Journal of Materials and Environmental Science
ISSN : 2028-2508
e-ISSN : 2737-890X
CODEN : JMESCN

J. Mater. Environ. Sci., 2023, Volume 14, Issue 02, Page 246-254

http://www.jmaterenvironsci.com

Investigation on Mechanical Behavior of Bio Based Natural Hybrid Epoxy Composites

Sadashiva K. *, Nataraja M M., Balaji J, Kishan G. B, Preetham V, Nithin Teja B M, Nitin N

Department of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bengaluru, Karnataka 560056, India
**Corresponding author, Email address: sadashiva41@gmail.com*

Received *05 Dec 2022,*
Revised *26 Feb 2023,*
Accepted *28 Feb 2023*

Keywords:
✓ *Ramie Fabric;*
✓ *Basalt Fabric;*
✓ *Epoxy resin;*
✓ *Quasi-static Properties;*
✓ *Scanning Electron Microscopy*

Citation*: Sadashiva K., Nataraja M M., Balaji J. Kishan G. B. Preetham V. Nithin Teja B M. Nitin N. (2023) Investigation on Mechanical behavior of Bio Based Natural Hybrid Epoxy Composites, J. Mater. Environ. Sci., 14(2), 246-254.*

Abstract: Nowadays, a technological urge has been created in the field of natural fibre hybrid composites (NFHC) to meet industrial requirements and satisfy customers' needs. In order to minimize the synthetic materials' concern for nature by utilizing natural fibres in the fields of automobiles, aviation, and structural industries. In the present studies, natural ramie and basalt fibres were mixed with epoxy resin to form the hybrid composites by using a manual hand layup method. As per the ASTM standards, various mechanical studies were conducted as per the ASTM standards. The tests are to be like tensile, flexural, impact, and hardness. The test results revealed that the mechanical studies are enhanced by the incorporation of natural fibres like ramie and basalt. Scanning electron microscopy was used to investigate fibre fractures and debonding.

1. Introduction

Now a days the most widespread naturally occurring fibre is still ramie fibre. It accounts for around 60% of all composite materials made today and is utilised in the construction of automobile bodies, surfboards, sporting goods, swimming pool linings, and boat hulls. Basalt fibre is a substance created from the rock's incredibly fine fibres. Materials with varied combinations of low weight, great strength, and reasonable price are needed for modern technology.

The most industries like aerospace, mechanical engineering, space exploration, building, and pharmaceuticals, hybrid composites are displacing traditional materials. But there is still a need for a better modulus to density ratio. In this work, hand lay-up techniques were used to create natural fibre reinforced hybrid epoxy composites. Ramie and silk fibres in plain weave are utilised as reinforcement materials. Utilizing established test techniques, all created composites with mechanical attributes were evaluated (Sadashiva K et al., 2022). The fast depletion of fossil fuels and new government regulations that mandate the use of more materials derived from non-renewable sources, which add to these demands, make green materials appealing, especially in the production of novel composite materials (Kommula V P et al., 2016; Madhu P et al., 2018). The demand for environmentally friendly materials has drawn more attention to the use of materials produced from natural sources, which has led to the substitution of natural fibre composites for man-made fibre composites (Daniel P et al., 2010). In many developing countries, natural fibres also have extensive conventional production infrastructure, and their plantations can continue to employ large numbers of rural workers (Costa F H M M et al., 1999). They have been widely used for many applications over the years due to their abundant availability, biodegradability, recyclability, improved energy recovery, low production cost, less weight, high strength and specific modulus, and lower health risk. They have low density, low cost, less skin irritation, less equipment abrasion, less tool wear, improved energy recovery, and reduced skin and respiratory irritation (Akin D E et al., 2006; Saravanakumar S S et al., 2014). By using the procedures of carding, needle punching, and pressing, basalt, fiber-reinforced polypropylene matrix hybrid composites were created. Hemp, glass, and carbon fibers were also added to the basalt fiber in these composites. The hybrid effect in these composites was investigated as a function of fiber content and fiber combination. It was discovered that the qualities of the reinforcing fibers had a significant impact on the mechanical behavior of the composites under study (Czigany T et al., 2006). They took into account the applied load range and various forms of hybridization as test criteria. It was found that the tensile modulus of the fibers affects the composite's failure mode and that the fatigue resistance of carbon/basalt hybrid composites has significantly improved compared to that of the homogeneous basalt composite (Zhishen Wu et al., 2006). Compared to carbon FRP (CFRP) and glass FRP, basalt FRP (BFRP) is a relative new arrival to FRP composites (GFRP). An environmentally beneficial material is basalt fiber. It is economical and has excellent qualities such as a high strength-to-weight ratio, good ductility and durability, high thermal resistance, and strong corrosion resistance. The Engineers have used BFRP as an exterior bonded sheet material for post-earthquake restoration and strengthening (Wu G et al., 2008; Sim J et al., 2005; Chen W et al., 2017). Conducted tensile testing to examine the mechanical properties of basalt fiber-reinforced plastic with two different types of cloth. The proposed numerical model was also validated using numerical simulation. Additional basalt fibre products, such as bars and concrete additives, were studied (Valentino P et al., 2013). Additionally, research was done on the fatigue properties of several FRP composites comprised of carbon, glass, basalt, and hybrid fibers. The failure mechanism of composite coupons was discovered to be influenced by the fiber's tensile modulus, and carbon/basalt hybrid composites considerably increased the capability for fatigue resistance (Wu Z et al., 2010). Also studied high-strength BFRP tendon fatigue behaviour was investigated for prestressing applications. To guarantee 95% reliability for BFRP tendons in prestressing applications, the stress range of 0.04 and the maximum stress of 0.53 were proposed (Wang X et al., 2016). Sadashiva K et al., 2023 studied the ramie and silk fiber with epoxy matrix and the results revealed that the hybridization of composite materials has been increased, while incorporation of natural fibers. In the present investigation, the static tests were conducted using a universal testing machine (UTM). Ramie and basalt fibres were used as reinforcement materials in these studies, and epoxy resin grade LY 556 was used as a matrix material. To determine the mechanical characterization, quasi-static tests such as tensile, flexural, impact strength, and micro-hardness tests were performed, and SEM analysis was used to determine the interfacial bonding of the matrix and reinforcement materials.

2. Materials and Methodology

Ramie and Basalt fibers were supplied by Vruksha composite Guntur Andra Pradesh, India. Epoxy LY556 and hardener HY951 were supplied by Ultra Nanotech India Pvt Ltd Bengaluru. The manual hand layup method was used to create the hybrid composites of basalt fibre and ramie fiber, and the matrix was epoxy resin. The physical properties of the ramie and basalt fibres were illustrated in **Table 1,** and the sequence of the laminates was represented in **Table 2**. The ramie and basalt fibres were well combined, and these were weighed to determine how much epoxy resin to use in a 1:1 ratio of fiber. Epoxy resin was cured by adding HY 951 hardener at a ratio of 10:1. A stirrer was used during the stirring procedure to ensure that the mixture was homogenous (**Figure 1**).

Table 1: Physical properties of basalt and ramie fabric

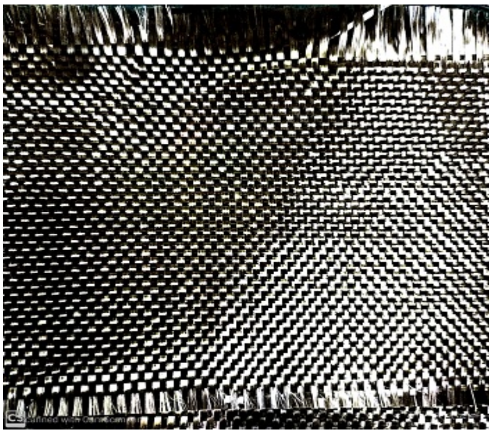
Properties	Basalt fabric	Ramie fabric
Density (g/cc)	2.75	1.50
Tensile strength (MPa)	4840	560
Elastic modulus (GPa)	89	61.4 - 128
Elongation at break	3.15	2-4
Moisture content (%)	0.15	8

Table 2: Laminate designations

Sl no	Laminates	Stacking Sequence
1	L1	R+R+R+R
2	L2	B+B+B+B
3	L3	R+R+B+B
4	L5	B+B+R+R
5	L6	R+B+B+R

A

B



C

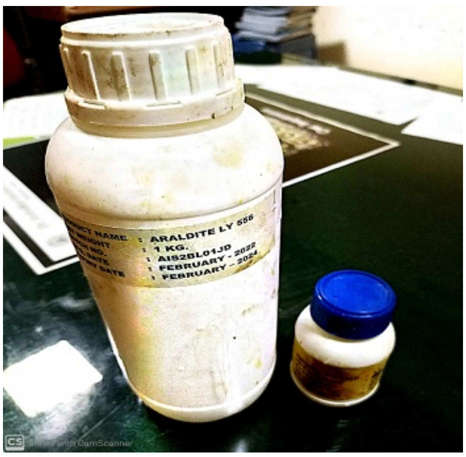


Figure 1. A. Ramie fabric B. Basalt Fabric C. Epoxy resin and hardener

Then, a mould with the dimensions of 300 mm x 300 mm x 3 mm was filled with the mixed fibre. Then the evenly distributed fibre arrangement was covered with the resin mixture. Then the evenly distributed fibre arrangement was covered with the resin mixture. Using the guiding pins set up on either end of the mould, the top mould (the other side) was positioned on top of the bottom mould. The mould was then placed under pressure in a compression moulding machine and left there for 3 to 4 hours at room temperature to cure, and the prepared laminates were put into an electrical oven at a temperature of 105^0 C to eliminate the moisture content and compensate the matrix material. Similar techniques were used to create specimens of various proportions, and the laminates were cut as per the ASTM standard.

3. Experiments

3.1 Tensile test

To determine the stress-strain behavior of the basalt and glass fibre reinforced polymer composites, a tensile test was conducted. According to ASTM D 3039 standard, this was carried out using a universal testing machine (UTM) with a cross head speed of 1.5 mm/min. The findings were averaged using four samples from each combination. This showed the polymer composites' tensile strength.

3.2 Flexural Test

The flexural modulus, flexural strength, and strain at break of the basalt and glass fibre reinforced polymer composites were determined using the three-point bending test. According to ASTM D790, a flexural test was performed on a UTM with a cross head speed of 1.5 mm/min. The sample included measurements of 127 mm, 13 mm, and 3 mm. The 80mm span length was preserved.

3.3 Impact strength

The amount of energy needed to break the specimen was measured using an impact test. According to ASTM D256 standard, an un-notched Izod impact test was used to measure the impact energy. The un-notched specimens were maintained in a cantilever posture, and the specimen was broken by rotating a pendulum. A dial gauge that was mounted on the machine was used to calculate the impact energy (J). For each test, five samples were used, and the average of the results was calculated.

3.4 Micro-Hardness Test

The hardness test for the various composition (L1 to L5) of hybrid filler composites was experimentally determined using a digital shore-D hardness durometer. The durometer is a device that is used for testing the hardness of polymer composites with an indenter pin that penetrates the specimen which is presented in digitally. (K. Sadashiva *et al.,* 2023) Hardness durometer measures up to 0.5 hardness number (HD) and the range of the measurement is about 0 to 100HD. It is noted that for HD being above 60, the material is considered to have high resilience, while the value below 60 is said to have a low resilience.

3.5 Scanning Electron microscopy (SEM)

A GABO qualimeter (Germany) model SEM instrument is used to observe the fracture surface of the tensile specimen. Before taking the photos, the surfaces of the shattered samples were covered with gold sputtering and chopped into small ($10x10x3mm^3$) pieces. This morphological test is used to understand fibre pullout, void identification in the composite, homogeneous filler content mixing in the matrix, reinforcement-matrix interface, and adhesion property behaviour between the fabric and matrix phases.

4. Result and discussions

4.1 Tensile Test

A universal testing machine (UTM) was used to study the tensile strength and tensile modulus of composite laminates L1, L2, L3, L4, and L5 of five different laminate designations was shown in **Figure 2**. The tensile strength of L1 laminates, which was 96.20 MPa for purely natural basalt fibre with epoxy, is higher than that of L2, which was 57.12 MPa for natural ramie fabric. The tensile modulus, which indicates material stiffness, is revealed by the composite L1, which has the highest modulus of 1806.21 MPa and the lowest modulus of 958.20 MPa. When the hybridization of composite materials is increased by incorporating and blending natural fibres and epoxy, natural rayon fibre performs better. The L3, a composite of two layers of ramie and two layers of basalt with an epoxy matrix, revealed a laminate with a result of 88.76 MPA and a modulus of 1208.50 MPa; thus, this hybrid composite combination outperforms the other two combinations. L4 has the strength of 80.70 MPa and a modulus of 1002.8 MPa, while L5 has the strength of 84.20 MPa and a modulus of 1158.6 MPa, respectively.

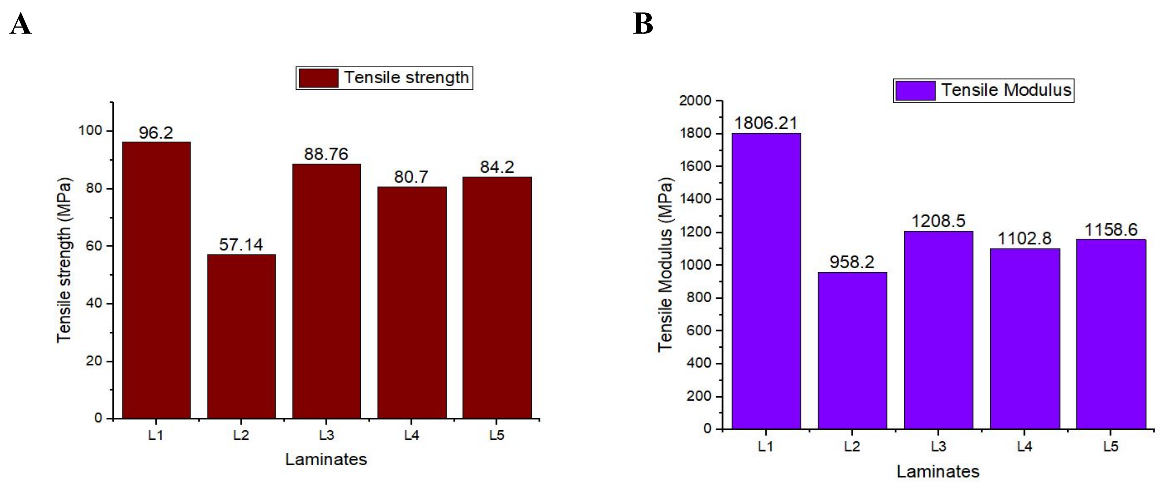


Figure 2. A. Tensile strength B. Tensile modulus

4.2 Flexural Test

Flexural testing is done to examine a material's resistance or bending characteristics. The flexural test was carried out by three-point bending methods, in which the specimens are placed between two points and supports, **Figure 3** illustrates the flexural strength and modulus of the composite materials. The laminate L1, which exhibited the highest value of flexural strength and modulus of 170.6 MPa and 14.40 GPa, was only made of natural basalt fabric with an epoxy matrix. The L1 has a pure ramie fabric with an epoxy composite, which revealed results of flexural strength and modulus of 154.40 MPa and 12.26 GPa, respectively. The hybridization of composite laminate L3, which was purely two layers of ramie and two layers of basalt fabric, shows the highest strength and modulus of 166.6 MPa and 13.66 GPa when compared to the other two hybrid composites. L4 has a strength of 162.4 MPa and a modulus of 12.24 GPa, and L5 has a strength and modulus of 163.40 MPa and 13.06 GPa, respectively.

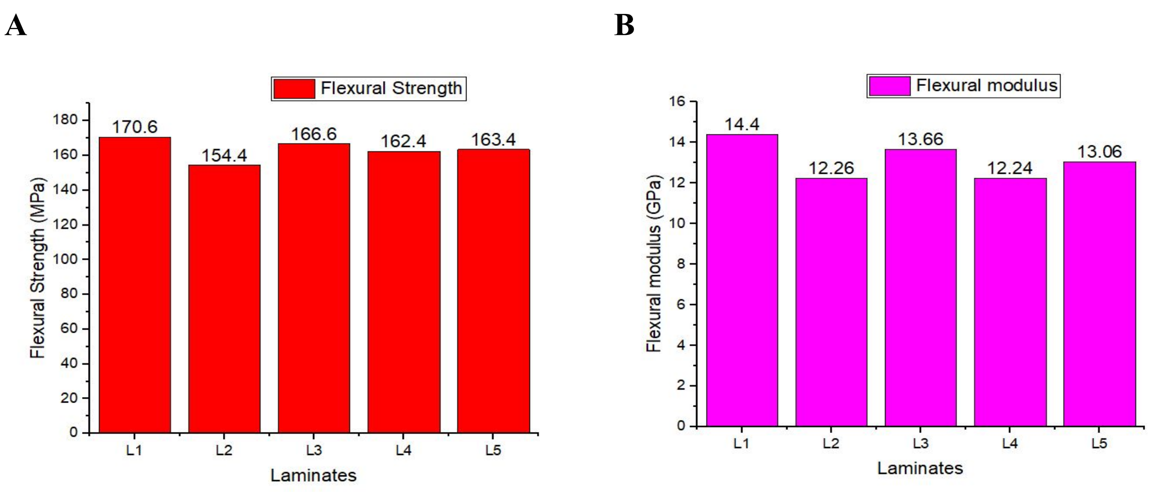


Figure 3. A. Flexural strength B. Flexural modulus

4.3 Impact strength

The ability of a material to bear a quickly imposed stress is known as impact strength, and it is expressed in terms of energy. It depicts how a material would react to a fast impact. **Figure 4** represents the impact strength of composite materials. This test demonstrates a material's capacity to absorb energy during an impact on the specimen. The laminate L1, with an impact strength of 37.68 kJ/m2, demonstrates the materials' ability to absorb energy; L2, on the other hand, has a pure ramie fabric composite material with an impact strength of 32.02 kJ/m2. The blended combination of hybrid composites is shown in Figure 4, i.e., L3, L4, and L5. L3, which was a combination of two layers of ramie and two layers of basalt, revealed the highest result when compared to the other two hybrid combinations. L3 has an impact strength of 33.04 kJ/m2, L4 has a strength of 31.62 kJ/m2, and L5 has a strength of 30.86 kJ/m2, respectively.

4.4 Micro-Hardness Test

The mechanical attribute of hardness is another important one. It assesses a component's resistance to minor plastic deformation, such as a scrape or dent. Any method for testing hardness involves forcing an indenter into the sample surface, followed by measuring the indentation. **Figure 5** illustrates the micro hardness of different composite materials. The L1 Laminate shows the highest hardness number, 92, which was a basalt fabric with epoxy matrix material. This kind of component resists scratch indentation. L2 has an 80 hardness rating and is made entirely of ramie fabric and epoxy. The hybrid composite material's hardness number has increased with the incorporation of both fibres with epoxy. L3 has an 88 hardness number, L4 has 86, and L5 has a hardness number of 85, respectively.

4.5 Scanning Electron microscopy

Figure 6 shows SEM images that correlate to the stacking order of all the produced composites. **Figure 6A** shows the stacking sequence of L1 laminates, which are four layers of purely basalt fibre with epoxy matrix, and **Figure 6B** L2, which is a composite of four layers of ramie fibre with epoxy matrix. It is observed that the ramie fibre has better bonding with the matrix. L3 has a composite of two layers of (outer layer) ramie and two layers of (inner layer) basalt fibres with an epoxy matrix shown in **Figure 6C;** in this instance, the fibres' ability to bind to the matrix is advantageous.

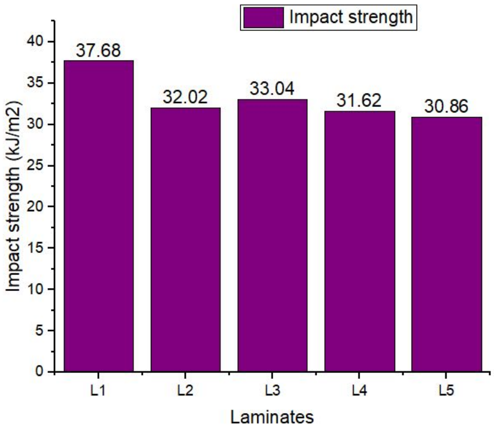


Figure 4. Impact strength of different laminates

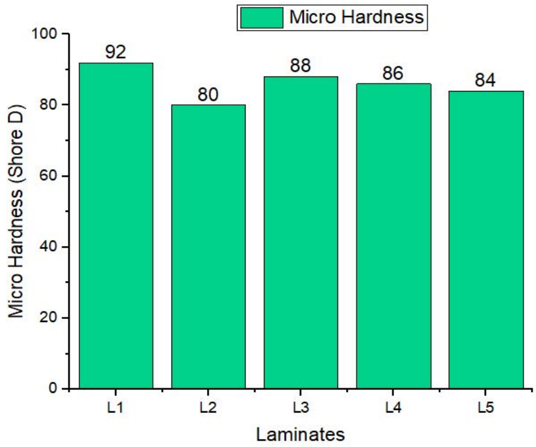
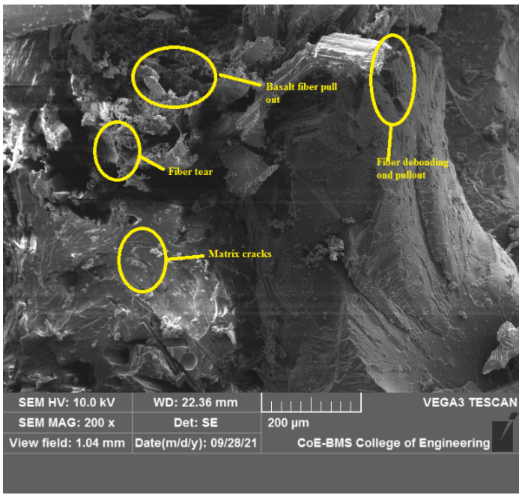
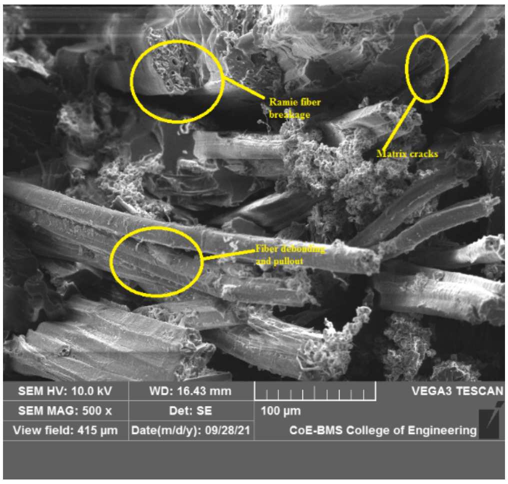


Figure 5. Micro- Hardness number of different laminates

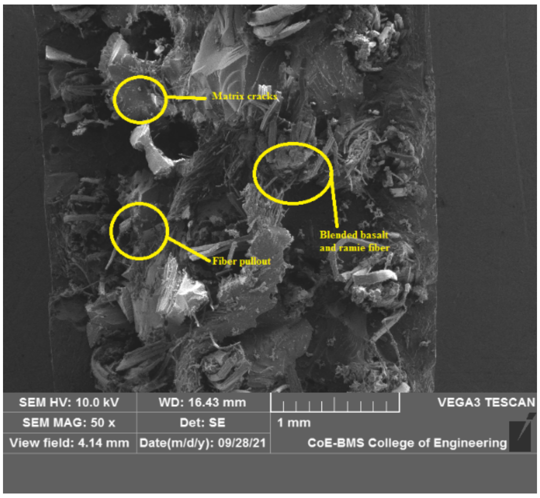
A



B



C



D

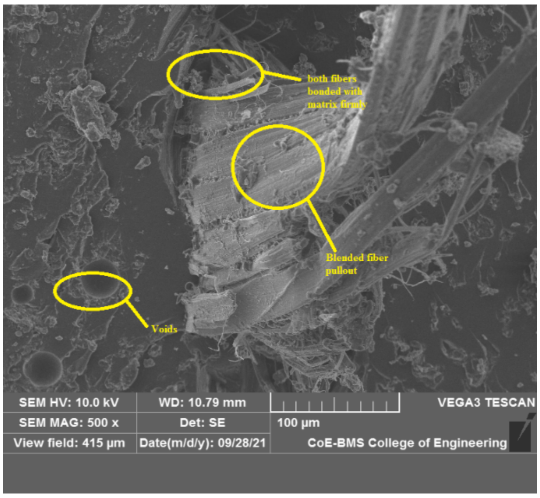


Figure 6. A. basalt composite B. Ramie composites C. Hybrid composites of L3 D. Hybrid composites of L4

L4 has a combination of two layers (the outer layer) of basalt and two layers (the inner layer) of ramie fibre with epoxy matrix were illustrated in **Figure 6D**. The fracture interface of an L1 composite, where excessive fibre debonding, fibre tearing, and fibre pullout occur as a result of inadequate matrix wetting, which reduces the composite's ultimate tensile strength. Since basalt fibre has more lumen and some lacuna, tensile loading cannot be applied to it, which transfers the load to the matrix and causes severe matrix cracks in the L1 composite. Ramie fibre exhibits better matrix bonding than basalt does in the L1 composite, as seen in **Figure 6A**. The narrower lumen and smaller diameter of ramie fibres enable them to withstand the tensile stress created during loading. As a result, the L2 composite's ultimate tensile strength is improved. The SEM image shows that crack initialization begins in the matrix before moving on to the ramie fibres. However, there is no fibre pullout because of the material's great tensile strength. In the composite, it is shown that the matrix splits and the fibres debond, resulting in low ultimate tensile strength. The ramie fibres' low strength causes greater fracture initialization in the matrix. **Figure 6D** demonstrates the basalt fibres' strong bonding properties with the matrix. This is mostly attributable to the surface treatment, which made it possible for the fibre to firmly attach to the matrix, increasing wettability. This characteristic contributed to the L4 composites' improved ability to support loads, which subsequently boosted their ultimate tensile strength**.**

Conclusion

This paper depicts the stacking sequence of basalt and ramie fabric materials with epoxy hybrid composites, the fabrication being done by hand layup. Most of the academicians and researchers in the polymer and polymer composite-based sectors view mechanical characterization testing as one of the most significant and widely used methods for assessing strength, stiffness, etc. In this investigation, basalt and ramie fibres reinforced with epoxy matrix were studied. The composite L1, which exhibited good mechanical characterization, enhanced the results when compared to L2 laminates. The hybrid composite laminate L3 (RRBB), which is made up of two layers of ramie and two layers of basalt, has better mechanical properties when compared to the other two hybrid composites, L4 and L5. As a result, this material is used in medium structural applications as well as railway coach interior parts.

Acknowledgement, The author express sincerely gratitude and heartfelt thanks to Department of Mechanical Engineering, Dr. Ambedkar Institute of Technology, Bengaluru for continuously supporting my Research work and publications..

Disclosure statement: *Conflict of Interest:* The authors declare that there are no conflicts of interest.
Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

References

Akin D. E., Foulk J. A., Dodd R. B., and Epps H. H. (2006). Enzyme-retted flax using different formulations and processed through the USDA flax fiber pilot plant. *Journal of Natural Fibers* 3, 55–68. doi: 10.1300/J395v03n02_04

Chen W., Pham T., Sichembe H., Chen L., Hao H. (2017). Experimental study of flexural behaviour of RC beams strengthened by longitudinal and U-shaped Basalt FRP sheet. *Compos Part B Eng* 2017. https://doi.org/10.1016/j.compositesb.2017.09.053

Costa F. H. M. M., and D'Almeida J. R. M. (1999). Effect of water absorption on the mechanical properties of sisal and jute fiber composites. *Polymer-Plastics Technology and Engineering* 38 (5), 1081–94. doi: 10.1080/ 03602559909351632.

Czigany T. (2006). Special manufacturing and characteristics of basalt fiber reinforced hybrid polypropylene composites: Mechanical properties and acoustic emission study Compos. *Sci. Technol.* 66, 3210–3220. https://doi.org/10.1016/j.compscitech.2005.07.007

Daniel P., Morais Teixeira E. D., Da Silva Curvelo A. A., Belgacem M. N., and Dufresne A. (2010). Extraction of cellulose whiskers from cassava bagasse and their applications as reinforcing agent in natural rubber. *Industrial Crops and Products* 32, 486–90. doi:10.1016/j.indcrop.2010.06.022.

Sadashiva K., Purushothama K. M. (2023). Physical and Mechanical Properties of Bio Based Natural Hybrid Composites” *Journal of Materials and Environmental Science,* 14 (01), 131-140.

K. Sadashiva, Purushothama K. M. (2022), Flexure and interlaminar shear properties of ramie/ silk fibre epoxy hybrid composite materials today: proceedings, 68, 2536-25. doi.org/10.1016/j.matpr.2022.09.357

Madhu P., Sanjay M.R., Senthamaraikannan P., Pradeep S., Saravanakumar S.S., Yogesha B. (2018). A review on synthesis and characterization of commercially available natural fibers: Part-I, *J. Nat. Fibers* 1–13 (2018) https://doi.org/10.1080/15440478.2018.1453433

Saravanakumar S. S., A. Kumaravel, T. Nagarajan, and I. Ganesh Moorthy. 2014. Investigation of physico-chemical properties of alkali-treated Prosopis juliflora fibers. International Journal of Polymer Analysis and Characterization 19 (4):309–17. doi:10.1080/1023666X.2014.902527.

Sim J., Park C., Moon D.Y. (2005). Characteristics of basalt fiber as a strengthening material for concrete structures. *Compos Part B Eng.;* 36, 504-12. https://doi.org/10.1016/j.compositesb.2005.02.002.

Valentino P., Furgiuele F., Romano M., Ehrlich I., Gebbeken N. (2013). Mechanical characterization of basalt fibre reinforced plastic with different fabric reinforcement’s tensile tests and FE-calculations with representative volume elements (RVEs). *CONVEGNO IGF XXII ROMA*; 2013. https://www.researchgate.net/publication/268141705

Kommula V.P., Reddy K.O., M. Shukla, T. Marwala, Reddy E.S., Rajulu A.V. (2016). Extraction, modification, and characterization of natural ligno-cellulosic fiber strands from napier grass, *Int. J. Polym. Anal. Char.* 21 (1), 18–28. doi:10.1080/1023666X.2013.784935.

Wang X., Shi J., Wu Z., Zhu Z. Fatigue behavior of basalt fiber-reinforced polymer tendons for prestressing applications. J Compos Constr 2016; 20(3). doi:10.1061/(ASCE)CC.1943-5614.0000649

Wu G., Wu Z., Lv Z., Wei H., Hu X. (2008). The outstanding advantages of applying Basalt Fiber Polymer (BFRP) in structure post-earthquake strengthening and rehabilitation. In: National symposium of Wenchuan earthquake damage investigation and analysis; 2008. doi:10.1016/j.compositesb.2017.05.069

Wu Z., Wang X., Iwashita K., Sasaki T., Hamaguchi Y. (2010). Tensile fatigue behavior of FRP and hybrid FRP sheets. Composites, Part B, 41, 396–402. https://doi.org/10.1016/j.compositesb.2010.02.001

(2023); http://www.jmaterenvironsci.com