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Experimental Investigations of Carbon Fiber Hybridization on Mechanical Strength Properties of Ramie Fiber Reinforced Epoxy Composite

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Abstract

In this study, an attempt is made to check whether a hybrid composite made up of both synthetic and natural fibers (Carbon and ramie respectively) can be made bio-degradable, at least to some extent, without much compromising on the mechanical strength properties. Hybridized composites were produced by reinforcing alkali treated ramie and carbon fibers into epoxy resin using hand lay-up and compression methods. By varying the number of layers of fibers in the composite samples and fixing 20 % fiber weight for all composites, nine distinct combinations of samples were prepared. The optimum tensile strength of 385.68 MPa, flexural strength of 646.08 MPa, and impact energy of 4.8 J were obtained for composites produced with pure carbon fiber, whereas hybrid composite exhibit tensile strength of 366.76 MPa, flexural strength of 645.41MPa and impact energy of 4.7 J. The interfacial bonding between the fibers and matrix of tested samples were studied using a scanning electron microscope (SEM), as well as the arrangement of fibers within the matrix for the manufactured composite.

KEYWORDS: Natural fiber; synthetic fiber; epoxy resin; hybrid composite materials; mechanical strength properties; SEM; FT-IR.

1. INTRODUCTION

Composite material is formed by the combination of two or more constituent materials. The matrix phase is used to hold the fibers together and also to transport the load to the fibers, and the reinforcing phase is used to take the maximum load, but these two phases are chemically distinct, i.e., there is no chemical reaction between them. This material has high strength with sufficient stiffness and toughness with a light weight. This combination of properties offers a great advantage in mechanical design. So, these properties may be suitable for various industries, such as automotive, aerospace, infrastructure and sports (Jenish et al. 2022; Madhu et al. 2020; Yashas Gowda et al. 2022; Okoronkwo et al. 2022). Metals are proven engineering materials for various applications in terms of strength and stability. Nowadays, their usage is declining significantly due to high weight and high corrosiveness. Later, synthetic fiber-reinforced composites have become popular, but they are non-biodegradable and costly. To overcome this, natural fibers are introduced due to their biodegradability, low cost, availability, low density, and renewability (Ilyas et al. 2019; Senthamaraikannan et al. 2016; Okoronkwo et al. 2022). Mechanical properties of natural fibers are varying in nature (inconsistent) due to their growing environment, extraction methods, and seasons. Therefore, natural fiber-reinforced composites (NFRC) may not be suitable for heavy-load bearing applications and high-temperature applications. Natural fibers derived from plants such as jute, sisal, coir, hemp, and kenaf have attracted great attention as a strengthening element in the NFRC composite (Dos Santos et al. 2019; Ramesh et al. 2022; Madu et al. 2019; Ezeokpube et al. 2021).

Natural fibers have few limitations, such as quality variations and high moisture absorption, which cause fibers to swell, leading to poor bonding. Natural fibers are hydrophilic in nature due to the presence of lignin, hemicelluloses, waxes, etc. Mechanical strengths of natural fiber-reinforced composite (NFRC) purely depend on the compatibility between fiber and matrix Okoronkwo et al. 2021). NFRC composites have poor compatibility or interfacial adhesion due to hydrophilic nature of fiber and hydrophobic nature of matrix Okoronkwo et al. 2019). As a result, NFR composite shows reduced mechanical properties. Chemical treatment of fibers removes fiber constituents such as wax, lignin, hemicelluloses, and other substances present over the surface of the fiber (Okoronkwo et al. 2020). As a result, a rough surface of the fiber is obtained, which is helpful in improving the interfacial bonding with the matrix. Because of alkali treatment, damage to fibers may be less at optimum weight proportions, and cost is also reduced. This increased interfacial bonding can transfer the load more effectively from the fiber to the matrix, improving the mechanical properties.

(Reddy et al. 2021) investigated and compared the mechanical properties of composites made with and without alkali-treated Prosopis juliflora fiber and epoxy, concluding that the composite made with alkali-treated fiber has superior mechanical properties. (Rizal et al. 2018) studied the mechanical, chemical, FT-IR, and XRD properties of Typha fiber-reinforced epoxy composites after alkali treatment. Compared to untreated Typha fiber composites, 5 % of NaOH-treated composites demonstrated improved mechanical characteristics.

Many works have employed alkali treatment for natural fibers such as cordia dichotoma (Reddy et al. 2020), abutilon indicum fibers (Mohana Krishnudu, Sreeramulu, and Reddy 2020) and foxtail millet (Reddy et al. 2020) into polymeric matrix composite and reported improved mechanical properties and interfacial bonding between the fibers and the matrix. (Reddy et al. 2020).

Hybrid composites are materials made from a common matrix by combining two or more separate types of synthetic fibers or different types of natural fibers, or by combining both synthetic and natural fibers in varied proportions (Shanmugam and Thiruchitrambalam 2013; Okoronkwo et al. 2022). The hybrid composite has superior qualities that a single type of reinforcement can't match. When natural and synthetic fibers are used, the cost of a hybrid composite can be greatly reduced. The weight content (Wt. %) of reinforcement and the layer in which synthetic and natural fibers are put influence the hybrid composite's final characteristics (TG et al. 2022). The mechanical properties and vibration characteristics have improved significantly with hybridization of carbon fiber with flax fiber as was investigated by (Flynn, Amiri, and Ulven 2016). (Ramesh et al. 2017) carried out studies on a banana/carbon fiber-reinforced hybrid composite to determine its mechanical capabilities and water absorption characteristics. The results of this experiment are the highest tensile strength for 20 % carbon and 80 % banana fiber, the highest flexural strength for pure carbon fiber and the highest water uptake for banana fiber compared to carbon fiber. The physical and mechanical properties of the fiber constituents were used to determine the performance of hybrid composites as seen from (Dinesh et al. 2020; Vinod et al. 2022). The shear strength, hardness, wear resistance, water absorption, and FT-IR properties of the carbon/flax fiber- reinforced composites were fabricated using a hand-lay-up approach. According to the findings, each of the aforementioned features of hybrid composites is comparable to that of pure carbon fiber-reinforced composites. This also suggested that carbon and flax fiber composite hybridization can be used as a structural application while also reducing environmental consequences reported by (Ramesh et al. 2018). (Nagappan et al. 2022) investigated on the effects of fiber length and fiber content along with alkali treatment effects on the mechanical properties of prepared natural fiber-based polymer composites. The work concluded that the optimum fiber length and fiber weight % for obtaining maximum mechanical properties are 7 mm and 30 wt. %, respectively, for both raw and alkali-treated fiber composites.

(Sarasini et al. 2016) developed a hybrid composite with two distinct stacking sequences, such as flax/carbon/flax (FCF) and carbon/flax/carbon (CFC) as well as pure carbon and pure flax epoxy composites, and examined their impact and flexural strengths. Results have confirmed that the impact and flexural performance of CFC composite laminate is slightly higher than that of FCF composite laminate, pure carbon and pure flax epoxy composite laminate. Several researchers have reviewed, studied and confirmed that carbon fiber is an effective hybridizing element of both natural and synthetic fiber-reinforced epoxy composite, due to improved mechanical performance, cost-effective material and decreased environmental impact (Okoronkwo et al. 2019). (Najafi, Khalili, and Eslami- Farsani 2014) manufactured the hybrid composite using pure basalt fibers, carbon fibers, and by altering the weight proportions of basalt fibers and carbon fibers into phenolic resins, and these fibers are stacked in layers within the phenolic resin. The impact and flexural strength of the hybrid composite are improved by incorporating basalt fiber into the carbon fiber-reinforced phenolic resin. BCFP composite with weight proportions of 0.83:0.17 in the stacking sequence B/C/B/C/B has the highest impact and flexural strength. (Jebadurai et al. 2021) selected low-cost and widely available coccinia grandis stem fibers and laid the composite by reinforcing it in polyester resin. The mechanical, thermal, and hardness properties of the produced composite were examined to ensure that it was suitable for structural purposes. The highest mechanical properties were reported when 40 % by weight of the coccinia grandis fibers were reinforced with polyester resin. Thermal stability (250°C) is also reasonable for the aforementioned hybrid composite. Such hybrid composites are used for a variety of applications, such as car interior, sporting equipment, bone plate and wind turbine blades (Jawaid and Khalil 2011; Jothibasu et al. 2020; TG et al. 2021). (Mahakur, Bhowmik, and Patowari 2022) reviewed the various works to identify the parametric effects on the machining of natural fiber-based composites. Work explored the various methods that can be implemented to reduce the machining defects. (Rangappa et al. 2022) reviewed the use of cellulosic fiber as a reinforcing element in the preparation of composites. The research work explored the recent developments on the utilization of cellulosic fibers in the polymer industries focusing much on the improvement of the mechanical properties, manufacturing methods and its applications in various industries.

The goal of this research is to combine carbon fiber with alkali-treated ramie fiber in an epoxy matrix using a hand-lay-up method and compression moulding. The study on alkali-treated ramie fiber-reinforced epoxy composite with carbon fiber was not published in the literature. Carbon fiber and alkali-treated ramie fibers reinforced with epoxy resin were used to create a hybrid composite. In this study experimental investigations were carried out to determine the tensile, flexural, and impact properties of ramie fiber and carbon fiber- reinforced epoxy composites. The mechanical properties could be applied in structural, automotive, wind turbine blades, aerospace, and infrastructure applications.

2. MATERIALS AND METHODS

2.1 Materials

Ramie fiber, carbon fiber, and epoxy resin are the materials utilized to make hybrid composites. Ramie fibers are harvested in and around the village of Nekade in Imo State, Nigeria. Nycil Company Limited, Nigeria, provided carbon fiber (unidirectional mat 200 gsm). Nycil Company Limited, Nigeria, provided the epoxy resin (LY556 with viscosity at 250°C: 0,7 ÷ 1, 1 Pa.s), which is a diglycidyl ether of biphenyl- A, and the hardener (HY 951 with specific gravity at 25°C: 0.95), which is triethylenetetramine.

Fiber extraction

The ramie fibers were extracted from the bark of the ramie tree by a water retting process followed by mechanical beating. Extracted fiber contains foreign impurities and wax substances; this has been removed by shaking and squeezing of the fiber in running water. Natural fibers are hydrophilic in nature because of their fiber constituents, such as lignin, wax, pectin, etc., which are responsible for water absorption and also lead to poor interfacial bonding. To overcome such phenomenon, a surface modification called alkali treatment is carried out on the fibers.

Alkali treatment

Alkali treatment is simple and economic for treating the natural fibers. In a separate beaker, create the alkali solution (5 wt. % NaOH) by dissolving 100 g of NaOH pellets in 2 L of pure water. After that, the dry fiber is soaked in the alkaline solution for 2 h at room temperature. The fibers were removed from the solution and thoroughly washed with distilled water to remove any NaOH that had adhered to the fiber surface. Hemicelluloses and other contaminants that cling to the fiber are also removed. The fibers were dried in an oven at a continuous temperature of 100 degrees Celsius for 24 h.

Fabrication of composites

For this work, the laminates of the hybrid composites were prepared using a hand lay-up method. Well-dried ramie (R) and carbon (C) fibers are segregated and chopped to a length of 150 mm. Nine different forms of laminates have been prepared with different stacking sequences R/R/R/R (Sample 1), R/R/C/R (Sample 2), C/R/R/R (Sample 3), R/C/R/C (Sample 4), C/R/C/R (Sample 5), C/R/R/C (Sample 6), C/C/R/C (Sample 7), C/C/C/R (Sample 8) and C/C/C/C (Sample 9). Along with a pure epoxy composite, pure alkali-treated ramie fiber-reinforced epoxy composite and pure carbon fiber-reinforced epoxy composites were manufactured to compare mechanical properties. The total fiber content was fixed at 20 wt%. Epoxy resin and hardener were properly mixed with the 100:10 weight ratio in a separate beaker. A glass mould with a size of 150 mm x 150 mm x 3 mm was used to prepare the composite laminates. Releasing gel was spread over the surface of mould for easy removal of composite laminate. A thin layer of epoxy mixture was applied on the surface of the mould, and then carbon fibers were uniformly laid over the mixture, and the required amount of epoxy mixture was poured over the carbon fiber.

Table 1. Layer designation and fiber weight content (wt. %) in hybrid composite.

Composite designation	Layering sequence	Position of Fibers (carbon and ramie fibers in the laminate with a constant weight of 5 (wt. %)			
		Layer 1 (5 wt.%)	Layer 2 (5 wt.%)	Layer 3 (5 wt.%)	Layer 4 (5 wt.%)
Sample 1	R/R/R/R	R	R	R	R
Sample 2	R/R/C/R	R	R	C	R
Sample 3	C/R/R/R	C	R	R	R
Sample 4	R/C/R/C	R	C	R	C
Sample 5	C/R/C/R	C	R	C	R
Sample 6	C/R/R/C	C	R	R	C
Sample 7	C/C/R/C	C	C	R	C
Sample 8	C/C/C/R	C	C	C	R
Sample 9	C/C/C/C	C	C	C	C

*C: Carbon fiber *R: Ramie fiber.

After proper impregnation of epoxy mixture on carbon fiber, ramie fibers were mounted on the first layer of carbon fiber. This procedure was continued for the rest of layers (four layers). The remaining mixture of resin was poured on top of fourth layer and roller was used to distribute the epoxy mixture and to eliminate air gaps formed between the layers during the processing. Releasing gel was applied to OHP (Over Head Projector) sheet and is placed above it to obtain a smooth surface. For 24 h, a weight of 20 kg was loaded onto each mould to obtain the required dimensions of the laminate and cure the laminate. Table 1 shows the reinforcement sequence arrangement in various composite samples.

Characterization

Tensile strength test

The tensile strength of a material refers to its ability to be stretched without breaking under uniaxial force. The INSTRON Universal Testing Machine (Model-3369) with a load cell capacity of 10 kN was used to determine tensile parameters such as tensile strength and the tensile modulus of hybrid material. With a dimension of 150 mm x 15 mm x 3 mm, a tensile test was performed according to the ASTM standard ASTM: 3039. Each hybrid composite sample was tested three times, with the average values recorded.

Flexural strength test

The INSTRON Universal Testing Machine (Model-3369) was used to assess the flexural properties of prepared hybrid composites under specific conditions (crosshead speed rate: 10 mm/min; load cell: 10 kN; support span length: 50 mm). The flexural characteristics of all prepared hybrid composite samples were tested using the three-point bending method. Samples were flexural tested in accordance with ASTM D 760–03 standards. For each of the hybrid composites, three samples were examined, and the average values were recorded.

Impact strength test

When impact or abrupt loads are applied, composite impact strength is defined as the amount of energy absorbed during fracture and was determined using an IZOD impact tester (Composite Lab-GPREC, Kurnool). The composite sample was impact tested according to the ASTM D-256 standard, with a test sample size of 63.5 mm x 12.7 mm x 3 mm.

Scanning Electron Microscope (SEM) analysis

SEM is an effective instrument for determining the failure mechanism, mode of failure, and interfacial bonding (between matrix and fiber) of a failed specimen. The JEOL/EO Model-JSM-6390 was used to investigate the cracked surface of the hybrid composite sample. For this analysis, the fractured surfaces of the hybrid composite samples were washed, air dried and a thin gold film of gold (3 μm) is coated with JEOL sputter ion coater to impart the conductivity of the sample, and SEM was observed at a voltage of 10 kV and 15 kV.

FTIR spectroscopy

In hybrid composite samples, Fourier transform infrared spectroscopy (Model-Thermo Nicolet, Avatar 370) was utilized to detect functional groups, chemical linkages, and their absorption bands. When the wavelengths of infrared (IR) rays match the vibrational wavelength of a bond with a functional group, absorption of bands occurs. The FTIR spectra of hybrid composites were collected with 32 scans with a resolution of 4 cm^{-1} in the spectral region of 4000 cm^{-1} to 400 cm^{-1}.

3. RESULTS AND DISCUSSION

3.1 Tensile test

Table 1 designates the laminates and Table 2 displays the experimental results of the tensile tests. Tensile strength is observed to be the highest (385.68 MPa) in only carbon laminate i.e., (C/C/C/C) and the lowest strength (62.62 MPa) in pure ramie epoxy composites (R/R/R/R). The addition of carbon fiber to natural fiber-reinforced composite laminate increases the tensile strength as carbon fiber is stronger and stiffer than natural fibers.

Table 2. Tensile properties of carbon and ramie fiber-reinforced hybrid composite laminate.

Sample Designation	Layering Sequence	Tensile Stress(MPa)	Tensile Modulus (MPa)	Tensile Strain (mm/mm)	% Elongation
Sample 1	**R/R/R/R**	62.62	5081.21	0.01617	1.617
Sample 2	**R/R/C/R**	109.98	5014.61	0.03667	3.667
Sample 3	**C/R/R/R**	132.11	5470.05	0.04050	4.05
Sample 4	**R/C/R/C**	169.56	7263.78	0.04283	4.283
Sample 5	**C/R/C/R**	220.93	7110.18	0.05300	5.3
Sample 6	**C/R/R/C**	253.94	7901.72	0.06300	6.3
Sample 7	**C/C/R/C**	280.49	7298.53	0.06650	6.65
Sample 8	**C/C/C/R**	366.76	7520.82	0.07450	7.45
Sample 9	**C/C/C/C**	385.68	8028.05	0.07500	7.5

(Okoronkwo et al. 2021). The same has been clearly observed in the present investigation. A carbon fiber layer that occupies the place of one of the layers of natural fibers in (R/R/R/R) resulted in an improvement in tensile strength (Sample 2 R/R/C/R) by 75.63 % to 110.98 MPa and Sample 3 (C/R/R/R) by 110.97 % to 132.11 MPa). The reason why the tensile strength of sample 3 is higher compared to Sample 2 may be because the carbon fiber bearing the total load acts on it and gradually transferring to other layers of natural fibers. To further increase the tensile strength of the composite sample, two layers of carbon fibers are introduced at different positions of sample 1 replacing natural fibers (R/C/R/C, C/R/C/R, C/R/R/C). Tensile strength improved by 170.78 %, 252.81 % and 305.53 %, respectively, compared to (R/R/R/R). The layers of carbon fibers at both ends of the sample of C/R/R/C, could've resisted the pulling force greatly, and hence the tensile strength is higher between the two layers of carbon fibers (Sample 4 and Sample 5). Similar results were obtained by (Venkatasudhahar, Kishorekumar, and Dilip Raja 2020) for the hybrid composite laminate with Carbon-Jute-Jute-Jute-Carbon layering sequence possessing superior mechanical properties than composite laminate without hybridizing elements such as pure banana (B-B-B-B-B) and pure jute fiber (J-J-J-J-J). Similarly, the strengths of the laminates with three layers of carbon fiber (C/C/R/C and C/C/C/R) increased by 347.92 % and 485.69 %, respectively, compared to those of Sample 1 (R/R/R/R). Three contiguous layers of carbon fibers appear to have added strength to sample 8 (C/C/C/R).

3.2 Flexural test

Plain carbon fiber, pure ramie fiber and carbon-ramie-reinforced epoxy hybrid composite subjected to flexural loading and results are displayed in Table 3. The highest flexural strength (646.08 MPa) was observed in only carbon epoxy composite Sample (C/C/C/C), while the lowest strength (173.03 MPa) was observed in pure ramie epoxy composites (R/R/R/R). The addition of carbon fiber to natural fiber-reinforced composite laminate increases the flexural strength as carbon fiber is stronger and stiffer than natural fibers (Okoronkwo et al. 2022).

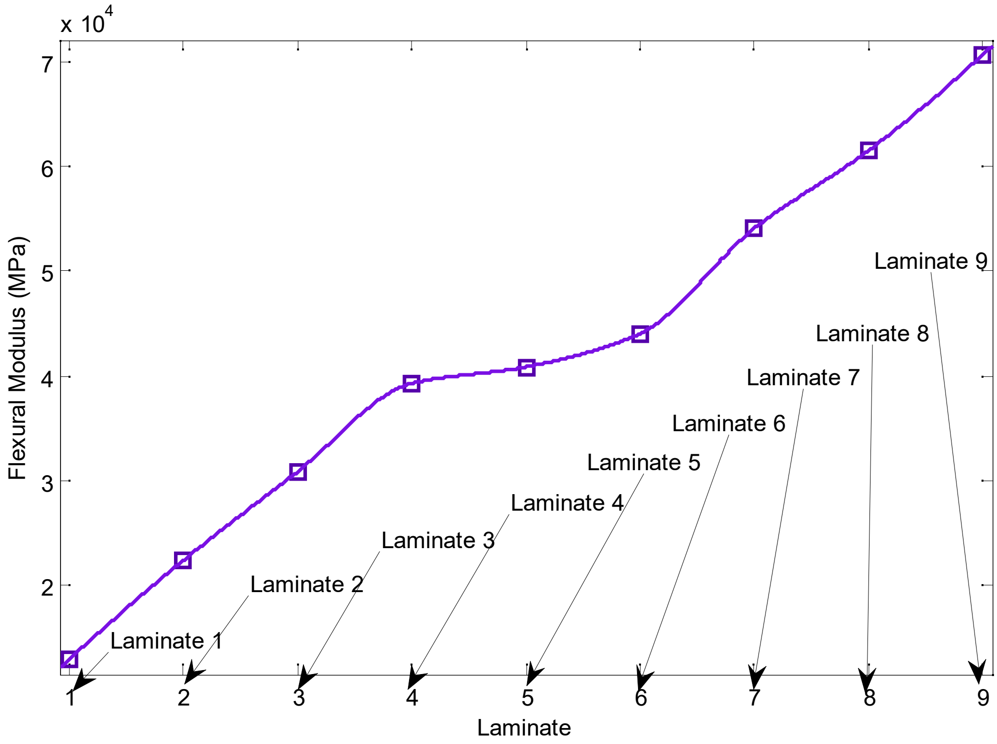

Figure 3: Carbon and ramie fiber-reinforced hybrid composite laminate vs Flexural modulus

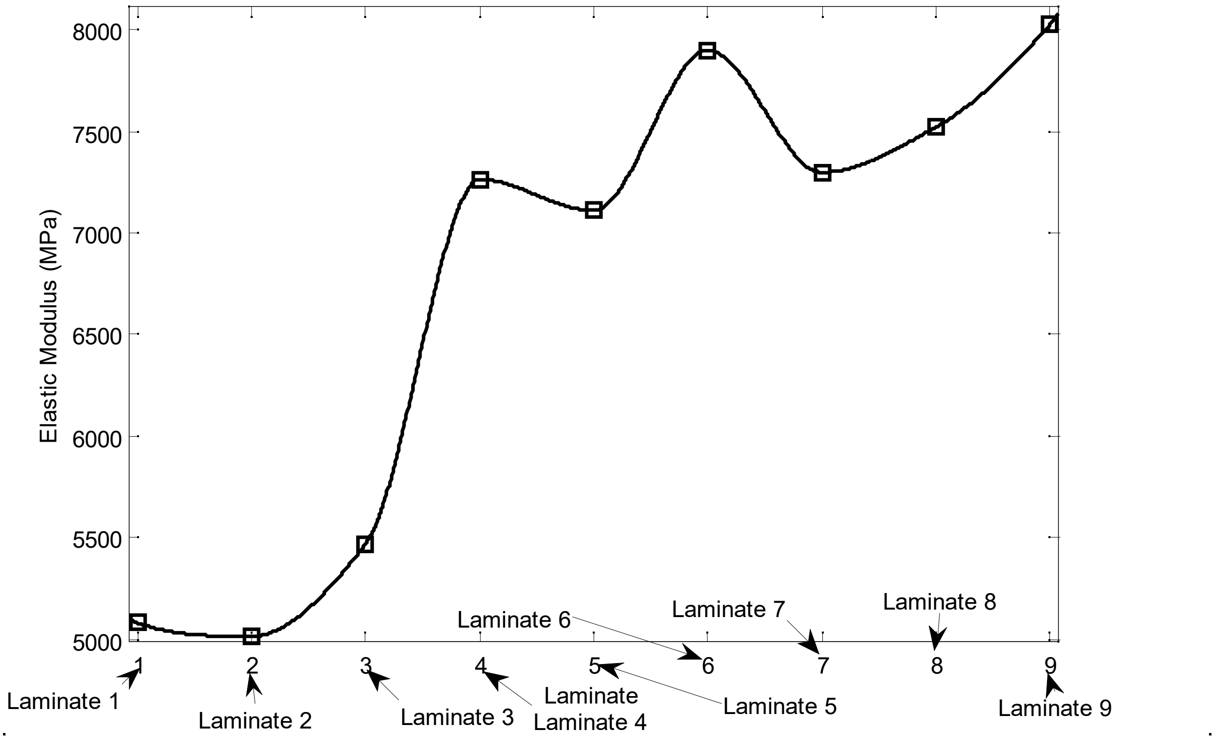

Figure 3: Carbon and ramie fiber-reinforced hybrid composite laminate vs Elastic modulus

Table 3. Flexural properties of carbon and ramie fiber-reinforced hybrid composite laminate.

Sample Designation	Layering sequence	Flexural stress (MPa)	Flexural modulus (MPa)
Sample 1	R/R/R/R	173.03	12816.09
Sample 2	R/R/C/R	233.12	22280.58
Sample 3	C/R/R/R	318.62	30768.68
Sample 4	R/C/R/C	412.00	39256.54
Sample 5	C/R/C/R	424.98	40847.50
Sample 6	C/R/R/C	457.40	44030.50
Sample 7	C/C/R/C	564.69	54110.00
Sample 8	C/C/C/R	645.41	61537.64
Sample 9	C/C/C/C	646.08	70747.44

The same has been clearly observed in the present investigation. A layer of carbon fiber occupying the place of one of the layers of natural fibers in (R/R/R/R) resulted in the improvement of the flexural strength Sample 2 (R/R/C/R) by 34.73 % to 233.12 MPa and Sample 3 (C/R/R/R) has 84.14 % to 318.62 MPa). The reason why the flexural strength of sample 3 is higher than that of sample 2 may be because the carbon fiber carries the total flexural load acting on it and gradually transfers to other layers of natural fibers. To further increase the flexural strength of the composite laminate, two layers of carbon fibers are introduced at different positions of sample 1 replacing natural fibers (R/C/R/C, C/R/C/R, and C/R/R/C). Flexural strength improved by 138.11 %, 144145.61 % and 164.35 %, respectively; compared to epoxy composite laminate reinforced with pure ramie fiber (R/R/R/R). The layers of carbon fibers at both ends of the sample of C/R/R/C could have resisted the flexural force greatly and therefore the flexural strength is higher among the two layered carbon fiber samples (Sample 4 and Sample 5). Similar results were obtained by (Venkatasudhahar, Kishorekumar, and Dilip Raja 2020) for the hybrid composite laminate with a carbon-jute-jute-carbon layering sequence that possesses superior mechanical properties than the composite sample without hybridizing elements such as pure banana (B-B-B-B) and pure jute fiber (J-J-J-J-J). Similarly, the strengths of the samples with three layers of carbon fiber (C/C/R/C and C/C/C/R) were enhanced by 226.35 % and 273.01 %, respectively, compared to that of Sample 1 (R/R/R/R). Three contiguous layers of carbon fibers appear to have added strength to sample 8 (C/C/C/R). The flexural strength of Samples 8 and 9 is nearly the same, indicating that the use of natural fiber in the Samples improves the load-bearing capacity. Another notable finding from Table 3 is that increasing the carbon fiber content while decreasing the natural fiber content increases the composite sample’s flexural strength and flexural modulus.

The carbon/flax hybrid composite laminate has superior flexural properties compared to the unhybridized composite laminate. Carbon fiber has stiffer and stronger than natural fibers. Showing that hybridization with synthetic fibers is an effective method to improve mechanical properties (Ezeokpube et al.2021). In general, natural fiber composite laminate has a non-linear behavior, which has been reduced by reinforcing synthetic fiber, such as carbon fiber in hybrid composite. This behavior is purely dependent on the amount of weight percentage (wt. %) of carbon fiber used in hybrid composite laminate (Kureemun et al. 2018).

3.3 Impact test

The impact strength of nine samples composed of carbon, ramie fibers, and epoxy components is evaluated using an impact test. The impact strength of various samples is determined by applying a transverse force with a hammer on the Izod impact tester, and the findings are presented in Table 4. When a transverse load is applied to the specimen, crack propagation occurs followed by fiber breakage and pull-out. Sample 9 (C/C/C/C) shows the highest impact strength (4.8 J) compared to the other samples, which happens due to the presence of carbon fibers in the sample. The impact strength of the sample of the pure ramie fiber composite (Sample 1) has a lower impact strength (1.25 J) than the carbon fiber hybrid composite. With the addition of one layer of carbon fiber (Samples 2 & 3) at different positions in the sample, a sharp increase in impact strength is observed, which is 68 % and 172 % higher than the sample of pure ramie fiber composite. The reason that impact strength of Sample 3 is more compared to Sample 2 may be because of carbon fiber resisted the impact load acting on it and gradually transferring to other layers of natural fibers. Two layers of carbon fibers are placed at different positions of the Sample (Sample 4, 5 & 6) which increases the impact strength by 228 %, 252 %, & 260 % when compared to pure ramie fiber composite. A composite with three or more than three layers of the carbon at different positions increases impact strength by 268 %, 276 %, and 284 % relative to the sample of pure ramie fiber composite sample. Layers of carbon fibers at both ends of the Sample C/R/R/C, could have resisted the impact load greatly and therefore the impact strength is higher among the two layered carbon fiber samples (Sample 4 and Sample 5). Similarly, the strengths of the samples with three layers of carbon fiber (C/C/R/C and C/C/C/R) improved by 268 % and 276 %, respectively, compared to that of Sample 1 (R/R/R/R). Three contiguous layers of carbon fibers appear to have added strength to sample 8 (C/C/C/R). From Figure 4, it was observed that an increase of the carbon fiber layer in the hybrid sample increases the impact strength; here a lot of energy is absorbed by the carbon fiber. Impact strength was also affected by the damping of the constituent materials (Assarar et al. 2015; RaviKumar et al. 2021) and height of dropping weight (Sarasini et al. 2014). The reason for

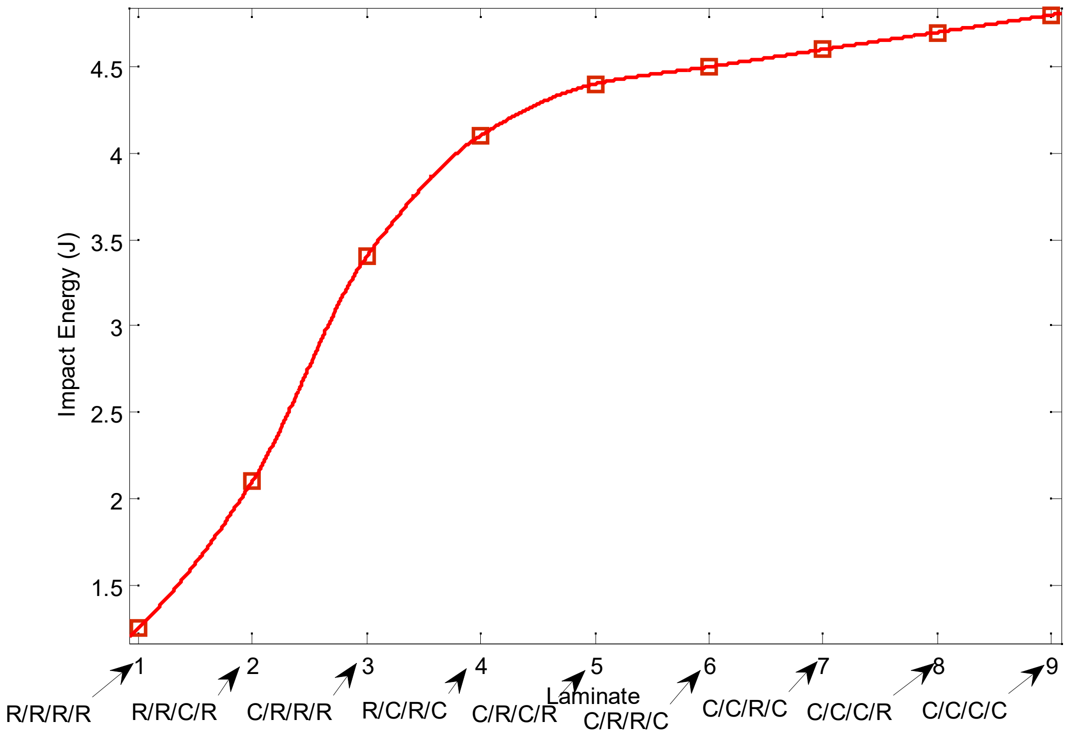

Figure 4. Impact strength of carbon and ramie fiber-reinforced hybrid composite laminate

Table 4. Flexural properties of carbon and ramie fiber-reinforced hybrid composite laminate.

Sample Designation	Layering sequence	Impact energy (J)
Sample 1	R/R/R/R	1.25
Sample 2	R/R/C/R	2.1
Sample 3	C/R/R/R	3.4
Sample 4	R/C/R/C	4.1
Sample 5	C/R/C/R	4.4
Sample 6	C/R/R/C	4.5
Sample 7	C/C/R/C	4.6
Sample 8	C/C/C/R	6.7
Sample 9	C/C/C/C	6.8

low impact strength in the case of composite sample with ramie fiber is due to the fiber breakage and fiber de-bonding (Tranchard et al. 2017).

3.4 Fourier transform infrared spectroscopy (FTIR)

Figure 5 shows the FTIR spectra of alkali treated ramie reinforced epoxy composite (R/R/R/R), the carbon fiber and ramie fiber-reinforced epoxy composite (C/R/R/C), and pure carbon fiber-reinforced epoxy composite (C/C/C/C/C). The H-bonded O-H group in the R/R/R/R composite was found to have a broad and high absorption peak at 3450 cm^{-1} (Sivaraman et al. 2015). This usually means that a good number of O-H groups and H-bonds were associated with each other in the composite sample. For C/R/R/C composites, a similar type of intensity peak is observed, whereas a shift in peak position in terms of magnitude is observed at 3439 cm^{-1}. Similar type of intensity peak was observed for C/R/R/C composites, while the peak position shifted to 3439 cm^{-1} in magnitude. In the case of C/C/C/C composites, a weak intensity of the peak and a different magnitude peak shift (3405 cm^{-1}) were observed due to changes in the H-bonding and O-H groups in the composite. A noticeable peak at 3049 cm^{-1} indicates the asymmetric stretching of C-CH_3 bond of its chemical formula is ($CH_3C{\equiv}CCH_3$) in C/R/R/C composite, whereas no such peak is observed in the

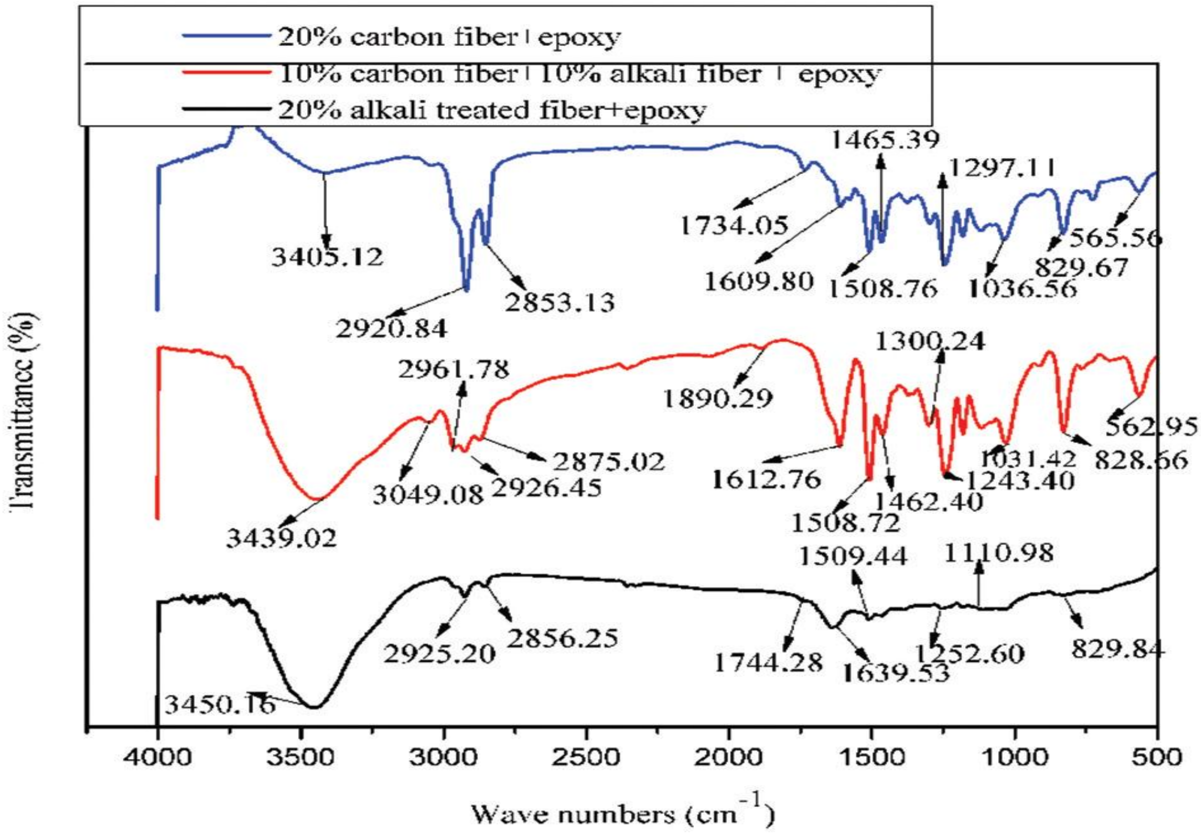

Figure 5: FTIR of the three different fabricated composite samples

other two composites (R/R/R/R and C/C/C/C) (Sivaraman et al. 2015). The weak absorption peak at 2925 cm^{-1} corresponds to the α-cellulose O-H group in the compound (R/R/R/R), indicating a reduced cellulose content after alkali treatment. In (C/R/R/C) composite, the rich content of cellulose is mainly responsible for shifting the absorption peak to 2961 cm^{-1}. But the absorption peak position is shifted to 2961 cm^{-1} due to rich content of cellulose present in the C/R/R/C composite. The narrow absorption peak was observed in the C/C/C/C composite at 2920 cm^{-1}, which represents the rich α- cellulose and O-H groups within it (Sivaraman et al. 2015). The weak absorption peaks at 2856 cm−1 (D/D/D/D), 2875 cm^{-1} (C/R/R/C), and 2853 cm^{-1} (C/C/C/C) were attributed to the methyl (-CH_3) and methylene (-CH_2-) groups present in it (Tran, Bénézet, and Bergeret 2014). The absorption peak at 1639 cm^{-1} in the (R/R/R/R) composite confirms the rich carbonyl groups (C=O) present in it, a decrease in carbonyl groups was observed in the C/R/R/C and C/C/C/C composites due to the hybridization of carbon fiber with the reinforced epoxy composite (Tran, Bénézet, and Bergeret 2014). All composites (R/R/R/R, C/R/R/C and C/C/C/C) exhibit similar absorption peaks at around 1508 cm^{-1} confirms the presence of aromatic C-H bond stretching in lignin (Tran, Bénézet, and Bergeret 2014). Similar absorption peaks appeared around 1508 cm^{-1} on the curves of R/R/R/R, C/R/R/C, and C/C/C/C composites, which can be recognized as C-H bond stretching, which is a characteristic of aromatic molecules. The oxidative alcohol stretching of the aliphatic ester group in lignin correlates with the absorption peak in the R/R/R/R compound at 1252 cm^{-1}. Peaks in both C/R/R/C and C/C/C/C composites were reduced to around 1243 cm^{-1}, indicating a reduction in ester and a drop in lignin (Tran, Bénézet, and Bergeret 2014). This FTIR spectrum shows the establishment of a bond between the fiber and the matrix. These results are consistent with previous research findings reported in the literature by other authors (Tran, Bénézet, and Bergeret 2014; Sivaraman et al. 2015).

3.5 Scanning Electron Microscope (SEM) analysis

The surface morphology and fractured surface area of alkali treated ramie fibers (R/R/R/R), carbon fiber and ramie fiber (C/R/R/C), and epoxy reinforced composites reinforced with pure carbon fiber (C/C/C/C) were studied as shown in Figures 6–8.

Figures 7–9 show the proper wetting of ramie fibers, carbon fibers and hybridization of these fibers into the epoxy composite. Alkali treatment (5 % NaOH) (R/R/R/R) removes impurities, hemicelluloses, and unwanted fiber constituent materials from the fiber surface and makes the fiber surface rougher and uneven, resulting in better mechanical interlocking (Figure 6). This mechanism results in better stress transfer with improved mechanical properties. It was also revealed that fewer amounts of fiber pullouts were observed due to alkali treatment.

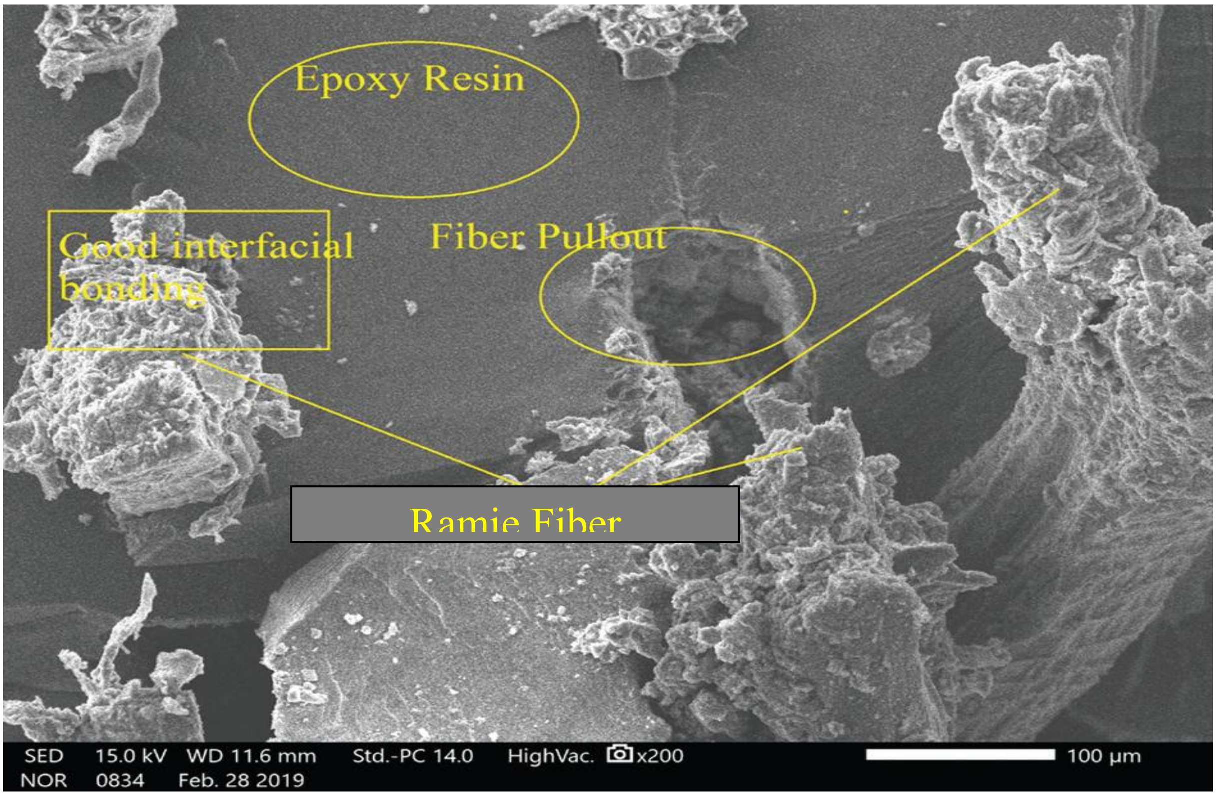

Figure 6: SEM image of ramie fiber-reinforced epoxy composite.

Figure 7 indicates strong interfacial adhesion between the carbon fiber and epoxy matrix (C/C/ C/C), as the epoxy matrix is properly infused into carbon fibers. Figure 8 shows a strong interaction between the hybridized fibers (C/R/R/C) and the epoxy matrix that leads to improved mechanical properties. SEM micrograph of ramie fiber and carbon fiber shows the predominance of brittle fiber failures and the indication of ductile failure of the matrix can be seen from Figure 8.

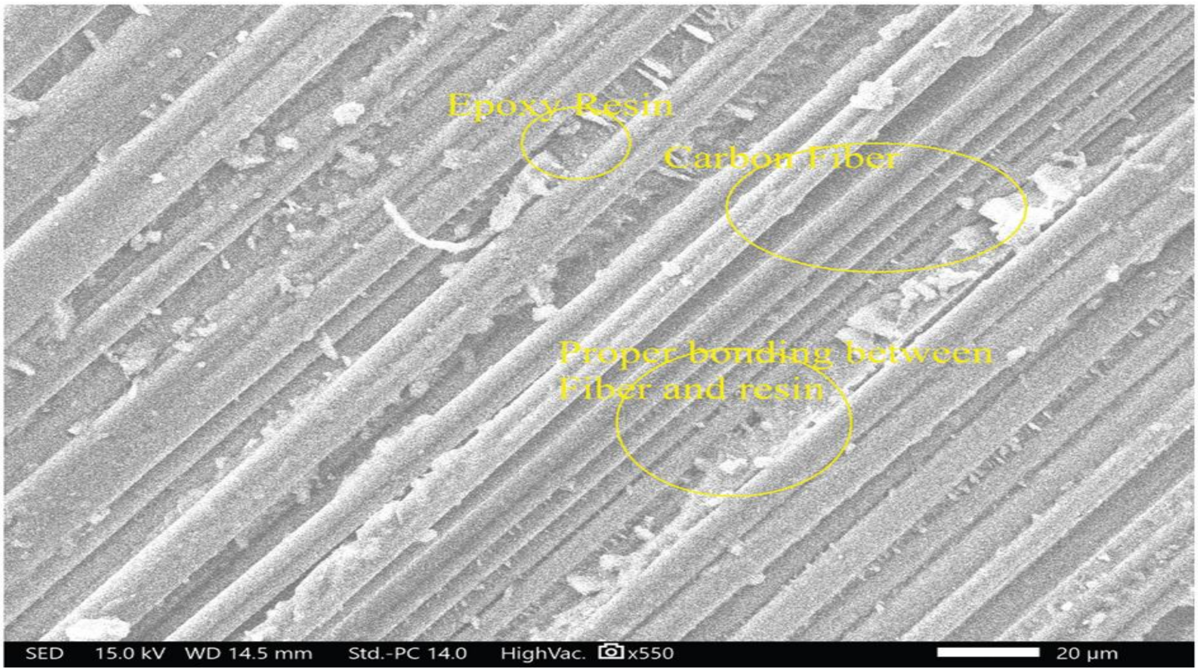

Figure 7: SEM image of carbon fiber-reinforced epoxy composite.

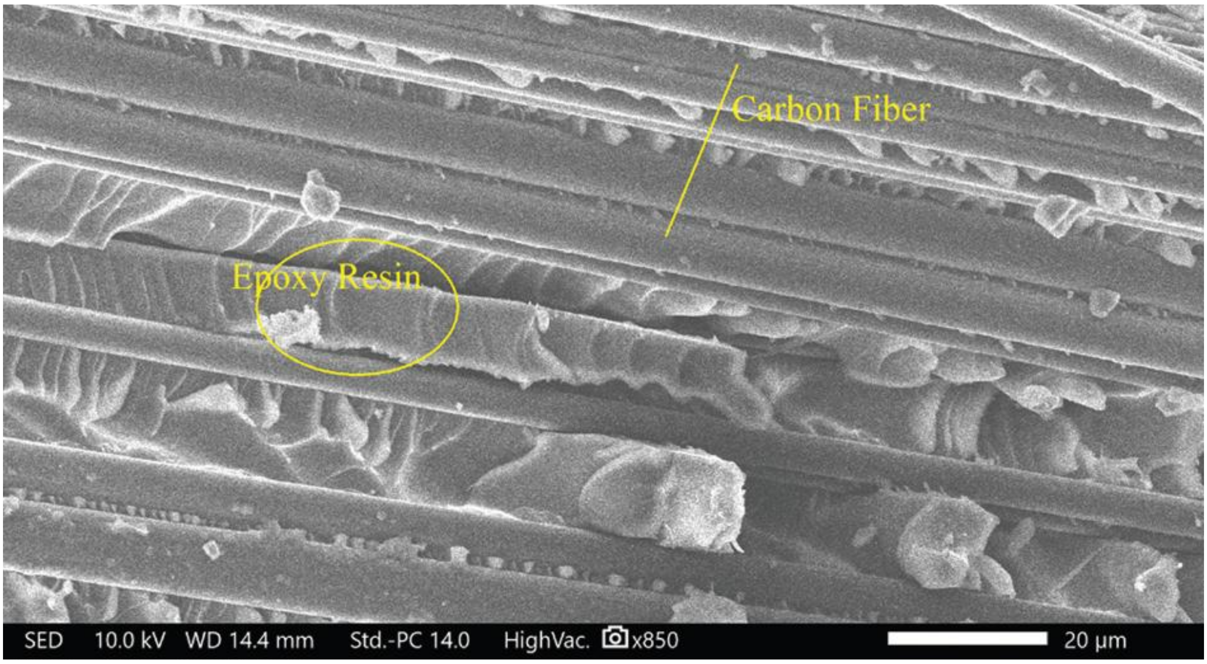

Figure 8: SEM image of ramie and carbon fiber-reinforced epoxy composite.

4. CONCLUSION

Current research focused on ramie fiber-based epoxy composites and carbon fiber hybridization into ramie fiber-reinforced epoxy composites, as well as their potential impact on tensile, flexural, and impact properties, with the following findings:

(1) The addition of carbon fiber to ramie fiber-reinforced epoxy hybrid composites increased mechanical properties such as tensile, flexural, and impact capabilities.
(2) Tensile strength of the laminates with three layers of carbon fiber (C/C/R/C and C/C/C/R) increased by 347.92 % and 485.69 %, respectively, compared to those of Sample 1 (R/R/R/R). This increase in mechanical properties may be suitable for aerospace, structural, infrastructural, packaging, sports, and automobile applications.
(3) Flexural strength of the samples with three layers of carbon fiber (C/C/R/C and C/C/C/R) was enhanced by 159.78 % and 196.92 %, respectively, compared to that of Sample 1 (R/R/R/R).
(4) Impact strength of the samples with three layers of carbon fiber (C/C/R/C and C/C/C/R) improved by 268 % and 276 %, respectively, compared to that of Sample 1 (R/R/R/R).
(5) The prepared hybrid composites are suited for a variety of applications like banners, fabrication of pipes and cylinders.

Conflict of interest
The authors declare that there is no conflicting interest in the publication of this paper.

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Highlights

- The addition of carbon fiber to ramie fiber-reinforced epoxy hybrid composites increased mechanical qualities such as tensile, flexural, and impact capabilities.
- Tensile and flexural test revealed that carbon fibers-reinforced ramie fiber epoxy composite gives enhanced strength and modulus.

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