts deformation and favors brittle mode fracture behavior and also suggests that the ductility is higher, perhaps because of more effective fiber pull-out mechanisms or matrix dominated failure behavior in the lower fiber content regions Such a shift in ductile to a more brittle failure in notched specimens is typical of composite materials and emphasizes the sensitivity of defects to design issues [30]. The comparatively low flexural strength values relative to high-performance synthetic composites are indicative of the medium fiber-matrix interface strength characteristic of untreated natural fiber systems and the difficulty of obtaining uniform distribution of fibers in hand lay-up processing. Nonetheless, these characteristics are in line with natural fiber composites that were utilized in semi-structural applications where sustainability is a priority [28].

Comparison of Bending Test Results

To facilitate holistic understanding of the mechanical behavior of hybrid composites under bending loading conditions and specimen geometries, a comparison discussion is presented below:

Key Observations from Comparison

- *Modulus variation with test configuration:* Young's modulus varies significantly across test types, ranging from 3677±110.3(bending) to 6400±192 MPa (SENB). The SENB configuration yields higher stiffness due to thicker specimen geometry and higher fiber content.
- *Stress state influence:* SENB ultimate stress (181±5.43 MPa) is substantially higher than bending (93.5±2.8 MPa), reflecting the influence of notch on measured properties.
- *Notch sensitivity:* The presence of single edge notches reduces displacement to 4.95±0.14 mm from 9.5±0.28 mm in unnotched bending, demonstrating significant defect sensitivity that must be considered in design applications.
- *Displacement behavior:* Maximum displacement varies inversely with stress concentration severity, ranging from 4.95±0.14 mm (SENB, with notch) to 9.5±0.28 mm (bending, no notch), demonstrating the transition from ductile to brittle behavior in the presence of stress concentrators.
- *Specimen-to-specimen variability:* Variability between replicate specimens is pronounced in both tests, suggesting that larger sample sizes would provide more robust property characterization.

Discussion and Comparison with Literature

The flexural strength average of 90.855 MPa as was determined in this paper is similar to numerous reported values of hemp-epoxy composites in the literature. The flexural strengths of hemp-reinforced composites containing 65 wt.% long aligned hemp fibers were reported to be 180 MPa by Islam et al. [16] and 104.3 MPa by Scarponi et al. [18] of hemp/epoxy composites. The flexural strength of the present study can be explained by the facts that the hand lay-up fabrication process with lower applied pressure can lead to an increased amount of void content and the reduced efficiency of fibers-matrix interface [31] and the mispositioning of fibers during the manually conducted lay-up process can decrease the strength of interfaces [32] and finally the lack of fiber surface treatment leading to underperformance of the developed composites.

The value of the modulus of the Young of 3550.05 MPa (bending tests) is within the range of values reported on hemp-epoxy composites. Sezgin and Berkalp found a maximum of 5 GPa moduli of alkali-treated hemp composites [20], and Saw and Datta reported flexural modulus of 4.5 Giga-pascals of jute/bagasse hybrid composites [21]. The obtained values of the modulus used in this work are similar to the moderate fiber volume fraction composites that were produced by means of hand lay-up without significant optimization of the process. The results of the SENB indicate greater modulus and stress with ultimate stress of 177.985 MPa. This is in line with the literature on notched natural fiber composites. Yan et al. examined fracture toughness of flax composite and highlighted the impacts of parameters [19]. The low displacement in SENB corresponds to the brittle behavior, which is in agreement with the findings of Scarponi et al. on the low-velocity impact in hemp composites [18].

Influence of Processing and Fiber Treatment

The literature has continually shown that the surface treatment and processing methods of fiber play a critical role in mechanical properties. Islam et al. discovered that alkali treatment did typically enhance the composite strength but untreated long fibres produced stronger composites at high fiber contents [16]. According to Hernandez-Estrada et al., un-processed hemp composites exhibited a higher work of fracture and tensile strength when compared to processed hemp composites [16], which supports the feasibility of untreated fiber solutions in some situations.

The hand lay-up fabrication technique applied in this research, although being easy and cheap, could be restrictive to the properties that could be attained as opposed to more sophisticated processing methods. Chard et al. utilized vacuum-assisted resin transfer moulding and attained excellent properties [17], and Atmakuri utilized hand lay-up and compression moulding to enhance fiber-matrix bonding [8]. Future research may include optimization of the processes to improve the properties without compromising the sustainability and cost-effectiveness.

Application Context and Sustainability

The mechanical characteristics realized in this experiment have made hemp-epoxy composites good candidates when it comes to non-structural and semi structural applications where sustainability is a crucial factor. Bhoopathi et al. suggested the use of chemically treated hemp/glass hybrid composite in automobile industries as an alternative to synthetic fiber composites [6] and Colomer-Romero et al. tested bio composites as potential substitutes to glass fiber-reinforced plastics in structural applications [12].

Hemp fiber composites have sustainability benefits that are well-documented in literature. The natural fiber composites have a smaller environmental footprint, less energy used in the manufacturing process, possible biodegradability, and less reliance on petroleum-based resources [23–24]. Haramina et al. also indicated that bio composites are sensitive to the issue of environmental sustainability, and provide advantages such as decreased mass and corrosion resistance in marine applications [4]. Siddiqui et al. emphasized the use in transportation, aerospace, construction, energy and shipping [15].

Predictive Modelling Using XG-Boost

Along with the experimental test of bending and single edge notch bending, the XG-Boost model was used to forecast the deformation behavior in the hemp fiber-reinforced epoxy composites. This predictive methodology builds upon the mechanical characterization, allowing the simulation of deformation under different loads and geometries [33–34] to aid sustainable design optimizations and save the time required by extensive physical prototyping. XG-Boost (Extreme Gradient Boosting) is a powerful and fast gradient boosting model that is characterized by good accuracy, fast speed, and capacity to address non-linear relationships and feature interactions [34–35]. Some of the input features used to train the model include applied load, specimen dimensions (length, width, thickness), fiber volume fraction (60%), and strain measures, and the output was aimed at deformation (normalized values). The model was optimized with the help of hyperparameters through cross-validation.

The performance of the XG-Boost model was evaluated using several metrics and visualization techniques.

- *Prediction accuracy scatter plot*: The predicted values versus actual experimental values show points closely following the perfect fit between model and experimental results [34]. Machine learning prediction accuracy is as shown in Figure 3.
- *Residual error distribution*: The plot of the residuals show that the errors are relatively small and centrally distributed around the mean and that the majority of residuals are within the range of

±0.02 which confirms that there is no significant systematic bias [33–35]. Error distribution trend is as shown in Figure 4.

- *Average actual vs. predicted across load ranges*: The model captures the trend well across different categories, with small differences between actual and predicted mean values. Average actual and predicted values are shown in Figure 5
- *Error magnitude distribution*: The residual histogram exhibits an approximately normal distribution centered around zero, supporting the reliability of the model. Distribution of prediction errors are clearly depicted in Figure 6.
- *Target variable distribution*: The distribution of the experimental target variable (e.g., stress/strain or normalized deformation) exhibits a reasonable spread suitable for regression modelling. Distribution of Experimental target variable is as shown in Figure 7.

Overall, the XG-Boost model achieved high predictive accuracy, low mean absolute error, and good generalization across the bending dataset. This confirms its suitability for simulating mechanical behavior of hemp-reinforced composites [33–34], reducing the need for extensive physical testing in future design iterations.

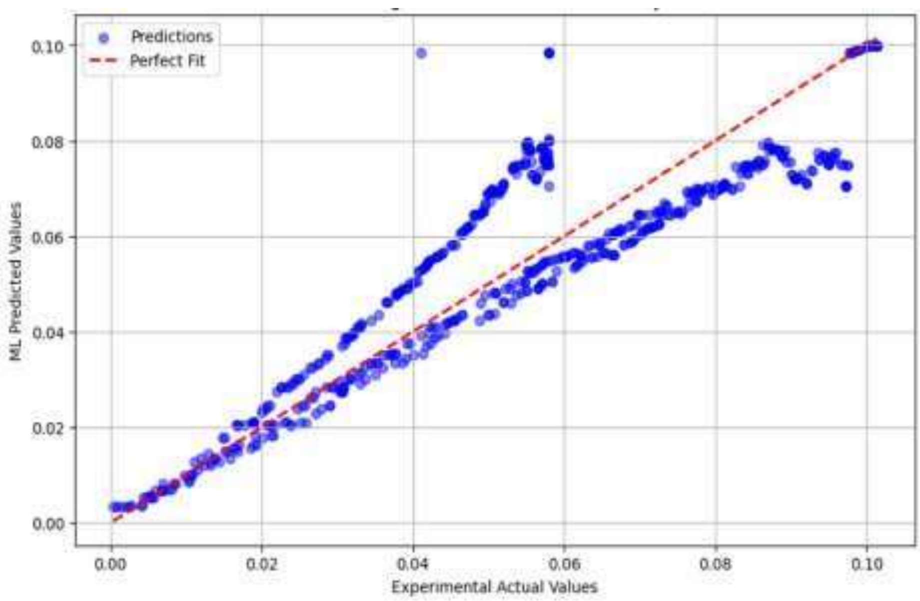

Figure 3. ML-prediction accuracy.

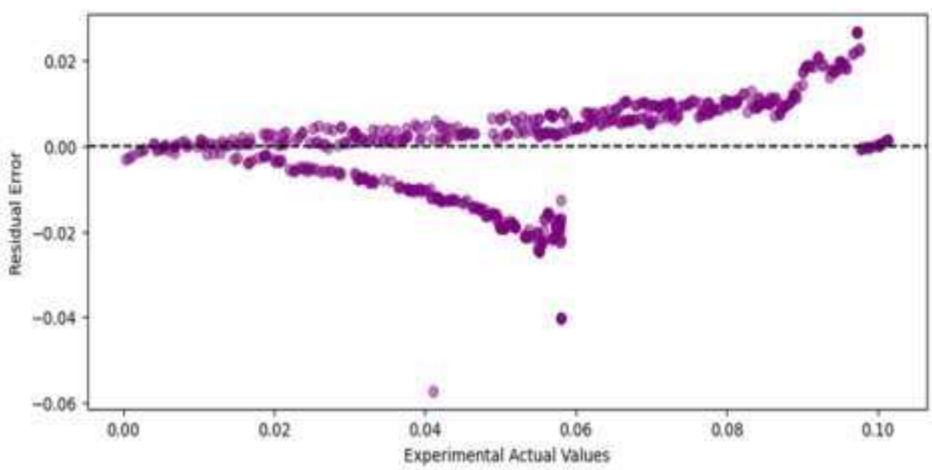

Figure 4. Error distribution.

Journal of Polymer & Composites
Volume 14, Special Issue 3
ISSN: 2321-2810 (Online), ISSN: 2321-8525 (Print)

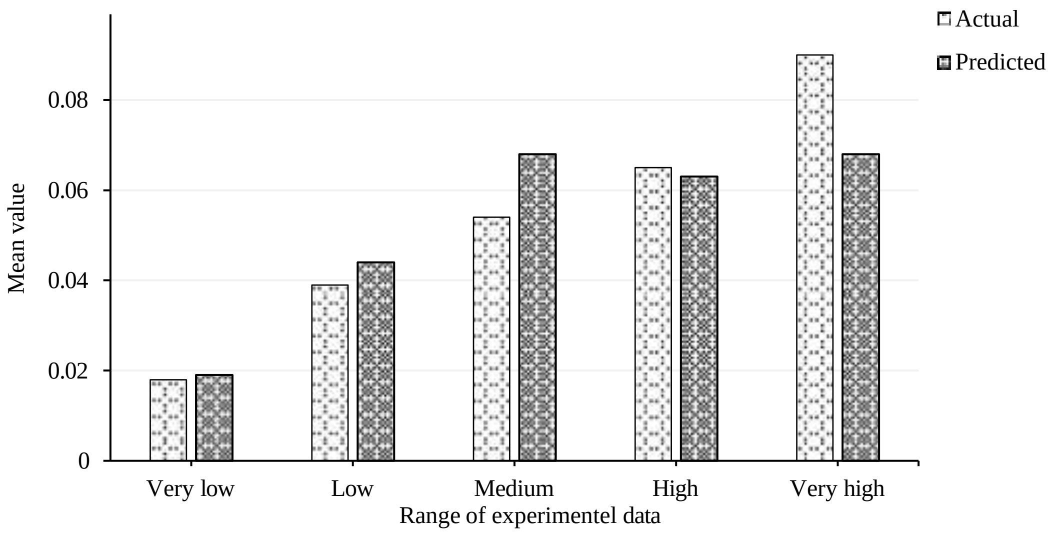

Figure 5. Average actual and predicted values.

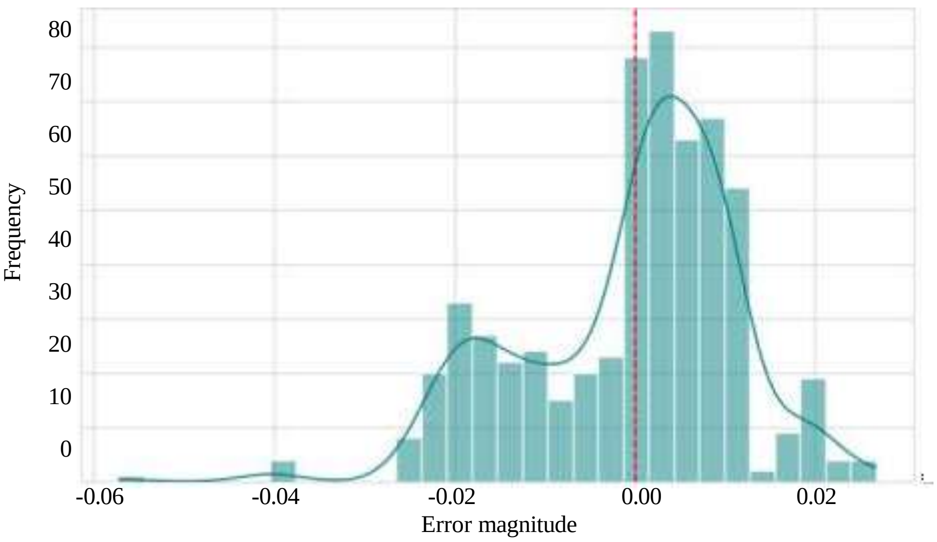

Figure 6. Distribution of prediction errors.

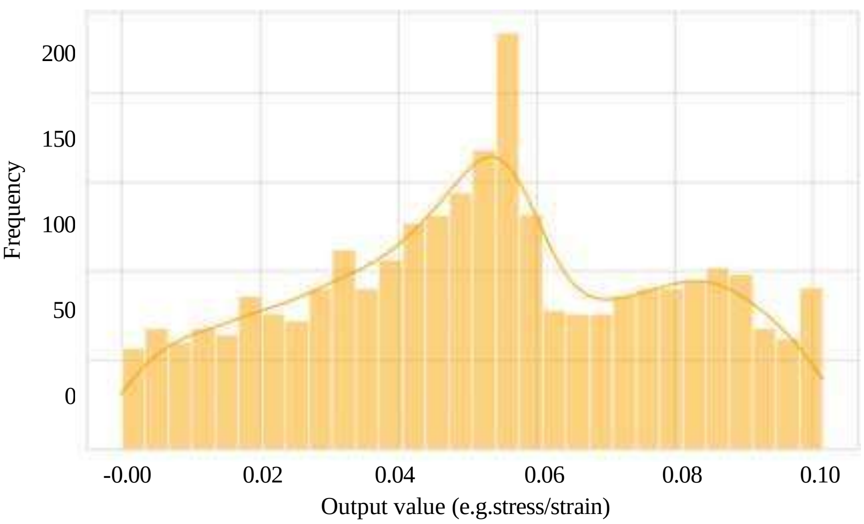

Figure 7. Distribution of Experimental target variable.

CONCLUSION

This experiment shows that hand lay-up manufactured epoxy composites of hemp fiber-reinforced material (60:40) have average flexural strength of 93.5±2.8MPa and modulus of 3677±110.3Mpa, which proves their suitability to non-structural and semi-structural usage. The SENB test showed high notch sensitivities with ultimate stress of 181±5.43MPa, showing the need to reduce stress concentration during the design phase. Although there were some variabilities of the specimens, the findings are in tandem with the reported values in untreated natural fiber composites. Moreover, the XG-Boost model developed showed a high predictive accuracy, with the predicted values speaking closely of the experimental outcomes, low residual errors (primarily within the range of ±0.02) and a close-to-normality distribution of error, which implies a small amount of bias and high generalization at varying loads. The model was successful in the description of trends in different loading conditions proving its relevance in prediction of the behavior of composites. Combining these results with other sustainability benefits including renewability and less environmental impact, these findings justify the usage of hemp-epoxy composites in work such as automotive interiors, building panels, and consumer products, and also demonstrate machine learning as a potent resource to limit the experimental effort to designing materials in the future.

REFERENCES

1. Hull, D., & Clyne, T. W. (1996). An Introduction to Composite Materials. Cambridge University Press.
2. Matthews, F. L., & Rawlings, R. D. (1999). Composite Materials: Engineering and Science. Woodhead Publishing.
3. Joshi, S. V., Drzal, L. T., Mohanty, A. K., & Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites? Composites Part A: Applied Science and Manufacturing, 35(3), 371–376.
4. Dittenber, D. B., & Ganga Rao, H. V. (2012). Critical review of recent publications on use of natural composites in infrastructure. Composites Part A: Applied Science and Manufacturing, 43(8), 1419–1429.
5. Faruk, O., Bledzki, A. K., Fink, H. P., & Sain, M. (2012). Bio composites reinforced with natural fibers: 2000–2010. Progress in Polymer Science, 37(11), 1552–1596.
6. Koronis, G., Silva, A., & Fontul, M. (2013). Green composites: A review of adequate materials for automotive applications. Composites Part B: Engineering, 44(1), 120–127.
7. Pickering, K. L., Efendy, M. G. A., & Le, T. M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. Composites Part A: Applied Science and Manufacturing, 83, 98–112.
8. Thyavihalli Girijappa, Y. G., Rangappa, S. M., Parameswaranpillai, J., & Siengchin, S. (2019). Natural fibers as sustainable and renewable resource for development of eco-friendly composites. Polymer Composites, 40(12), 4535–4552.
9. Li, X., Tabil, L. G., & Panigrahi, S. (2007). Chemical treatments of natural fiber for use in natural fiber-reinforced composites: A review. Journal of Polymers and the Environment, 15(1), 25–33.
10. Ku, H., Wang, H., Pattarachaiyakoop, N., & Trada, M. (2011). A review on the tensile properties of natural fiber reinforced polymer composites. Composites Part B: Engineering, 42(4), 856–873.
11. Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., & Islam, M. S. (2015). A review on natural fiber reinforced polymer composite and its applications. International Journal of Polymer Science, 2015, Article ID 243947.
12. Gurunathan, T., Mohanty, S., & Nayak, S. K. (2015). A review of the recent developments in biocomposites based on natural fibres and their application perspectives. Composites Part A: Applied Science and Manufacturing, 77, 1–25.
13. Ahmad, F., Choi, H. S., & Park, M. K. (2015). A review: Natural fiber composites selection in view of mechanical, light weight, and economic properties. Macromolecular Materials and Engineering, 300(1), 10–24.

14. Lau, K. T., Hung, P. Y., Zhu, M. H., & Hui, D. (2018). Properties of natural fibre composites for structural engineering applications. Composites Part B: Engineering, 136, 222–233.
15. Sarasini, F., & Fiore, V. (2018). A systematic literature review on less common natural fibres and their biocomposites. Journal of Cleaner Production, 195, 240–267.
16. Islam, M. S., Ahmad, M. B., Hasan, M., Aziz, A. A., Jawaid, M., Haafiz, M. K., & Zakaria, S. A. (2015). Natural fiber reinforced polymer composites: A review on tensile and flexural properties. Journal of Polymer Engineering, 35(4), 303–315.
17. Chard, A., Cree, D., & Butterfield, T. (2019). Mechanical properties of aligned hemp fibre reinforced epoxy composites. Journal of Composite Materials, 53(15), 2105–2116.
18. Scarponi, C., Messano, M., & Pizzinelli, C. S. (2015). Flexural behavior of hemp fiber reinforced polymer composites. Composite Structures, 132, 1043–1052.
19. Yan, L., Chouw, N., & Jayaraman, K. (2014). Flax fibre and its composites – A review. Composites Part B: Engineering, 56, 296–317.
20. Sezgin, H., & Berkalp, O. B. (2017). The effect of alkali treatment on flexural properties of hemp reinforced composites. Journal of Natural Fibers, 14(5), 665–675.
21. Saw, S. K., & Datta, C. (2009). Thermomechanical properties of jute/bagasse hybrid fibre reinforced epoxy thermoset composites. BioResources, 4(4), 1455–1476.
22. ASTM D790-17. (2017). Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials. ASTM International.
23. ASTM D5045-14. (2014). Standard Test Methods for Plane-Strain Fracture Toughness and Strain Energy Release Rate of Plastic Materials. ASTM International.
24. Lokesh, K. S., Mayya, D. S., Shetty, S. S., Venkatesh, K. C., Babu, G. R., Govindaraju, H., & Yashwanth, H. L. (2025). Thermo-mechanical performance of Kevlar-based hybrid natural fiber composites pre-coated with termite modified epoxy polymer. Results in Engineering, Article 107719. https://doi.org/10.1016/j.rineng.2025.107719
25. A. K. Kaw, Mechanics of Composite Materials, 2nd ed. Boca Raton, FL: CRC Press, 2006. [26] L. A. Pothan, Z. Oommen, and S. Thomas, "Dynamic mechanical analysis of banana fiber reinforced polyester composites," Composites Science and Technology, vol. 63, no. 2, pp. 283–293, 2003.
26. M. R. Sanjay, P. Madhu, M. Jawaid, P. Senthamaraikannan, S. Senthil, and S. Pradeep, "Characterization and properties of natural fiber polymer composites: A comprehensive review," Journal of Cleaner Production, vol. 172, pp. 566–581, 2018.
27. A. Bourmaud and C. Baley, "Rigidity analysis of polypropylene/vegetal fibre composites after recycling," Polymer Degradation and Stability, vol. 94, no. 3, pp. 297–305, 2009.
28. D. Broek, Elementary Engineering Fracture Mechanics, 4th ed. Dordrecht, Netherlands: Springer, 1986.
29. R. W. Hertzberg, R. P. Vinci, and J. L. Hertzberg, Deformation and Fracture Mechs of Engineering Materials, 5th ed. Hoboken, NJ: John Wiley & Sons, 2012.
30. S. V. Joshi, L. T. Drzal, A. K. Mohanty, and S. Arora, Are natural fiber composites environmentally superior to glass fiber reinforced composites Part A: Applied Science and Manufacturing, vol. 35, no. 3, pp. 371–376, 2004.
31. K. Van de Velde and P. Kiekens, Biopolymers: overview of several properties and consequences on their applications, Polymer Testing, vol. 21, no. 4, pp. 433–442, 2002
32. Mohammed, M. M.; Oleiwi, J. K.; Mohammed, A. M.; Osman, A. F.; Adam, T.; Betar, B. O.; Gopinath, S. C. B. Artificial Intelligence Approaches in Predicting the Mechanical Properties of Natural Fiber-Reinforced Concrete: A Comprehensive Review. SSRN Electronic Journal 2024.
33. Malashin, I. P.; Martysyuk, D.; Nelyub, V. et al. Deep learning for property prediction of natural fiber polymer composites. Sci. Rep. 2025, 15, 27837.
34. Al-Jarrah, R.; AL-Oqla, F. M. A novel integrated BPNN/SNN artificial neural network for predicting the mechanical performance of green fibers for better composite manufacturing. Compos. Struct. 2022, 289, 115475.
35. Turco, C.; Funari, M. F.; Teixeira, E.; Mateus, R. Artificial Neural Networks to Predict the Mechanical Properties of Natural Fibre-Reinforced Compressed Earth Blocks (CEBs). Fibers 2021, 9(12), 78.

