Fabrication and Mechanical Characterization of Bio-Based Reinforced Natural Fiber Composites

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Abstract:

The growing environmental concerns and depletion of non-renewable resources have increased the demand for sustainable and eco-friendly materials in engineering applications. Bio-based reinforced natural fiber composites have emerged as a promising alternative to conventional synthetic composites due to their biodegradability, low cost, light weight, and renewability. In this project, natural fibers such as jute, sisal, or hemp are used as reinforcement along with a suitable polymer matrix like epoxy or polyester resin. The study mainly focuses on the fabrication of these composites using the compression moulding technique and evaluating their mechanical performance. The fabrication process involves the preparation of natural fibers, including cleaning and alkali treatment to improve fiber–matrix bonding. The treated fibers are then arranged in a mould, combined with the resin matrix, and subjected to controlled pressure and temperature using a compression moulding machine. This method ensures uniform thickness, proper fiber distribution, reduced voids, and improved surface finish. After fabrication, the composite laminates are cooled, removed from the mould, and cut into standard specimens for testing. Mechanical characterization is carried out through tensile, flexural, impact, and hardness tests to evaluate the strength, stiffness, toughness, and surface properties of the composites. The results show that compression moulded natural fiber composites exhibit enhanced mechanical properties due to improved interfacial bonding and optimized processing conditions. These composites are found to be suitable for various applications such as automotive components, construction materials, and consumer products, thereby offering a sustainable and efficient alternative to traditional materials.

Keywords: Raime, Hemp, Jute fibers, Shell Powder, Resin, Hardner

1. INTRODUCTION

In recent years, the rapid depletion of natural resources and increasing environmental concerns have driven the need for sustainable and eco-friendly materials in engineering and industrial applications. Conventional composite materials, which typically use synthetic fibers such as glass or carbon, offer high strength and durability but pose significant environmental challenges due to their non-biodegradability, high energy consumption during production, and difficulties in disposal. As a result, researchers and industries are increasingly focusing on the development of bio-based reinforced natural fiber composites as a sustainable alternative. Natural fibers such as jute, sisal, hemp, bamboo, and coir are widely available, renewable, biodegradable, and cost-effective. These fibers possess good specific mechanical properties (strength-to-weight ratio), making them suitable for reinforcing polymer matrices. When combined with suitable resins such as epoxy, polyester, or biodegradable polymers like polylactic acid (PLA), they form composites that can be used in various engineering applications. Additionally, natural fiber composites offer advantages such as low density, reduced weight, less abrasion to machinery, and improved environmental compatibility. Among the various fabrication techniques available, compression moulding is one of the most effective and widely used methods for producing high-quality natural fiber composites. This method involves placing the fiber and matrix material into a mould and applying controlled pressure and temperature to form a dense and uniform composite structure. Compression moulding provides better fiber-matrix bonding, uniform thickness, reduced void content, and improved surface finish compared to other methods such as hand lay-up. It is also suitable for large-scale production, making it attractive for industrial applications.

The performance of these composites largely depends on factors such as fiber type, fiber orientation, fiber-matrix interaction, and processing conditions. To evaluate their suitability for practical applications, it is essential to study their mechanical properties through standardized testing methods. Mechanical characterization, including tensile, flexural, impact, and hardness tests, helps in understanding the strength, stiffness, toughness, and durability of the fabricated composites. This project focuses on the fabrication of bio-based reinforced natural fiber composites using the compression moulding technique and the evaluation of their mechanical properties

2. METHODS AND MATERIAL

The selection of materials utilized in composite fibers holds significant importance in defining the properties and potential applications of these sophisticated materials. Composite fibers are commonly fabricated by amalgamating two or more dissimilar materials, resulting in a unified structure that exhibits enhanced performance attributes. Presented below is a comprehensive outline detailing the materials employed in the production of composite fibers.

A. Jute Fiber Mat

Jute fiber mat is a natural reinforcement material made from jute fibers, which are extracted from the stems of the jute plant. It is widely used in composite fabrication due to its low cost, biodegradability, and good mechanical properties. Jute fiber mats are lightweight and possess a good strength-to-weight ratio, making them suitable for eco-friendly composite applications. They also exhibit good insulation and damping properties. In composite manufacturing, jute mats are used as layered reinforcement to improve strength and stiffness. Additionally, they are renewable, easily available, and contribute to sustainable development, making them an excellent alternative to synthetic

Figure:1 Jute Fiber Mat

B. Hemp Fiber Mat

Hemp Fiber Mat fiber mat is a natural reinforcement material made from fibers extracted from the stalk of the hemp plant. It is widely used in composite applications due to its high strength, durability, and eco-friendly nature. Hemp fibers have a good strength-to-weight ratio and provide excellent mechanical properties when used as reinforcement. The fiber mats are lightweight, biodegradable, and renewable, making them suitable for sustainable material development. In composite fabrication, hemp fiber mats improve stiffness, impact resistance, and structural performance. Additionally, they have good thermal and acoustic insulation properties, making them useful in automotive, construction, and industrial applications.

Figure:2 Hemp Fiber Mat

C. Ramie Fiber Mat Ramie fiber mat is a natural reinforcement material obtained from the fibers of the ramie plant, known for its high strength and durability. It is one of the strongest natural fibers and exhibits excellent tensile strength, making it suitable for composite applications. Ramie fiber mats are lightweight, biodegradable, and resistant to microbial attack, which enhances their performance and lifespan. They also possess good moisture absorption and thermal stability. In composite fabrication, ramie mats improve strength, stiffness, and dimensional stability. Due to their eco-friendly nature and superior mechanical properties, they are widely used in automotive, construction, and textile-based composite applications.

Figure:3 Ramie Fiber Mat

D. SEA SHELL POWDER

Seashell powder was used as a filler material in the composite. Sea shells are mainly composed of calcium carbonate ($CaCO_3$), which improves the stiffness, hardness, and strength of polymer composites. Sea shells were collected from coastal areas and cleaned thoroughly to remove impurities such as sand and organic matter. The shells were then dried and crushed into small particles using a grinding machine. The crushed shells were further pulverized into fine powder. The prepared powder was then dried in an oven at around 100–120°C for 2–3 hours to remove moisture before mixing with the epoxy resin.

Figure:4 Seashell powder

E. MATRIX MATERIAL

In composite materials, the constituent which is continuous and present in greater quantity is called matrix. The main functions of the matrix are to hold or bind the fiber together, distribute the load evenly between the fibers and protect the fiber from the mechanical and environmental damage. Epoxy resins are unique among all the thermoset resins due to several factors. The distinct properties of epoxy such as high corrosion and chemical resistance, outstanding adhesion to various substrate, good thermal and mechanical properties, good electrical insulating properties, low shrinkage upon cure, and the ability to processed under a variety of conditions make it suitable matrix material for the fiber reinforced composite materials . Epoxy resin has been used for the fabrication of polymer composites by several authors . Due to the above mentioned advantages, Epoxy (LY 556) chemically belongs to the epoxide family is selected as the matrix material for this project. The epoxy resin (density 1.15 gm/cc) and the corresponding hardener is HY-951.

Figure:4 Epoxy Resin and Hardner

F. Compression Moulding Method

Compression moulding is one of the commonly used techniques for manufacturing fiber reinforced polymer composites. In this method, pressure and heat are applied to shape the composite material and ensure proper bonding between the matrix, reinforcement fibers, and filler material. In the present study, the composite specimens were fabricated using the compression

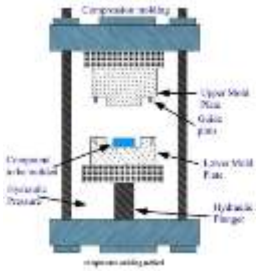


Figure: 5 Compression moulding

moulding technique with the help of a heater maintained at 80°C. Initially, the mould was cleaned thoroughly and a release agent was applied on the inner surfaces to prevent the composite from sticking to the mould. After that, the prepared resin mixture consisting of Epoxy Resin LY556 and Hardener HY951 in the ratio of 10:1 was poured into the mould. The previously prepared fiber mats of Jute fiber, Hemp fiber, and Ramie fiber were then placed layer by layer inside the mould. The resin mixture containing Seashell powder was applied uniformly over the fiber mats to ensure proper impregnation. After arranging the layers, the mould was closed and placed in the compression moulding setup. Heat was applied using a heater at 80°C, and pressure was applied uniformly for about 2–3 hours to allow proper curing of the composite laminate. After the curing process, the mould was allowed to cool at room temperature before removing the composite specimen. This method helps in producing composites with good strength, uniform thickness, and improved mechanical properties. After that we have to leave it for curing for 24hr at room temperature.

G. COMPOSITES

1) 110gms of (epoxy +hardener) + 80gms of fiber mats
2) 100gms of (epoxy +hardener) + 80gms of fiber mats + 14gms of seashell powder
3) 90gms of (epoxy +hardener) + 80gms of fiber mats + 18gms of seashell powder
4) 80gms of (epoxy +hardener) + 80gms of fiber mats + 22gms of seashell powder

3. RESULTS and DISCUSSION

The mechanical performance of the developed natural fiber reinforced composites was evaluated through tensile, flexural, and hardness tests. The results obtained for different compositions of epoxy resin, sisal fiber mat, seashell powder, and bird feather quill were analyzed to understand the effect of reinforcement and filler materials on the overall behavior of the composite.

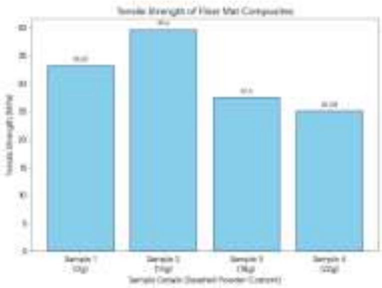
Table 1. Details of the Sample

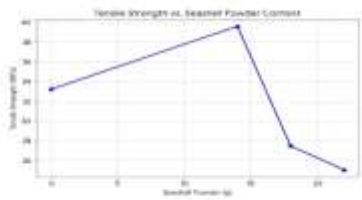
SN	Composite material	Size of sample(mm)	Tensile strength (MPa)	Elongation (%)	Hardness (ShoreD)	Flexural strength (Mpa)
1	Jute, Hemp, Ramie Fiber Mat 80gms+resin hardener 110g	100*150mm	33.22	5.54	76,77,78	69.86

2	Jute, Hemp, Ramie Fiber Mat 80gms+resin hardener 100g+seashell powder 14g	100*150mm	39.60	6.15	80,79,79	89.84
3	Jute, Hemp, Ramie Fiber Mat 80gms+resin hardener 90g+-seashell powder 18g	100*150mm	27.50	5.34	80,78,79	64.15
4	Jute, Hemp, Ramie Fiber Mat 80gms+resin hardener 80g+seashell powder 22g	100*150mm	25.08	5.68	76,77,77	67.27

Tensile Properties

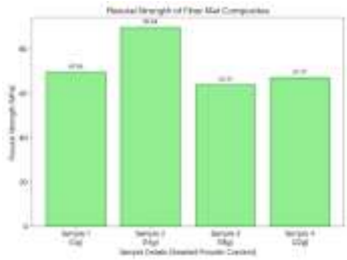
Tensile properties of the developed natural fiber composite were evaluated using tensile testing. The results showed that Sample 2 exhibited the highest tensile strength of 39.60 MPa and elongation of 6.15%, indicating improved ductility and strength due to optimal filler content. The addition of seashell powder enhanced the interfacial bonding between fiber and matrix. However, excessive filler content resulted in reduced tensile properties due to poor dispersion and weak bonding. Thus, tensile performance depends significantly on filler concentration and fiber-matrix interaction.

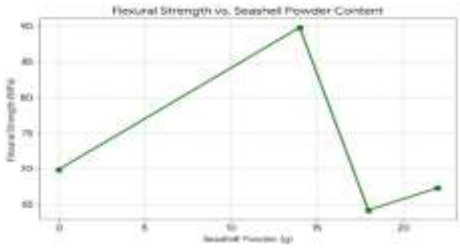




Flexural Properties

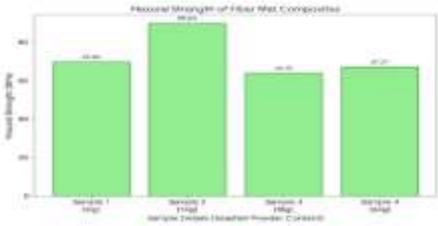
Flexural properties of the natural fiber composite were evaluated using a bending test. The results indicated that Sample 2 exhibited the highest flexural strength of 89.84 MPa due to optimal filler content and strong fiber-matrix bonding. The addition of seashell powder enhanced stiffness and load-bearing capacity under bending. However, excessive filler content in Samples 3 and 4 resulted in reduced flexural strength due to poor dispersion and weak interfacial adhesion. Thus, flexural performance is highly dependent on filler concentration and bonding quality





Hardness Properties

Hardness properties of the developed natural fiber composite were evaluated using the Shore D hardness test. The results indicated that Sample 2 exhibited the highest hardness value of approximately 79 Shore D due to the optimal addition of seashell powder, which enhanced surface rigidity and resistance to indentation. The presence of calcium carbonate-based filler improved the hardness of the composite. However, excessive filler content resulted in reduced hardness due to poor dispersion and weak interfacial bonding. Overall, the composites demonstrated good hardness suitable for engineering applications.



Overall Discussion

The overall mechanical performance of the natural fiber composite is strongly influenced by the filler content and fiber–matrix interaction. The results demonstrate that the incorporation of seashell powder up to an optimal level significantly enhances tensile, flexural, and hardness properties due to improved interfacial bonding and stress transfer. However, excessive filler content leads to agglomeration, void formation, and weak adhesion, resulting in reduced mechanical performance. Therefore, achieving uniform dispersion and optimal filler concentration is essential for developing high-performance natural fiber composites.

5. CONCLUSION

The mechanical characterization of the developed natural fiber reinforced composite (jute, hemp, and ramie fiber mat with seashell powder filler) revealed that filler content plays a crucial role in determining performance.

Among all samples, Sample 2 (14g seashell powder) exhibited the best overall properties, with:

- Highest tensile strength (39.60 MPa) indicating strong resistance to pulling forces
- Highest flexural strength (89.84 MPa) showing excellent bending performance
- Maximum elongation (6.15%) reflecting improved ductility
- Good hardness (~79 Shore D) indicating better surface resistance

The improvement in properties is mainly due to optimal fiber–matrix bonding and uniform filler dispersion, which enhances stress transfer within the composite.

REFERENCES

[1] Vivek, S., Kanthavel, K., Torris, A. and Kavimani, V., 2020. Effect of bio-filler on hybrid sisal-Banana- Kenaf-flax based epoxy composites: A statistical correlation on flexural strength. *Journal of Bionic Engineering*, *17*, pp.1263-1271.
[2] Srinivasan, V.S., Boopathy, S.R., Sangeetha, D. and Ramnath, B.V., 2014. Evaluation of mechanical and thermal properties of banana–flax based natural fibercomposite. *Materials & Design*, *60*, pp.620-627.
[3] Ari, A., Karahan, M.E.H.M.E.T., Kopar, M., Ahrari, M.A.Z.Y.A.R., Waseem, R.M. and Hussain, M.U.Z.A.M.M.A.L., 2023. Comparative analysis of natural fibers characteristics as composite reinforcement. *Ind*

Textila, *74*(4), pp.10-35530.

[4] Parre, A., Karthikeyan, B., Balaji, A. and Udhayasankar, R., 2020. Investigation of chemical,thermal and morphological properties of untreated and NaOH treated banana fiber. *Materials Today: Proceedings*, *22*, pp.347-352.

[5] Taj, S., Munawar, M.A. and Khan, S., 2007. Natural fiber- reinforced polymer composites. *Proceedings-Pakistan Academy of Sciences*, *44*(2), p.129.

[6] Tian, H., Zhang, Y.X., Yang, C. and Ding, Y., 2016.Recent advances in experimental studies of the mechanical behaviour of natural fiber-reinforced cementitious composites. *Structural Concrete*, *17*(4),pp.564-575.

[7] Manimaran, P., Pillai, G.P., Vignesh, V. and Prithiviraj, M., 2020. Characterization of natural cellulosic fibers from Nendran Banana Peduncle plants. *International Journal of Biological Macromolecules*, *162*, pp.1807-1815.

[8] FA, F., Siregar, J.P. and Tezara, C., 2016. Investigation of thermal behavior for natural fibers reinforced epoxy using thermogravimetric and differential scanning calorimetric analysis. In *MATEC Web of Conferences* (Vol. 78).

[9] Nurazzi, N.M., Asyraf, M.R.M., Rayung, M., Norrahim, M.N.F., Shazleen, S.S., Rani, M.S.A., Shafi, A.R., Aisyah, H.A., Radzi, M.H.M., Sabaruddin, F.A. and Ilyas, R.A., 2021. Thermogravimetric analysis properties of cellulosic natural fiber polymer composites: Areview on influenceofchemical treatments. *Polymers*, *13*(16), p.2710.

[10] Meenakshi, C.M. and Krishnamoorthy, A., 2018. Preparation and mechanical characterization of flax and glass fiber reinforced polyester hybrid composite laminateby hand lay-up method. *Materials Today: Proceedings*, *5*(13), pp.26934-26940.

[11] Fong, T.C., Saba, N., Liew, C.K., De Silva, R., Hoque,
M.E. and Goh, K.L., 2015. Yarn flax fibers for polymer- coated sutures and hand layup polymer composite laminates. *Manufacturing of natural fiber reinforced polymer composites*, pp.155-175.

[12] Holbery, J. and Houston, D., 2006. Natural-fiber- reinforced polymer composites in automotive applications. *Jom*, *58*, pp.80-86.

[13] Poddar, P., Islam, M.S., Sultana, S., Nur, H.P. and Chowdhury, A.M.S., 2016. Mechanical and thermal properties of short arecanut leaf sheath fiber reinforced polypropyline composites: TGA, DSC and SEM analysis. *J Material Sci Eng*, *5*(270), pp.2169-0022.

[14] E. Nirmala Devi, A. Surya Teja, K. Bhargav, M.Nithin Sai, N.Srikanth, 2019. Fabrication and Study of Mechanical Properties of Composite Natural Fiber. JETIR April 2019, Volume 6, Issue 4. pp 243-247.

[15] P.V.V.S.Maneendra, K.S.V.Gopala Reddy, K.Lokesh Kumar, CH.Rajesh, D.Saibabu, 2022. Determination and Analysis of Tensile Strength for Epoxy Refined Coconut Fiber Composite with Rice Hulls and Sawdust as Refinements. International Journal of Mechanical Engineering, Vol.7 No.4 (April, 2022) pp 1716-1719.

[16] Ismail, M., Rejab, M.R.M., Siregar, J.P., Mohamad, Z.,
Quanjin, M. and Mohammed, A.A., 2020. Mechanical properties of hybrid glass fiber/rice husk reinforced polymer composite. *Materials Today: Proceedings*, *27*, pp.1749-1755.

[17] Fuqua, M.A., Huo, S. and Ulven, C.A., 2012. Natural fiber reinforced composites. *Polymer reviews*, *52*(3), pp.259-320.

[18] Prabhu, L., Krishnaraj, V., Sathish, S., Gokulkumar, S., Karthi, N., Rajeshkumar, L., Balaji, D., Vigneshkumar, N.,Elango, K.S., Karpagam, J. and Vijayalakshmi, V.J., 2021. Experimental investigation on mechanical properties of flax/banana/industrial waste tea leaf fiber reinforced hybrid polymer composites. *Materials Today: Proceedings*, *45*, pp.8136-8143.

[19] FA, F., Siregar, J.P. and Tezara, C., 2016. Investigation of thermal behaviour for natural fibers reinforced epoxy using thermogravimetric and differential scanning calorimetric analysis. In *MATEC Web of Conferences* (Vol. 78).

[20] Siregar, J.P., Salit, M.S., Rahman, M.Z.A. and Dahlan, K.Z.H.M., 2011. Thermogravimetric analysis (TGA) and differential scanning calometric (DSC) analysis of pineapple leaf fiber (PALF) reinforced high impact polystyrene (HIPS) composites. *Pertanika Jour-nal of Science and Technology*, *19*(1), pp.161-170.

[21] Domke, P.V. and Mude, V.D., 2015. Natural fiber
reinforced building materials. *IOSR Journal of Mechanical and Civil Engineering*, *12*(3), pp.2320- 2334.

[22] Taj, S., Munawar, M.A. and Khan, S., 2007. Natural fiber-reinforced polymer composites. *Proceedings-Pakistan Academy of Sciences*, *44*(2), p.1