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

J. Mater. Environ. Sci., 2023, Volume 14, Issue 8, Page 890-902

http://www.jmaterenvironsci.com

Investigative Studies on Mechanical and Morphological Characteristics of Ramie-Kevlar Fiber Reinforced Epoxy Hybrid Composites with Rice Husk as Filler

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Received *01 July 2023,*
Revised *21 July 2023,*
Accepted *23 July 2023*

Citation*: Sadashiva K., Nataraja M.M., Preetham V. Santhosh Y Chaturvedi K.C. Tarakeshwar Jane (2023) Investigative Studies on Mechanical and Morphological Characteristics of Ramie-Kevlar Fiber Reinforced Epoxy Hybrid Composites with Rice Husk as Filler, J. Mater. Environ. Sci., 14(8), 890-902.*

Abstract: The purpose of the current study is to determine the effects of laminate stacking arrangement on the physical, mechanical, and morphological properties of ramie and kevlar fabric reinforced with epoxy and filled with rice husk (RH). The aforementioned hybrid composite laminates were made using a manual hand layup technique, in accordance with ASTM standards, and for testing. Ramie and kevlar fibre laminates are put together with RH filler in weight ratios of 2%, 4%, and 6%. These laminates' hardness and density characteristics were investigated together with their tensile, flexural, and impact strengths. Pure synthetic kevlar composites perform better than pure natural ramie fibre composites in moisture absorption tests conducted at varying depths of immersion. A scanning electron microscope was also used to analyse the hybrid composites' surface morphology.

Keywords: *Ramie fiber; Kevlar fiber; Hybrid composites; rice husk; mechanical characterization*

1. Introduction

The current study examines the impact of laminate stacking pattern on physical, mechanical, and numerous commonplace products contain polymer composites. The automobile and maritime industries both use composites extensively. These applications' robustness and creep resistance are aided by good corrosion resistance, high stiffness-to-weight ratios, and other factors (Gujjala *et al,* 2014). Natural fibres are being used in consumer items and public structures due to the exorbitant expense of synthetic fibres used in aviation and military applications, such as alfa, banana, coconut husk, hemp, and sisal (Elidrissi *et al,* 2012; Elfalef *et al,* 2023; Mohammed *et al,* 2023). Natural and synthetic additives in banana peduncle fibre reinforced by polyester composites exhibited excellent fire-retardant properties (Ezeh *et al,* 2021). In comparison to conventional fibres, natural fibres provide a number of benefits, including biocompatibility, renewable resources, nontoxicity, combustibility, and high specific mechanical qualities (Mohanavel *et al,* 2021). Researchers have previously used natural fibres like silk and Ramie fibre to build composites (Sadashiva *et al,* 2022). Composite materials are regular composites that just have one form of reinforcement. Hybrid composites, made of more than one kind of fibre, are made using a single matrix material. As a result of their unique qualities, hybrid composites are more affordable than conventional composites. The focus of many researchers has been in this direction. The mechanical properties of hybrid polypropylene-banana-glass-fibre composites were calculated using the fibres of bananas reinforced polypropylene composites. The findings showed that a 30 weight percent fibre addition provided the biggest increase in characteristics (Mishra *et al,* 2014). The dynamic as well as static mechanical characteristics of reinforced epoxy FRP composites made of Graphite composites were examined (Fadi Alfaqs *et al,* 2021). Researchers studied the results of mixing fibre from banana and sisal plants with different oriented glass fibres (Sapuan *et al,* 2006). They investigated the mechanical properties of composite materials made from different-sized fibres. In comparison to hybrid composites, single-fibre composites perform less well. Mechanical properties such as tension, robust strength, and resistance were carefully studied using a sisal-jute-glass-fibre reinforced epoxy composite (Banerjee *et al,* 2014; Samal *et al,* 2009). The results of the investigation showed that jute and sisal fibres reinforced polymer composites enhanced the material's characteristics. They examined the mechanical characteristics of hybrid composites reinforced with coir and epoxy (Pothan *et al,* 2005; Arthanarieswaran *et al,* 2014; Liu *et al,* 2020). Investigations were made into the impact, tensile, flexural, interlaminar, and hardness properties of the hybrid composites as well as the effects of fibre loading and fibre length. High tensile and modulus strengths for hybrid composites reinforced with ramie and silk natural fibres are envisaged (Sadashiva *et al,* 2023). The hybrid mixture rule is used to compare the experimental outcomes. The rule of hybrid mixes discovered in this work is somewhat bigger than the experimental findings because tiny gaps between the fibre and the matrix emerge during composite manufacturing (Abdullah *et al,* 2013). The composites consisting of banana, glass, and flax fibres were the subject of this investigation. All of the materials outperformed a single fibre glass reinforced composite in terms of flexural and impact stresses (FRP). However, as the previous work shown, it might be difficult to pinpoint the precise physical properties of polymer composites made with unidirectional banana and jute fibres. Interest in composite materials made of hybrid fibres and polymers is high (Sathishkumar *et al,* 2013). In this work, a mixed composite with hybrid surface effects was created using unidirectional basalt fibers and Aluminium as a filler were used. One composite material was discovered to have a harder surface than the other two while having a different density (Ezhil Vannan, 2015; Bhagat *et al,* 2014). The organic (aramid) fibre known as Kevlar has a high modulus and tensile strength. It has become a popular material for a variety of uses, from body armour to structural components for aero planes. Due to its chemical stability, low weight, and incredible strength, Kevlar 49 is frequently utilized (Srinivasan *et al,* 2014). In this paper, we examine the basic physicochemical characteristics of Kevlar fibre. Therefore, we make a distinction between study on commercially available fibre and research on laboratory-produced polymers, which might be entirely different materials (Agarwal *et al,* 2019). The fiber's thermal properties, spectral properties, surface features, and long-term stability are all discussed in addition to its crystal and chemical structure. When applicable, we employ Kevlar qualities, a chemically similar but lower modulus fabric, together with mechanical attributes. Fibre-reinforced composites have a high performance-to-weight ratio, which makes them very promising in a range of sectors (Standard, 2014). In addition to being lightweight and surpassing ordinary metallurgical products in terms of tensile modulus and weight, carbon fibre composite components are widely known, particularly in aviation and other specialized technological domains. Kevlar aramid fibres might replace carbon fibres in various applications because of its greater specific strength, increased extensibility, and high modulus (Dhal *et al,* 2013). These aramid fibres (PPT) begin as poly-(p-phenylene terephthalamide). Molecular chains' stiffness causes a liquid-crystalline solution to develop. This procedure will produce an organized piece of fabric with originally designed pleated sheets. Only if they have poor collisional qualities in comparison to other fibres can they be utilised as reinforcing components in engineering assemblies. Tensile strength to compressive strength ratios for Kevlar 49, glass and carbon fibre are 5.0, 1.1, and 1.9 respectively. Greenwood and Rose contend that rather than the matrix, the very low compressive yield strength of the fibres is the primary cause of the poor performance of Kevlar composites (Elbehiry *et al,* 2021; Cabral *et al,* 2005). The stems of the ramie plant, Boehmeria nivea, are used to make the fibre known as ramie. The use of technologies and clothing made in Ramie has not extended to other continents. Ramie finds it very difficult to separate the gum content of collected fibres, which may include up to 30% gum by weight of fibre. The gum prevents spinning the fibre if it is present. The gum must be removed as a consequence. The perennial plant ramie, often called China grass, belongs to the Urticaceae family. Currently, China and other Asian countries like the Philippines and Thailand are where the majority of it is cultivated. Ramie fibre, which originates from the plant's stem bast and used to make fabrics, has properties including maximum tensile, a thermal characteristics, cooling, aeration, wettability, and antibacterial activities (Mahna *et al,* 2021; Srinivasa *et al* 2019). The aim of this study is to examine the potential use of kevlar and ramie in epoxy matrix composites, as well as the effects of adding rice husk as a filler to the composites to enhance their kevlar and ramie content on their morphological, mechanical, and physical behaviour.

2. Materials and Methods

In this investigation, the reinforcing materials used are the Ramie and Kevlar fabric supplied by Vruksha Composite Guntur, Andhra Pradesh, India. Table 1 displays the physical characteristics of the fibres and epoxy. UltrananoTech India Pvt. Ltd. acquired the epoxy resin in grade LY556 and the hardener in grade HY951. Epoxy and hardener were used in a 10:1 ratio to prepare the matrix section for printing. The paddy shells, which had been powdered and dried for two to three days in the sun, were used to make the rice husks. The composites were manufactured by manually hand-laying up laminates filled with rice husk, ramie, and kevlar. The four layers of ramie and kevlar textiles, totaling six distinct kinds of laminates, were made to measure at 300x300x3 mm3. Variable weight percentages of 2, 4, and 6 are inserted into the filler. The weight % approach was taken into consideration while preparing the reinforcing layers. In order to create the aforementioned laminates, a metal mould was used. The mould's bottom and top surfaces were originally sprayed with silicon. According to the necessary laminate designation shown in **Table 2**, where R stands for ramie fibre and K stands for kevlar fibre, the fibre fabric was laminated one after the other. Brushes were used to apply the epoxy glue between the layers of fabric, and a roller action was used to readily remove any air bubbles that may have developed throughout the procedure on the reinforcement. After the mould has dried for about 48 hours, the hybrid composite laminates are next placed in an electric oven at 110^0 C for 5 hours to remove the moisture content. In accordance with ASTM recommendations for quasi-static testing, the laminates were removed from the oven and processed using a water jet cutting apparatus. The primary sources used in the present research are shown in **Figure 1**.

Table 1: physical properties of the epoxy and fibres

Description	Ramie fiber	Kevlar fiber	Epoxy
Density (g/cm^3)	1.5	1.45	1.1
Tensile strength (MPa)	560	3176	35 - 135
Tensile modulus (GPa)	61.4 - 128	135	3.4

Elongation (%)	2-4	2.8	1-8.5

Table 2: Laminate Identification

Sl no	Laminates	Stacking Sequence
1	L1	R+R+R+R
2	L2	K+K+K+K
3	L3	R+K+R+K
4	L4	R+K+R+K (2% RH)
5	L5	R+K+R+K (4% RH)
6	L6	R+K+R+K (6% RH)

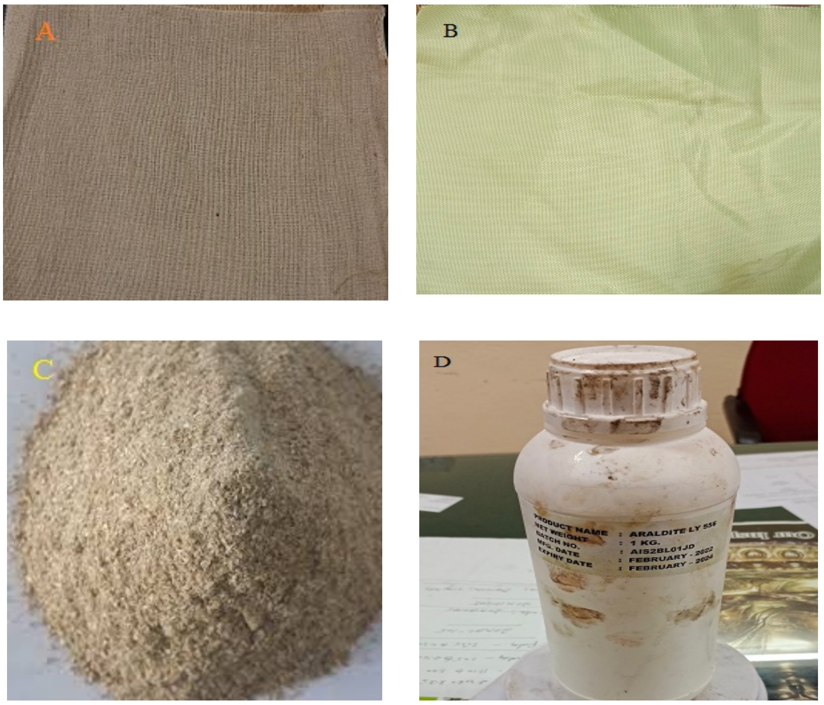


Figure 1. A. fibre ramie **B.** fibre kevlar **C.** rice husk and **D.** epoxy resin

3. Experimental Details

3.1 Density Test

According to ASTM D2734-94 standards, the density of polymer composite materials is determined, which allows us to determine the amount of voids present in laminates. Using the Archimedes principle to calculate the sample's weight in air and water, this approach calculates the theoretical density. For each of the six laminates, the experimental density is determined using **Eqn. 1** (Sadashiva K et al, 2023):

$$\rho_p = \rho_{liquid} \frac{W_{air}}{W_{air} - W_{liquid}} \quad \textbf{Eqn.1}$$

Where W_{air} stands for sample weight in air, W_{liquid} for sample weight in liquid, and ρ_{liquid} is the liquid density. ρ_{exp} stands for experimental density.

Each laminate's theoretical density was calculated based on the weight fraction as per **Eqn. (2)** (Sadashiva *et al,* 2023):

$$\rho th = \frac{100}{\frac{Wx}{\rho x}+\frac{Wy}{\rho y}} \qquad \textbf{Eqn.2}$$

Where W_x displays the weight fraction percent of the matrix phase, ρ_x displays the density of the matrix phase, W_y represents the weight fraction percent of the fabric, and ρ_y indicates the density of the fabric, ρ_{th} denotes the theoretical density.

Voids would emerge through the composite manufacturing process as a result of faulty composite fabrication technology. Laminates with more than 5% of voids are undesirable, whereas these composites with less than 1% voids are excellent. The composite's characteristics decline with decreasing water resistance as the void percentage increases. The densities and vacancy fraction percentages of the aforementioned six laminates are shown in **Table 3. Eqn (3)** (Sadashiva *et al,* 2023) was used to compute the percentage of void using experimental and theoretical densities.

$$Vp = \frac{\rho th-\rho exp}{\rho th} \qquad \textbf{Eqn.3}$$

Table 3: Density and void fraction of six laminates

Laminates	Theoretical density ρ_{th} (g/cm^3)	Experimental density ρ_{exp} (g/ cm^3)	Void (%)
L1	1.329	1.319	0.75
L2	1.316	1.312	0.45
L3	1.255	1.247	0.63
L4	1.229	1.223	0.48
L5	1.221	1.215	0.49
L6	1.153	1.148	0.43

3.2 Tensile Test

According to ASTM standard D638-80, the hybrid composite's tensile strength was assessed using a specimen with the dimensions 115x19x3 mm3. The test was conducted on a computerised UTM with a 100 kN maximum load capacity and a 2 mm/min strain rate. The UTM's immovable grippers are used to hold the standard-sized specimens in position while the load is gradually added until the specimen achieves the breaking load. The yield strength for each specimen is calculated using this load.

3.3 Flexural Test

A three-point bending load with a continuous strain rate of 1.5 mm/min was applied to the produced specimens, which were then tested for flexural strength in accordance with ASTM standard D790-07. The instrument's center, where the UTM jaws are used to hold the ends, is loaded with the six distinct kinds of laminate specimens.

3.4 Impact test

To determine the impact strength of the laminates, every specimen with dimensions of 63x12.7x3mm3 (as per the ASTM D-256 standard) is put into the grippers of the impact testing apparatus. The bonding strength of the reinforcement and matrix with filler at failure is expressed in terms of energy, i.e., Joules, which is how much energy was absorbed by these specimens.

3.5 Hardness Test

Using a digital shore-D hardness durometer, an experimental determination of the hardness test for the various compositions L1 to L6 of hybrid filler composites was produced. The durometer is a tool for measuring the hardness of polymer composites by penetrating the specimen, which is shown digitally, with an indenter pin. [26] The measuring range of a hardness durometer is around 0 to 100HD, and it measures up to 0.5 HD. It should be noted that if HD is more than 60, the material is said to have strong resilience, and if HD is lower than 60, the material is said to have poor resilience.

3.6 Moisture Absorption Test (MAT)

The manufactured composite, which consists of kevlar and ramie with epoxy fillers, was evaluated for moisture absorption by submerging the sample in distilled and ordinary water for 30 days. The dimensions of the test specimens, which are 30x28x3mm3, are made in accordance with ASTM standard D570. By removing the water particles on the sample surface, the mass of the examined specimens was weighed on a very accurate numerical balance with a 10-day interval. Eqn. 4 (Qi H. J, et al, 2003) is used to compute the moisture absorption rate.

$$\text{Moisture absorption rate } (\%) = \frac{W_S - W_r}{W_S} * 100 \qquad \textbf{Eqn. 4}$$

Where Ws depicts the specimen's weight after dipping for 10 days and Wr depicts the specimen's weight before to dipping.

3.7 Scanning Electron Microscopy

The fracture surface of the tensile specimen is inspected using a SEM instrument of the Germany type, the GABO qualimeter. The shattered samples were reduced in size (10x10x3mm3), and gold sputtering was used to cover the surfaces before taking the photos. The purpose of this morphological test is to evaluate the reinforcement-matrix interface, evaluate the reinforcement pullout, evaluate the voids in the composite, evaluate the filler content in the matrix, and evaluate the behaviour of the adhesion characteristics during the fabric and matrix phases.

4. Results and Discussion

4.1 Density

The difference between actual and theoretical densities, which showed various changes (from table 3), was used to compute the void percentage (%) in composite laminates. Due to the close compatibility of the fabric, matrix, and filler material, Laminate L6 has less voids (0.43%) than those of other laminates. Laminate L2 has a 0.45% void content, which is a little bit more than laminate L6. Additionally, L1 laminate (ramie and kevlar), which is made completely of natural ramie reinforcement, contains 0.75 percent voids. The six various configurations of laminates have void fractions ranging from 0% to 1%, which indicates that the composites were made correctly and the void percentages achieved are acceptable. Higher filler material percentages were shown to have lower void fractions, but traditional textiles had greater voids overall.

4.2 Tensile strength

The tensile strength and tensile modulus of the composite laminates L1 to L6 were evaluated using a Universal Testing Machine. The laminate L2 with pure kevlar reinforcement shown in figure 2 exhibited a greater tensile strength of 137.68 MPa and a 3.42 GPa tensile modulus. According to the plots, the laminate L1 with pure natural ramie reinforcement has a tensile strength of 60.05 MPa and a modulus of 2.42 GPa. The tested hybrid composites with ramie and kevlar reinforcement laminate L3 have a tensile strength of 98.65 MPa and a tensile modulus of 2.19 GPa. In this respect, it is concluded that the inclusion of conventional fibre reinforcement results in an improvement in tensile strength. The hybrid composite laminate with 2% RH-fillers showed a somewhat lower modulus and tensile strength as compared to laminate L3. Additionally, 2.06 GPa of modulus and 89.23 MPa of lower strength were seen in 4% of the RH-filled composite. The hybrid composite laminate sequence of two-layer ramie and two-layer kevlar with 2% RH filler had the best tensile strength and modulus values, whereas laminate L2 had the greatest tensile strength and modulus. The integration of synthetic kevlar reinforcement and the addition of 2% filler (RH) material resulted to an improvement in tensile strength and tensile modulus.

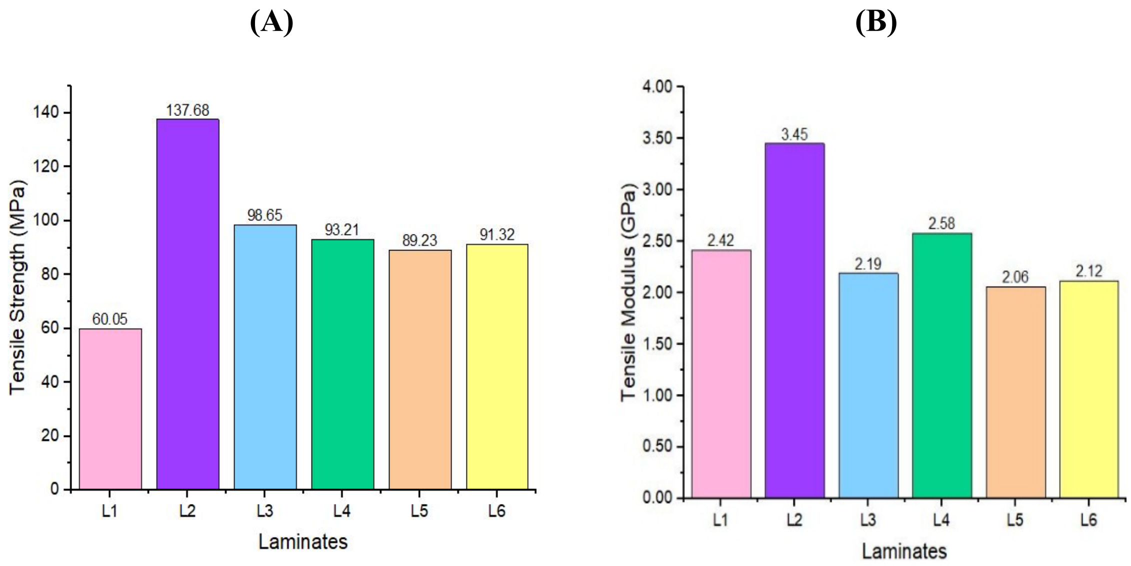


Figure 2: Tensile property of the samples: **A.** Tensile strength and **B.** Tensile Modulus.

4.3 Flexural strength

Figures 3 (A) and 3 (B) show the flexural strength and flexural modulus of all the laminates under consideration. Flexural strength of the material demonstrates the improved binding qualities between the matrix, reinforcement, and filler material.

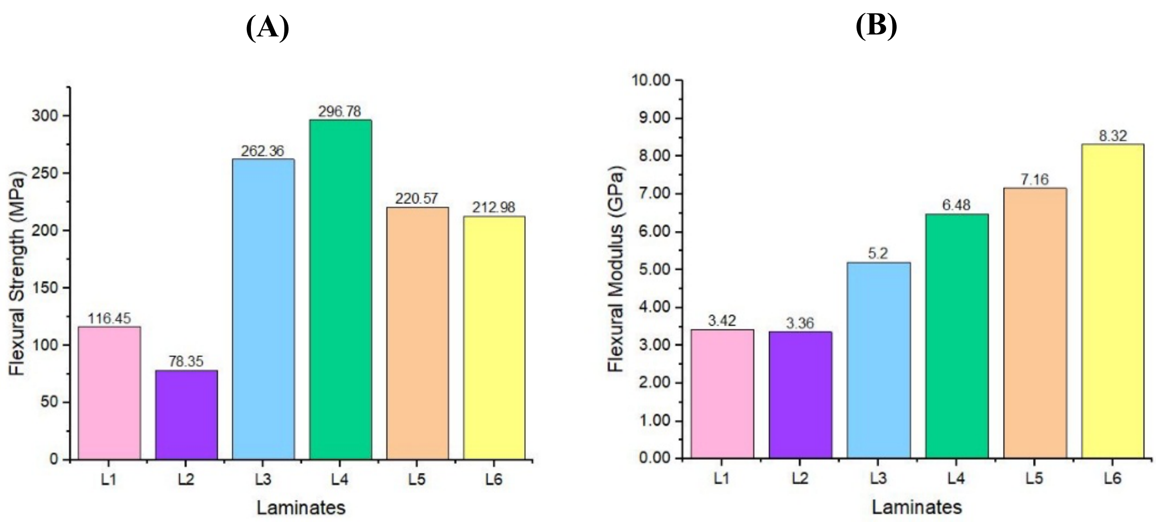


Figure 3: Flexure property of the samples: **A.** Flexure strength and **B.** Flexure Modulus.

The hybrid laminate L4 with 2% RH filler material attained the highest flexural strength with a 296.78 MPa flexural strength and a 6.48 GPa flexural modulus. The laminate L2, which has four layers of kevlar reinforcement, had the lowest flexural strength and flexural modulus at 78.37 MPa and 3.36 GPa, respectively. The hybrid two-layered ramie and two-layered Kevlar laminates L3 had a flexural strength of 262.36 MPa and a modulus of 5.20 GPa, compared to the pure natural ramie reinforced laminate L1's flexural strength of 116.45 MPa and 3.42 GPa. Additionally, for laminates L5 and L6, decreasing the filler content by 4% and 6% correspondingly lowered the modulus and flexural strength. This experimental investigation revealed that the flexural modulus of hybrid composites increases as filler % increases.

4.4 Impact strength

The bonding of the reinforcement matrix, the composite geometry, the fabric alignment, the matrix stacking order, and the type of the reinforcing material are some of the elements that have an influence on the impact characteristics of laminates. The following equation is used to determine the effect of energy absorption.

$$\text{Impact strength} = \frac{\text{Impact energy in joules}}{\text{Area of crossection in m}^2} \qquad \textbf{Eqn.6}$$

Figure 4 displays the impact strength (kJ/m2) of the various laminates. The laminate L2 has a greater impact strength of 61.68 kJ/m2 than that of other laminate designations because of the enhanced stiffness of the kevlar reinforcing. Due to its only use of natural ramie fabric as reinforcement, laminate L1 has the lowest impact strength. These data clearly show that the reduced stiffness and hemicellulose content are what because the lower impact strength. With an increase in filler percentage, the impact strength of the hybrid composites likewise significantly decreases. Laminate L4 has an impact strength of 35.12 kJ/m2, Laminate L5 has a value of 29.58 kJ/m2, and Laminate L6 has a value of 27.74 kJ/m2. Filler material and a less compatible reinforcement-matrix interface both lower impact strength.

4.5 Hardness number

Figure 5 shows the results obtained using the Shore-D durometer to depict the hardness values for various laminate designations. The laminate L6 with hybrid composite layers of ramie and kevlar and 6% RH filler material can endure the hardest value of 78. The hardness values for the other hybrid composite laminates with 4% and 2% filler ranged from 75 to 72, respectively. This demonstrated that the filler material provided resistance to the material's indentation and distortion. Because it included more cellulose and was softer, the pure ramie fabric composite had a lower value and was more likely to distort the laminate.

4.6 Moisture Absorption Test (MAT)

Usually, after soaking in water, the specimens grow in size as a result of absorbing moisture. This MAT test was run for 30 days in both distilled water and regular water, with 10-day breaks in between. Tables 4 and 5 show the sample weights in both situations before and after the water absorption phase. The results of the test show that laminate L1, which contains just pure natural ramie fibre, has a greater moisture absorption percentage. The laminate L2, which is made entirely of synthetic kevlar fibre, shows the least degree of moisture absorption. Due to its natural filler, which is composed of lignin and cellulose, the hybrid composite of plane laminate (L3) has a lower capacity to absorb water than the laminate that is filled with filler. Additionally, according to tables 4 and 5, all of the composite laminates absorbed more normal water and absorbed less distilled water.

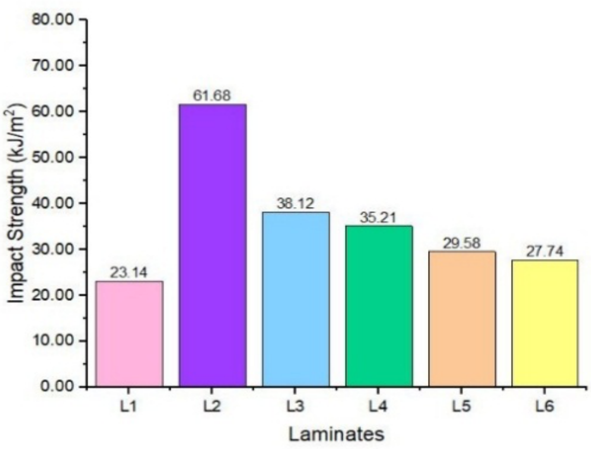


Figure 4: Impact strength of composites

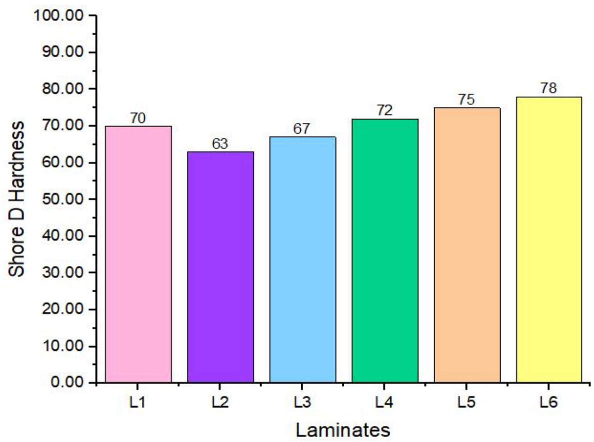


Figure 5: Micro Hardness values of different laminates

Table 4: Moisture absorption % in distilled water

Laminates	Weight of the samples before absorption (g)	% increase in weights		
		Day 10	Day 20	Day 30
L1	4.425	7.1	12.36	16.89
L2	3.721	3.69	7.25	10.48
L3	4.126	3.91	8.35	13.96
L4	4.185	3.94	9.35	14.28
L5	4.214	4.10	8.21	14.36
L6	4.361	4.02	7.32	14.96

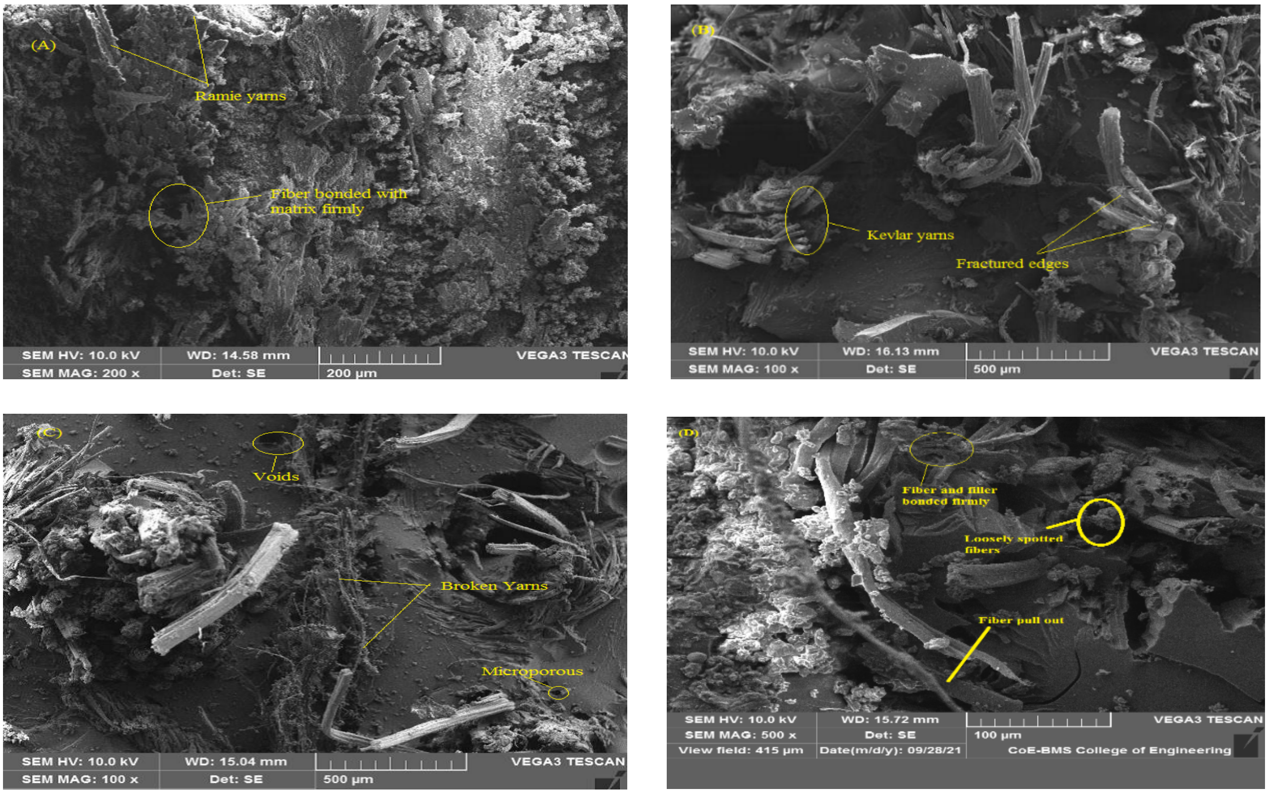
Table 5: Moisture absorption % in normal water

Laminates	Weight of the samples before absorption (g)	% increase in weights		
		Day 10	Day 20	Day 30

L1	4.585	6.9	12.85	17.59
L2	3.731	3.49	7.95	11.06
L3	4.136	4.10	8.72	14.09
L4	4.190	4.12	10.21	14.82
L5	4.356	4.21	9.14	15.06
L6	4.412	4.5	9.5	15.66

4.7 Scanning Electron Microscopy

The composite was analysed and the interface between the reinforcement and matrix was examined using a scanning electron microscope (SEM) on the broken surfaces of the composite. In figure 6, you can see the fractured SEM pictures of the hybrid composites made of ramie, kevlar, and filler. Figure 6A shows how the matrix material and ramie reinforcement yarns L1 are mixed, with the smooth surface starting from the structure. As seen in figure 6B, certain matrix-deficient areas also occur surrounding kevlar textiles. On the surface of the composite specimen, void development is visible because there is less connection between the reinforcement and matrix. The hybrid composite laminate L3, which has high adhesive qualities and specifies the fracture yarns, forms some gaps on the surface of laminates as a result of air entrapment during the hand layup manufacturing process. The laminates in the images include tiny micro porous areas because air became trapped in the laminates during the composite fabrication process. The hybrid ramie and kevlar filler-filled composites shown in Figure 6C have fewer voids because the reinforcement and matrix have a strong adhesive bond. Additionally, reduced void formation was seen as a result of the use of RH fillers of various parentage.



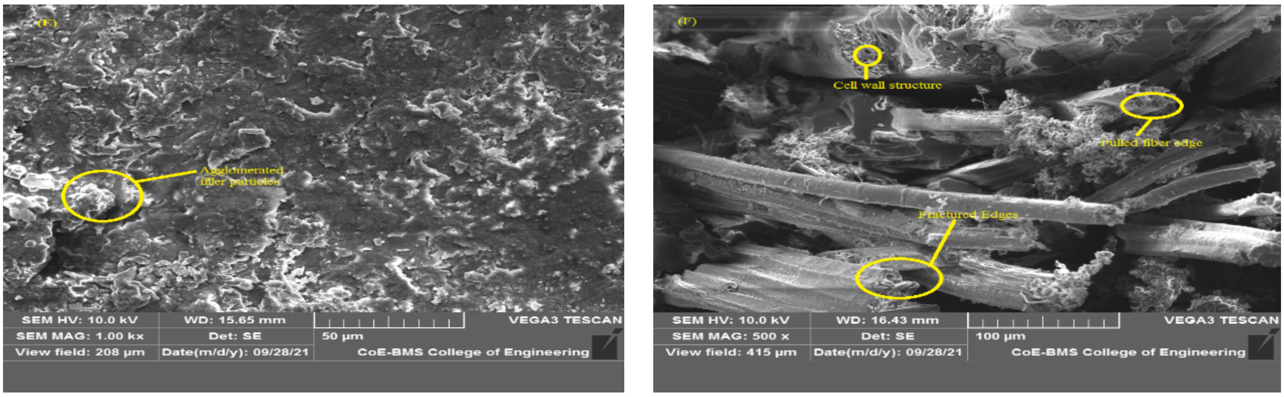


Figure 6: Tensile fractured specimens of SEM: **A.** Ramie Laminate **B.** Kevlar laminate **C.** Hybrid laminates **D.** Hybrid laminates with 2% RH filler **E.** Hybrid laminates with 4% RH filler **F.** Hybrid laminates with 6% RH filler

Figure 6D depicts hybrid laminates with 2% RH filler. It demonstrates the bonding between the fibre and matrix filled with rice husk, which is tightly compressed with the matrix and fillers. In this way, interesting results were obtained by RH and polylactic acid (PLA) which presented enhanced water resistance in PLA composites developed with modified rice husks is because alkali modification improved interfacial bonding between them and the PLA matrix (Yiga *et al.*, 2023). Also, show the addition of filler in increasing percentages of 4% and 6% of rice husk. The interfacial bonding and tensile characteristics of composite specimens are decreased as a result of the penetration of water molecules into the fiber-matrix region. The fiber-matrix adhesion is also weakened as a result of fibre expansion, which also causes fibre separation from the matrix depicted in Figure 6E. The fracture surfaces of hybrid basalt and jute composites are significantly better understood thanks to the SEM study. The difference between treated and untreated, dried composites shows how important alkali treatment is for improving the interface and overall mechanical performance shown in Figure 6F. These discoveries promote the development of lightweight, environmentally friendly, and mechanically robust materials for a range of industrial applications and help to understand the microstructural changes that take place in composites

Conclusion

In the current study, ramie and kevlar textiles were expertly strengthened with epoxy matrix and natural rice husk fillers at 2%, 4%, and 6% to create a novel designed hybrid composite in the area of Natural Fiber Polymer Composite (NFPC). The hybrid composite of several designated laminates was created using a manual hand layup process and put through a number of tests, including morphological, mechanical, and physical characterization. The newly created ramie kevlar-filled rice husk reinforced hybrid composite laminates hint to their usage in medium structural applications due to their increased impact, flexural, tensile and hardness characteristics. The use of natural fillers greatly enhances the moisture resistance of the manufactured fiber composites, according to tests on moisture absorption. The filler-based composite with a decreased void percentage demonstrated robust bonding, according to an investigation using SEM. Due to the use of filler material and kevlar reinforcement, the laminate L6 had less voids than the natural ramie reinforcement. since of this, it is advised to utilize the hybrid composite with 2% RH filler in applications like automobile door panels, safety helmets, bicycle frames, computer spare parts, and interior design materials for railway coaches since it yields superior results overall.

Acknowledgement, The author is grateful to the department of mechanical engineering at the Dr. Ambedkar Institute of Technology, Bengaluru, for providing the research facility to complete this project.

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.

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