Nano World Journal

https://doi.org/10.17756/nwj.2023-s4-027

Research Article

Open Access

Study of Mechanical, Thermal, and Morphological Behavior of *Cordia dichotoma* Carbon Fiber Hybrid Composite

Madhusudhan Reddy Bandi[1*], Suresh Kumar Gudimetta[1], Meenakshi Reddy Reddygari[1], Venkata Mohan Reddy Yerasu[1], Madhava Reddy Koppula[1] and Venkateshwar Reddy Pathapalli[2]

[1]*Department of Mechanical Engineering, G. Pulla Reddy Engineering College, Kurnool, Andhra Pradesh, India*

[2]*Department of Mechanical Engineering, Vardhaman College of Engineering, Hyderabad, Telangana, India*

[*]Correspondence to:
Madhusudhan Reddy Bandi
Department of Mechanical Engineering,
G. Pulla Reddy Engineering College,
Kurnool, Andhra Pradesh, India.
E-mail: madhusudhanr4@gmail.com

Received: September 15, 2023
Accepted: November 22, 2023
Published: November 27, 2023

Citation: Bandi MR, Gudimetta SK, Reddygari MR, Yerasu VMR, Koppula MR. 2023. Study of Mechanical, Thermal, and Morphological Behavior of *Cordia dichotoma* Carbon Fiber Hybrid Composite. *NanoWorld J* 9(S4): S151-S160.

Copyright: © 2023 Bandi et al. This is an Open Access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CCBY) (http://creativecommons.org/licenses/by/4.0/) which permits commercial use, including reproduction, adaptation, and distribution of the article provided the original author and source are credited.

Published by United Scientific Group

Abstract

Man made fibers have superior mechanical properties when compared with natural fibers, but their application is restricted due to cost and non-biodegradability concerns. Contrary to manmade fibers, natural fibers are biodegradable, renewable, and relatively inexpensive. The water absorption and inferior mechanical properties of natural fibers are poses a challenge to employ for industrial applications. The objective of this study is to improve the mechanical, structural, thermal, and water absorption properties of *C. dichotoma* natural fiber/polyester composites using hybridization with carbon fibers. The hybrid composites are made using the hand lay-up procedure, and subsequently by compression molding. Three distinct composite combinations were developed by altering the stacking sequence of *C. dichotoma* (F) and carbon fiber (C) as F/F/F, F/C/F and C/F/C. It was observed that the hybrid composite C/F/C has 48% higher tensile strength, 32% higher flexural strength, and 55% higher impact energy when compared to single fiber composite (F/F/F). Scanning electron microscope (SEM) analysis revealed the strong juncture among the fibers and matrix of failed hybrid specimens. Further, Fourier transform Infrared (FTIR) spectroscopy employed has identified the chemical and functional groups in the hybrid composite. Water absorption decreased with the insertion of carbon fiber in the layers of the hybrid composite laminate. It was found out from thermogravimetric analysis (TGA) that the hybrid composite was thermally stable up to 560 °C and is recommended for moderate and high-temperature applications since their working temperatures range from 220 °C to 560 °C.

Keywords

C. dichotoma fiber, Carbon fiber, Mechanical properties, Thermogravimetric analysis, Scanning electron microscope

Introduction

Composite materials are a novel class of materials that differ in many ways from traditional materials like metals, ceramics, and plastics. These materials are often used in mechanical design because of their high strength, adequate stiffness and toughness, and low weight. The matrix phase of a composite material, which consists of thermosetting and thermoplastic materials, is having ability to clamp the fibers intact and transmit the load to the fibers, while the reinforcing component - natural or synthetic fibers - is used to bear the greatest load. However, both of these components are chemically different and there is no chemical interaction within them. The choice of different types of reinforcing and matrix materials, as well as their production process, affects the properties of composite materials. The reinforcing of polymers with nano-fillers and nano-fibers, which enhances

mechanical properties, is one development in the creation of composites.

Fiber that comes from plants, animals, and vegetables is known as natural fiber. Natural fibers are naturally occurring hair-like strands derived from plant stems, leaves, branches, fruit, or animals that are used to make a variety of products [1, 2]. To meet contemporary demands, nano-fillers are now used in along with fires. The nano-fillers are nanoparticles that are made up of mineral silicates and nano-fibers. Natural fibers can be employed to be a reinforcing component in the manufacture of Natural Fiber Reinforced Composites (NFRPs) since they have specific properties like low density, lightweight, and inexpensive and also they are abundantly available, renewable, recyclable, less health issues, and environmentally friendly materials [3, 4]. Many natural fibers, namely sisal, *Acacia pennata*, hemp, kenaf, banana, and coir, have already been identified, extracted, and used as fortification in the Fiber Reinforced Polymer Composites [5-7]. Various researchers reinforced the aforementioned fibers to make thermosetting composites and explored their mechanical, thermal, and other important characterizations such as SEM, FTIR, and so on for their industrial usefulness. These composites have moderate strength, low specific weight, high stiffness, excellent thermal and acoustic insulation, and high fracture resistance, so they find applications in automotive, dashboards, packing, boats, and sports [8, 9]. However, the use of these natural fibers was restricted to parts with less demanding mechanical performance, because of their inadequate strength, incompatibility with polymer resin, strong water uptake properties, and disintegration of fiber due to water uptake. The aforementioned drawbacks were tried to be get rid of by researchers through chemical and physical treatments, hybridizations, and changes to the layering sequences [10, 11]. The most frequently used fiber modification techniques (chemical treatments) to reduce fiber incompatibility, hydrophilicity, and disintegration due to water uptake includes alkali (NaOH), saline, and KOH. Reddy et al. [12] developed the composite with *C. dichotoma* fiber/ polyester with a hand lay-up process and examined the mechanical, thermal, and structural characterizations of the prepared composite, recommending various applications such as automotive and packing. Prasad and Rao. [13] employed jowar fiber in their investigation and concluded that it is used for lightweight applications such as household, partition panels, automobile body building, and packaging.

To address the aforementioned drawbacks of NFRPs, researchers have chosen the synthetic material i.e., carbon fiber as a substitute material and fabricated the carbon fiber reinforced polymer composites (CFRPs) [14]. Carbon fibers are chosen as the reinforcing material in CFRPs owing to its unique properties, including considerable strength, high modulus, lightweight, and robustness [15, 16]. Due to their high strength-to-weight ratios, they are extensively employed in aircraft, sailboats, contemporary bicycles, and vehicle applications [17, 18]. In terms of strength and stiffness per unit of weight, CFRPs are substantially stronger and more rigid than glass fiber and even stronger than steel [19]. Even though CFRPs are amazing materials, we can't use them in every application because of a few drawbacks, including, brittleness, and crack-prone tendency with a weak adhesion leading to failure of the composite structures in terms of delamination and catastrophic failure, price of the fiber, their tremendous electrical and thermal conductivity, and the fact that they are not biodegradable.

As single NFRCs are not having adequate strength to substitute the traditional materials, hybrid combinations of natural fiber and synthetic fibers are preferred [20]. Hybrid composites, which are produced with at least two distinct kinds of fortifications, have three major advantages over single-reinforcement composites. First, they allow designers greater flexibility in customizing composites to attain desired qualities. Second, substituting expensive artificial fibers such as carbon and boron with less expensive natural fibers may outcome in more gainful use of these expensive fibers. Third, they offer the possibility to attain a well-proportioned merging of properties including strength, rigidity, and ductility [20-22]. Many researchers have recently experimented with the combining of natural and artificial fibers and demonstrated the importance of hybridization to both industry and society. The significance of the inter-ply positioning of Kevlar-sisal fiber reinforced polyester composite was explored by Prabhushankar et al. [23]. The studies concentrated on the evaluation of hydrophobicity, and mechanical, and wear characteristics of the composite. The outcomes showed that C3 composite records the highest mechanical and fracture toughness properties and C4 composite has the lowest specific wear rate. As a result of these findings, hybrid composites are used in items such as building materials, automotive components, and aircraft bodies. Investigations were conducted by Shubam et al. [24] on the mechanical characteristics and layering order of Kevlar/banana fiber/ nano graphene oxide hybrid composites. It is indicated that requirements for sustainable development include biodegradability, good mechanical strength, and lightweight.

This research is primarily focused on the influence of hybridization on mechanical, morphological, and water assimilation characteristics of a hybrid combination of carbon and *C. dichotoma* fibers as it is still unstudied. A hybrid composite is prepared by fortifying the carbon fiber and *C. dichotoma* fiber in a polyester using a hand lay-up method followed by pressing to make laminates. The mechanical capabilities of the aforementioned hybrid composite were tested experimentally with the universal testing machine. Using an Izod impact tester, the impact strength was evaluated. Using SEM, the compatibility of the carbon fiber, matrix was *C. dichotoma* fiber, and polyester examined. Furthermore, FTIR spectroscopy was used to illustrate the detection of both chemical and functional groups in the hybrid composite. The temperature-stability of the hybrid composite was examined using TGA, which measured weight loss to be function of temperature increase. In light of the findings, it is recommended that these hybrid composites to be used in wind turbine blades, aircraft bodies, and automotive components. Natural nano *C. dichotoma* fibers will be mixed with carbon fiber and reinforced with an epoxy matrix in the future, and their mechanical properties will be investigated.

Materials and Method

Materials

C. dichotoma fiber and its extraction

C. dichotoma trees are widely grown in palkonda hills in the Ananthapur district of Andhra Pradesh, India. Traditional technique of removing fibers from tree bark is water retting. It entails extracting fibers from tree bark and soaking them in water for two weeks. Water was changed at regular intervals to prevent the formation of greenish material on the bark. The fibers were extracted by mechanical beating and squeezed with water to eliminate greenish material or any contaminants that had stuck over the fiber. These fresh fibers were sun-dried until the moisture in the fiber was eliminated. To remove the fiber's hydrophilicity, it was soaked in an alkaline (NaOH) solution for two hours. The fibers are then trimmed to required length and wrapped in polythene covers to prevent moisture absorption.

Carbon fiber

Carbon fiber is a widely accepted synthetic fiber that is manufactured from several precursor materials such as Polyacrylo nitrile, viscose rayon, and pitch. The carbon fiber used in this study is a unidirectional mat of 200 gsm.

Polyester

Polyesters have several advantages, including low cost, low viscosity, and a comparatively short curing time. The chemical reaction of propylene/ethylene glycol and maleic anhydride produces polyester resin. The accelerator is methyl ethyl ketone peroxide, and the catalyst is cobalt naphthenate. The blending ratio of the polyester with the catalyst and accelerator is 100:1:1 by weight.

Composite preparation

The composite sample plates were ready by a combination of hand lay-up technique and compression. For the initial composite preparation, a chopped *C. dichotoma* (F) fiber and carbon-fiber (C) mat with a dimension of 150 x 150 mm^2 was used. In all, three layers *C. dichotoma* and carbon fibers were used in every laminate. Three kinds of hybrid sample plates were prepared with different sequence of *C. dichotoma* (F), carbon fiber (C) reinforced into polyester resin and labeled as F/F/F, F/C/F, and C/F/C, as shown in table 1. In a 100:1:1 weight ratio, polyester resin, catalyst, and accelerator were blended before placing them in the mold. The two fibers were then laid out uniformly, and a resin mixture was introduced in between them to maintain the required thickness and adherence in the composite laminate. Finally, the resin was poured on top of the composite laminate, and placed on the overhead projector sheet to get the smooth surface. For obtaining the correct dimensions, a compression machine was employed. Constant pressure was maintained for the laminate for almost 12 h to get better curing as sensed from physical touch.

Mechanical characterization

Tensile testing

The hybrid composite specimen's response to tensile forces was assessed using the tensile test. These properties were measured using the universal testing equipment (INSTRON-Model: 3369) by the ASTM (ASTM: 3039) standard.

Table 1: Laminate designation and layering sequence of fibers in the hybrid composites.

Designation of the laminate	Layering sequence L1/L2/L3	*C. dichotoma*/Carbon fiber wt. ratio (Wt.%)		
		L1	L2	L3
Laminate 1	F/F/F	6.6	6.7	6.6
Laminate 2	F/C/F	6.6	6.7	6.6
Laminate 3	C/F/C	6.6	6.7	6.6

Note: F - *C. dichotoma* fiber and C - Carbon fiber.

Flexural testing

The hybrid composite specimen's flexural strength must be evaluated using the flexural test. Flexural strength is the highest value of transverse force that a hybrid composite specimen can withstand without bending failure. These strengths were measured using a three support bending arrangement on a universal testing machine (Model: INSTRON 3369) in compliance with the ASTM (ASTM D 760-03) standard.

Impact testing

The Izod impact tester was used to evaluate the impact strength of the hybrid composite specimen. The impact test hybrid composite specimens were made by ASTM D-256, with dimensions of 6.35 (length) x 1.27 (breadth) x 0.3 (thickness) cm^3 and a v-groove of 25.4 mm depth and groove gradient of 45° in the middle of the impact specimen by a jigsaw machine.

Other characterization

FTIR spectroscopy

The functional groups and chemical compounds present in the hybrid composite specimens were identified using FTIR spectroscopy, which was done using a thermo-nicolet Avatar 370 analyzer. The principle behind this study is the transmission of IR rays through a hybrid composite sample; when the IR frequency coincides with the vibrational frequency of the sample, absorption takes place and a spectrum can be captured.

TGA analysis

The TGA measures the heat resistance capacity of a hybrid composite sample in terms of weight loss as the temperature rises gradually. The TGA graphs of above samples were captured using a thermogravimetric analyzer (NETZSCH STA 2500) in a nitrogen environment with a 2 ml/min rate of flow and a stable heating rate of 10 °C/min.

Water absorption test

Water absorption capacity of the material, under given weather conditions, can be measured with this test. Using ASTM D570-98, the hybrid samples was prepared for the water absorption test. Samples for testing are dried for 24 h at 105 °C in an oven and then cooled in desiccators. The weighted individual test samples are submerged in distilled water for 24 h at 25 °C and record the time. Every day at the time specified, the submerged specimens were taken out of the water, superficial cleaning was done with a clean cloth; and weighed. The weight growth was then noted. For 240 h, this

procedure was repeated.

$$\% \text{ of water absorption} = \frac{W_2 - W_1}{W_1}$$

Where, W_1 = Dried laminate weight in grams and W_2 = Wet laminate weight in grams.

SEM analysis

The morphological structure of the fractured laminates was investigated using a SEM. A JEOL/EO SEM machine (Model-JSM-6390), with an accelerating voltage of 20 kV. Before the SEM, each sample was given a thin coating of conductive material (gold/palladium) using a sputter coater.

Results and Discussion

Tensile properties

The tensile properties of the laminates involving the two fibers were compared to *C. dichotoma* fiber composites and results are shown in table 2. Laminate 2 (F/C/F) and laminate 3 (C/F/C) showed substantial enhancement in the tensile properties of the composites in contrasted to the laminate 1 (F/F/F) composite.

Table 2: Tensile properties of hybrid composite laminates.

Composite laminate	Layering sequence	Tensile strength (MPa)	Tensile modulus (MPa)	Tensile strain (mm/mm)
Laminate 1	**F/F/F**	117.96	4245.68	0.04983
Laminate 2	**F/C/F**	191.41	6976.29	0.05217
Laminate 3	**C/F/C**	228.12	7167.35	0.06700

Note: F - *C. dichotoma* fiber and C - Carbon fiber.

Comparing laminate 2 (F/C/F) composites to laminate 1 (F/F/F), the tensile yield strength is enhanced by about 38% and the modulus of elasticity is raised by about 39%. Comparing laminate 3 (C/F/C) composites to laminate 1 (F/F/F), the tensile yield strength is enhanced by about 48%, and the modulus of elasticity is enhanced by about 40%. Figure 1, figure 2, and figure 3 shows the tensile strength, modulus of elasticity, and tensile strain of laminate 1, laminate 2, and laminate 3 composites, respectively. Tensile properties were enhanced in hybrid composite laminate 2 (F/C/F) due to the stronger and stiffer carbon fiber that is capable of bearing the load as compared to laminate 1 (F/F/F). Similarly, as compared to laminate 1, the tensile properties of the hybrid composite laminate 3 (C/F/C) were improved due to the stronger and stiffer carbon fiber inserted in the core and skin positions. Another reason for increasing the tensile properties of a hybrid composite laminate is the adhesive bond between the two fibers and matrix; this was demonstrated through the SEM pictures. Khanam et al. [25] evaluated the tensile properties of a laminate with untreated and 18% NaOH-treated Sisal, carbon fiber and polyester. According to the results, the inclusion of carbon fiber in the laminate improved its tensile properties. Similar results have been observed, when various fillers, such as carbon nanotubes, nanoparticles, and nano-fillers such as clay, $CaCO_3$, and others, are added into epoxy composites. These inclusions help to improve mechanical properties, according to Ravikumar et al. [27].

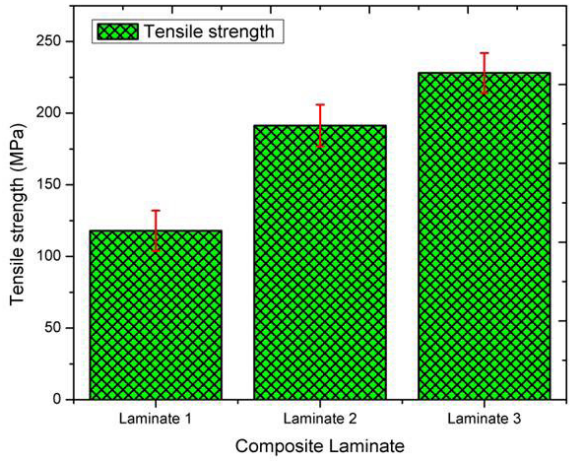

Figure 1: Tensile strength of hybrid composite laminates.

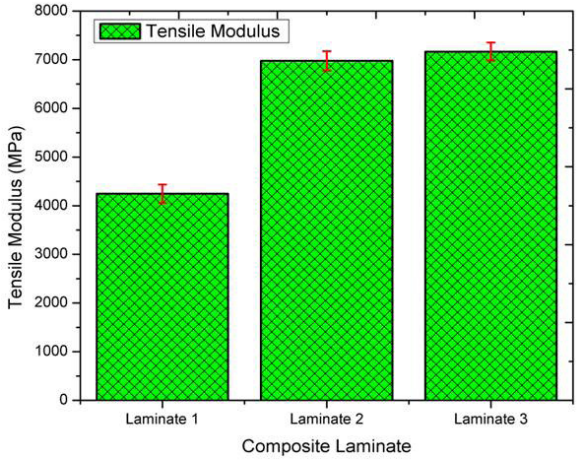

Figure 2: Tensile modulus of hybrid composite laminates.

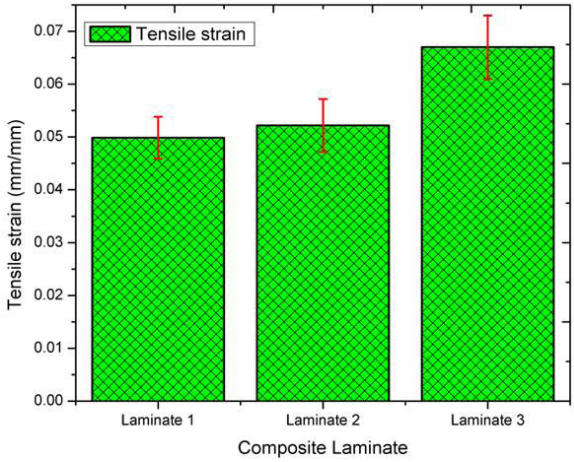

Figure 3: Tensile strain of hybrid composites.

Flexural properties

The flexural properties of *C. dichotoma*-carbon fiber hybrid composites were compared to *C. dichotoma* fiber composites are

shown in table 3. Comparing laminate 1 (F/F/F) to laminate 2 (F/C/F) and laminate 3 (C/F/C), it was evident that the flexural properties of the latter two had significantly improved.

Comparing laminate 2 (F/C/F) and laminate 3 (C/F/C) with laminate 1 (F/F/F), the flexural strength is higher for laminate 2 and much higher for laminate 3. Discussion on flexural modulus results are almost on the same line. Figure 4 and figure 5 shows the flexural strength, and flexural modulus of laminate 1, laminate 2, and laminate 3 composites, respectively. Flexural properties were better in hybrid composite laminate 2 (F/C/F) due to the stronger and stiffer carbon fiber that is capable of bearing the load as compared to laminate 1 (F/F/F). Similarly, as compared to laminate 1 and laminate 2, the flexural properties of the hybrid composite laminate 3 (C/F/C) were even better due to the stronger and stiffer carbon fiber with two layers inserted in the core and skin positions. Another reason for the better flexural properties is the adhesive bond between the two fibers and matrix; this was demonstrated through the SEM pictures. Khanam et al. [25] assessed the flexural performance of a laminate comprised of raw and 18% NaOH-treated carbon fiber and polyester resin. According to the results, the inclusion of carbon fiber in a hybrid composite improved its flexural properties. Murdani et al. [26] developed a hybrid composite using three fibers: jute, glass, and carbon fiber, and their laminates are J, JG, JC, JJ, JJG, JJC, JJJ, JJJG, and JJJC. When jute-carbon laminates were compared to jute-glass and plain jute laminates, it was determined that jute-carbon laminates had the highest flexural strength.

Impact properties

The impact energy for the laminates is presented in table 4. When the specimen was subjected to a transverse load, crack initiation, crack growth, crack propagation, and fiber fracture took place in order. Compared to the other two samples, laminate 3 (C/F/C) has the maximum impact energy (3.38 J) (Figure 6). This is because carbon fibers present in the core and skin of the samples resist the impact force exerted on it and then gradually transfer it to natural fiber. The impact energy of laminate 1 (F/F/F) has a lesser impact energy (1.26 J) than laminates 2 and 3. A rapid increase in impact energy was seen with the insertion of carbon fiber in laminates 2 (F/C/F) and 3 (C/F/C) of the composite sample. According to Ravikumar et al. [27] and Assarar et al. [28], the Impact energy of the laminate relies on both the damping of the constituent materials and the height of the dropping weight. According to Tranchard et al. [29], fiber breakage and debonding also affect impact strength.

FTIR spectroscopy

The samples for FTIR spectroscopy were made from *C. dichotoma* (F), carbon fibers (C), and polyester resin. It is necessary to identify the functional groups and chemical compounds in three composite samples: laminate 1 (F/F/F), laminate 2 (F/C/F), and laminate 3 (C/F/C). Figure 7, figure 8, and figure 9 depicts the FTIR spectroscopy of composite laminates 1 (F/F/F), 2 (F/C/F), and 3 (C/F/C). Similar peaks were seen, indicating that nearly all of the composite samples had similar bonds. Few additional peaks were found in hybrid composite laminates: a broad absorption peak at 3036.23 cm^{-1} that was caused by the stretching of the aromatic C-H bond in cellulose, lignin, and hemicelluloses. The absorption band at 1412.59 cm^{-1} is weak and sharp, showing symmetric bending (CH_2) and symmetric stretch of the carboxyl group, and C-H distortion in cellulose, lignin, and hemicelluloses. A weak and distinct absorption band at 1107.10 cm^{-1} attributed

Table 3: Flexural properties of hybrid composite laminate.

Composite laminates	Layering sequence	Flexural strength (MPa)	Flexural modulus (MPa)
Laminate 1	F/F/F	164.99	8786.22
Laminate 2	F/C/F	209.99	22662.57
Laminate 3	C/F/C	243.63	43157.91

Note: F - *C. dichotoma* fiber and C - Carbon fiber.

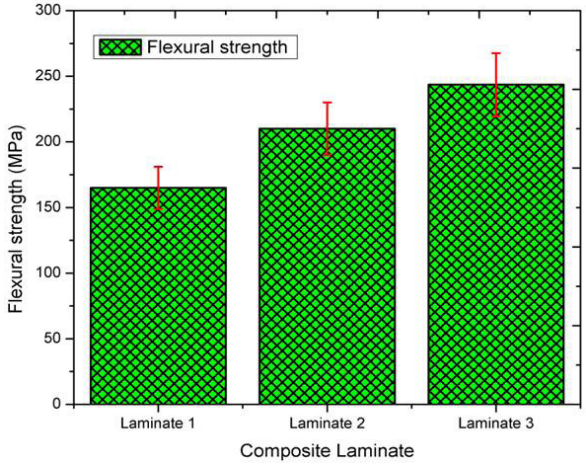

Figure 4: Flexural strength of hybrid composite laminates.

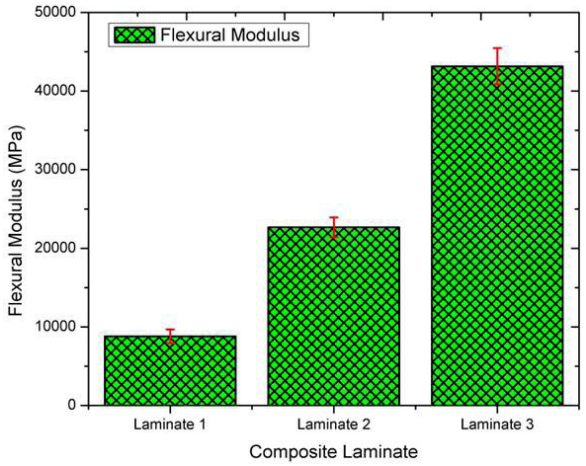

Figure 5: Flexural modulus of hybrid composite laminates.

Table 4: The impact energy of hybrid composite laminates.

Composite laminates	Layering sequence	Impact energy (J)	Impact strength (kJ/m^2)
Laminate 1	F/F/F	1.54	40.42
Laminate 2	F/C/F	2.66	69.81
Laminate 3	C/F/C	3.38	88.71

Note: F - *C. dichotoma* fiber and C - Carbon fiber.

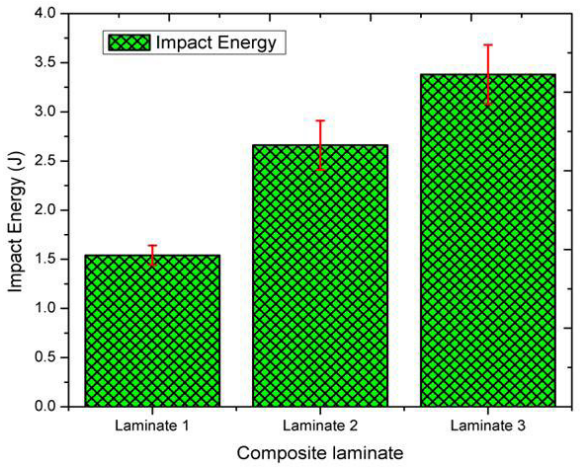

Figure 6: Impact energy of hybrid composites.

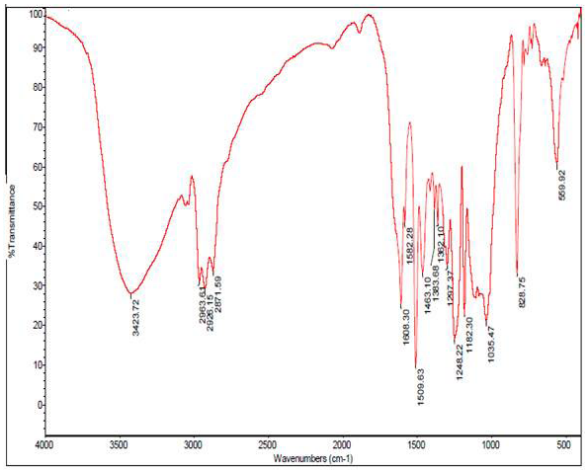

Figure 7: FTIR spectroscopy of hybrid polyester composite laminate (Laminate 1-F/F/F).

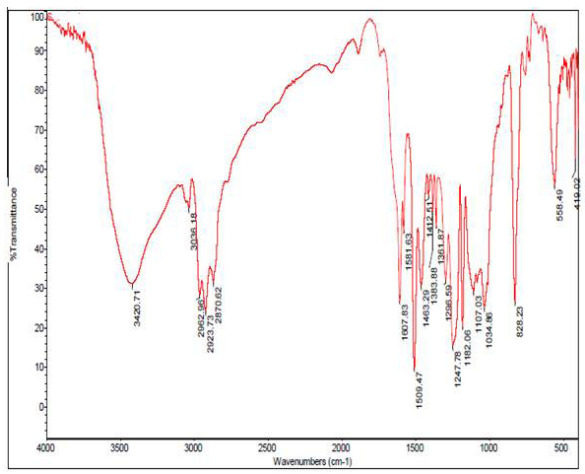

Figure 8: FTIR spectroscopy of hybrid polyester composite laminate (laminate 2-F/C/F).

to aromatic C-H in a plane deformed in lignin. The presence of a strong and sharp absorption band at 419.02 cm^{-1}, which falls inside the fingerprint region, validates the C-I stretch in lignin. Table 5 lists their wave numbers; assigned functional groups, components, and reference sources.

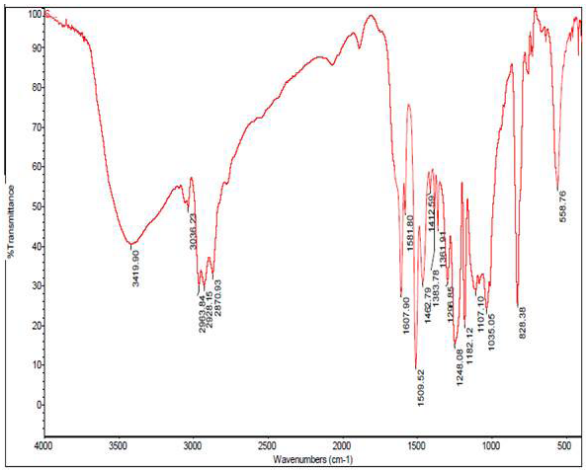

Figure 9: FTIR spectroscopy of hybrid polyester composite laminate (laminate 3-C/F/C).

TGA analysis

Thermal stability is measured by the percentage change in mass or weight loss as a function of temperature or time. Figure 10 displays pertinent TGA graphs. The onset Temperature (T_o) seen in the TGA graph of laminate 1 (F/F/F) is around 120 °C, which is the temperature at which weight loss or mass loss starts. This loss could be attributed to absorbed moisture, essential water, and volatile substances in the fiber. Thermal stability of laminates decreases, when temperature rises, resulting decomposition in three steps. The first stage occurs between 220 °C - 380 °C, 220 °C - 390 °C and 250 °C - 400 °C for laminate 1 (F/F/F), laminate 2 (F/C/F), and laminate 3 (C/F/C) composites, respectively. This shows that the lignin and hemicellulose components of the fiber have been eliminated. In these three temperature ranges, the mass loss was roughly 36%, 34%, and 27%, respectively. Carbon fiber hybridization resulted in reduced mass loss and increased thermal stability. Next phase of decomposition happens in the ranges of 380 °C- 420 °C, 390 °C - 425 °C, and 400 °C - 430 °C for laminate 1 (F/F/F), laminate 2 (F/C/F), and laminate 3 (C/F/C) composites, respectively. At these temperatures, the cellulose and lignin components could disintegrate and weight loss was roughly 82%, 80%, and

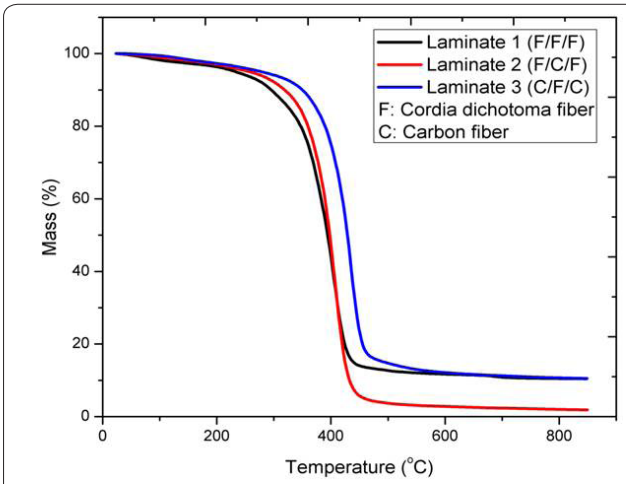

Figure 10: TGA graph of hybrid polyester composite laminates 1, 2, and 3.

Table 5: Wavenumber (cm^{-1}) for *C. dichotoma* (F), carbon fibers (C), and polyester resin and functional groups assignment for hybrid composite laminates.

Laminate 1 (F/F/F)	Laminate 2 (F/C/F)	Laminate 3 (C/F/C)	Assigned functional group	Components	Ref.
3423.72	3419.90	3420.71	Water; H-bonded OH stretching	Cellulose, Lignin, Hemicellulose	[30]
-	3036.23	3036.18	Aromatic C - H stretching	Cellulose, Lignin, Hemicellulose	[30]
2963.61	2963.84	2962.96	C - H stretching of methyl group and symmetric CH_2 stretching	Cellulose, Hemicellulose, Lignin	[30, 31]
2926.15	2928.15	2923.73	C-H stretching	Cellulose, Hemicellulose, Lignin	[31]
2871.59	2870.93	2870.62	Antisymmetric CH_2 stretching	Cellulose, Hemicellulose, Lignin	[30, 32]
1608.30	1607.90	1607.83	Aromatic skeletal vibration, C=O stretching, adsorbed O-H	Hemicellulose, Lignin	[31]
1582.28	1581.80	1581.63	Aromatic ring stretching	Lignin	[30]
1509.63	1509.52	1509.47	stretching and vibration in C=C-C aromatic ring	Lignin	[31]
1463.10	1462.79	1463.29	Deformation of the C-H bond in methyl and methylene	Lignin	[31]
-	1412.59	1412.51	Symmetric CH_2 bending and stretching of carboxyl group, C-H deformation	Cellulose, Lignin, Hemicellulose	[31]
1383.68	1383.78	1383.88	C-H stretching and bending in CH_3	Cellulose, Hemicellulose, Lignin	[31]
1362.10	1361.91	1361.87	C-H bending and stretching in CH_3	Cellulose, Hemicellulose, Lignin	[31]
1297.37	1296.85	1296.59	C-O-C ester stretching band ("regularity band")	Cellulose, Hemicellulose, Lignin	[30, 31]
1248.22	1248.08	1247.78	C-O stretching of guaiacyl unit	Lignin	[31]
1182.30	1182.12	1182.06	C-O-C stretching	Cellulose, Hemicellulose	[31]
-	1107.10	1107.03	In-plane aromatic C-H deformation	Lignin	[31]
1035.47	1035.05	1034.86	C-O stretching, In-plane deformation in aromatic C-H	Cellulose, Lignin	[31]
828.75	828.38	828.23	Aromatic C-H	Lignin	[31]
559.92	558.76	558.49	C-Br stretch	Lignin	[31]
-	-	419.02	C-I stretch	Lignin	[31, 32]

79%, respectively. The final phase of decomposition was in the ranges of 420 °C - 518 °C, 425 °C - 522 °C, and 430 °C - 560 °C for laminate 1 (F/F/F), laminate 2 (F/C/F), and laminate 3 (C/F/C) composites, respectively. This temperature range may cause the decomposition of lignin and strong components. Over this temperature range, the weight loss was nearly 88%, 86%, and 86%, respectively. The foregoing results show that hybrid composite laminate 1 (F/F/F), laminate 2 (F/C/F), and laminate 3 (C/F/C) are employed for moderate and high-temperature applications since their working temperatures range from 220 °C to 560 °C.

Several authors conducted TGA analyses by hybridizing natural and synthetic fibers and concluded that thermal stability was improved in the case of carbon fiber-reinforced hybrid composites rather than single natural composites.

Water absorption test

Figure 11 depicts the percentages of water absorption by the laminates (Laminate 1 - F/F/F), (Laminate 2 - F/C/F), and (Laminate 3 - C/F/C). The composite laminate 1 has a strong tendency for water assimilation. The hydroxyl and other groups in the fiber hold water because of hydrogen bonding [33]. Permeability defects in the composite also affect absorption ability because they provide a channel for absorbed water. During the composite's fabrication, this

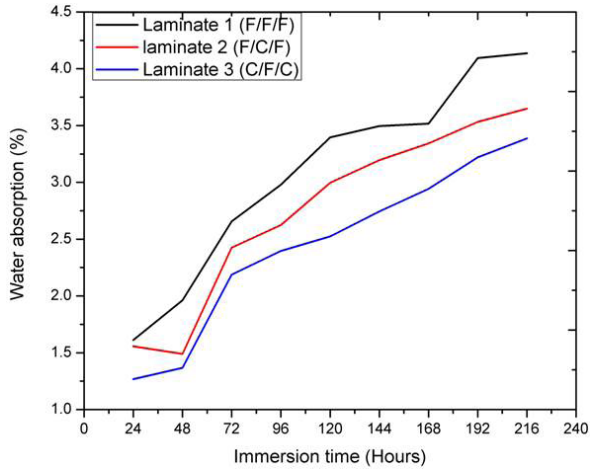

Figure 11: Water absorption test results of hybrid polyester composite laminates 1, 2, and 3.

porosity would have developed. According to figure 11, for laminate 2/laminate 3, the presence of carbon fiber in the core/outer layers, has decreased the water absorption property compared to laminate 1. Ouarhim et al. [34] investigated the water resistance characteristics of laminate comprise of jute-glass fiber in a polyester matrix. The outcome revealed that the hybridization and stacking series increased the moisture proof.

Furthermore, Sreekala et al. [35] concentrated on the behavior of water assimilation of used fibers. The findings addressed the causes of it in natural fibers, including the existence of different substances like wax, hemicelluloses, cellulose, that are liable for capturing of water particles in the fibers.

SEM analysis

The morphology of three laminates was assessed using scanning electron microscopy. The final images are shown in figure 12, figure 13, and figure 14. SEM images are obtained to observe the bonding between the reinforcements and matrix, internal cracks, and internal structure of the failed surfaces of the composite laminates. Figure 12 shows the failed substrate of the fiber and void that resulted from the fiber pullout for laminate 1. Another important observation is that the frontier adhesion among the polyester matrix and the *C. dichotoma* fiber has been significantly improved as a result of the alkali treatment. The alkali treatment removes surface contaminants, resulting in a rough surface that improves mechanical interaction between the constituents. Figure 13 clearly shows the fibers and their orientation and their bonding with the polyester. It also displays the void formation after the testing is over due to the manufacture of the composite in laminate 2. Figure 14 depicts the carbon fibers are positioned on the outer layers and natural fiber is seen inside the laminate 3. The distribution of the fibers is uniform, and their bond is strong thus the mechanical properties are enhanced due to the bonding between the constituents. After testing, it became clear that some areas had experienced fiber breakage and void formation due to flaws in composite manufacture.

Conclusions

The three kinds of composite laminates (Laminate 1 with layering sequence F/F/F; Laminate 2-F/C/F, Laminate 3-C/F/C) were fabricated using *C. dichotoma* fiber (F), carbon fiber (C), and polyester resin. Tensile, flexural strengths, and impact energy, were investigated and the following findings have been drawn. In addition, thermal stability, and morphological behavior of the laminate were examined:

- When carbon fiber is added to the outer/inner layers of *C. dichotoma* fiber and polyester matrix resulted in increased tensile, flexural, and impact-holding capacities.
- The laminate 3 (C/F/C) was found to have maximum tensile strength and elastic modulus of 228.12 MPa and 7167.35 MPa, respectively.
- The flexural strength of laminate 3 (C/F/C) was 32% greater than that of laminate 1 (F/F/F) and has a maximum flexural strength of 243.63 MPa.
- Highest impact energy also was obtained for laminate 3 (C/F/C) and has a value of 3.38 J.
- The findings from FTIR spectroscopy indicate that the structural characteristics of all three composites (F/F/F), (F/C/F), and (C/F/C) remain unchanged even after the carbon fiber is hybridized. Hybrid composites showed very minimal structural changes.
- TGA results revealed that the prepared hybrid composite is thermally stable up to 560 °C and is recommended for moderate and high-temperature applications since its operating temperatures range from 220 °C to 560 °C.
- A reduction in water absorption was noticed with the addition of carbon fiber in the outer or inner layers (C/F/C), (F/C/F) in the composite when compared to a

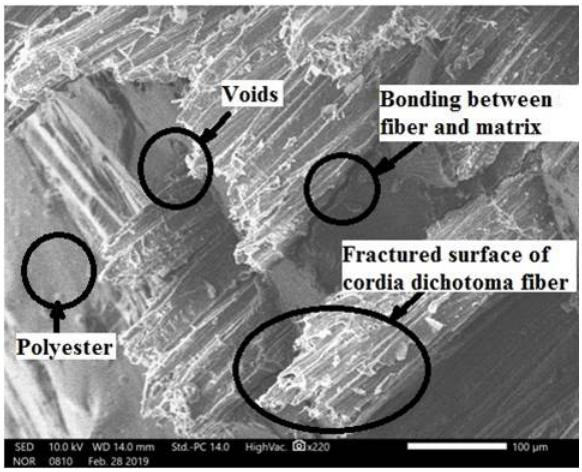

Figure 12: SEM morphology of hybrid composite laminate (Laminate 1-F/F/F).

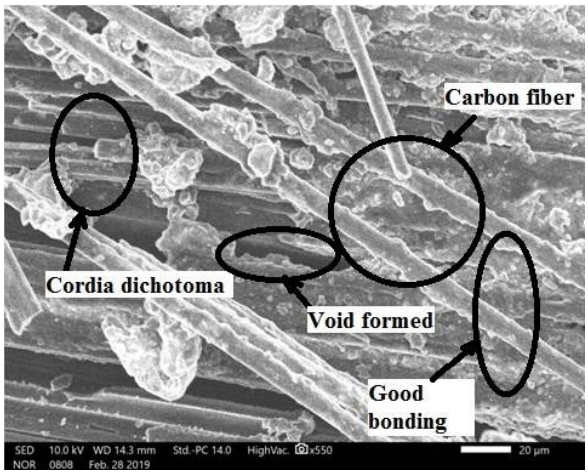

Figure 13: SEM morphology of hybrid composite laminate (Laminate 2-F/C/F).

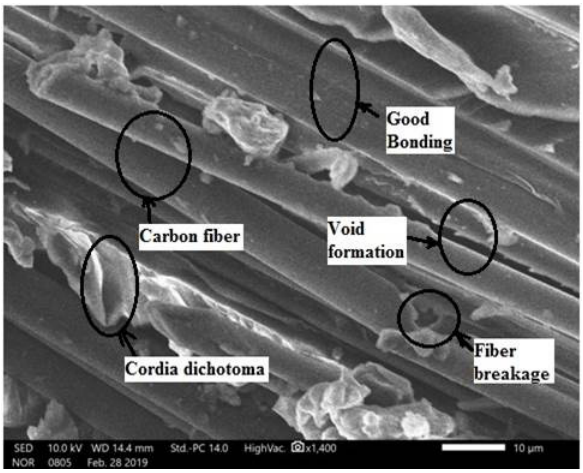

Figure 14: SEM morphology of hybrid composite laminate (Laminate 3-C/F/C).

composite without carbon fiber (F/F/F). Another factor causing a decrease in water absorption characteristics is the bonding between the matrix and reinforcements.

- SEM morphology showed that the broken surfaces of the tested composite samples of laminate 1 (F/F/F) had good interfacial bonding and fewer voids. Both laminate 2 (F/C/F), and laminate 3 (C/F/C) demonstrated good alignment and polyester infusion in the middle of the fibers layers, leads to few flaws and tiny holes in the laminate.
- The outcomes of all of the aforementioned studies demonstrated the applicability of composites to a variety of industries, including those in the automotive, aerospace, marine, sports, packaging, decking, and infrastructure sectors.
- In future, the incorporation of nano-fillers such as MMT clay and nanotubes reinforced into composites to improve their application in a variety of applications.

Acknowledgements

None.

Conflict of Interest

None.

References

1. Obame SV, Betené ADO, Naoh PM, Betené FE, Atangana A. 2022. Characterization of the *Neuropeltis acuminatas* liana fiber treated as composite reinforcement. *Results Mater* 16: 100327. https://doi.org/10.1016/j.rinma.2022.100327
2. Ramesh M, Deepa C, Selvan MT, Reddy KH. 2022. Effect of alkalization on characterization of ripe bulrush (*Typha domingensis*) grass fiber reinforced epoxy composites. *J Nat Fibers* 19(3): 931-942. https://doi.org/10.1080/15440478.2020.1764443
3. Tesfay AG, Kahsay MB, Kumar PS. 2022. Effects of chemical treatment, hybridization, and hybrid fiber stacking sequence and orientation on tensile and impact strength of continuous sisal fiber reinforced polyester composites. *J Nat Fibers* 19(7): 2619-2631. https://doi.org/10.1080/15440478.2020.1821283
4. Gupta MK, Deep V. 2019. Effect of water absorption and stacking sequences on the properties of hybrid sisal/glass fibre reinforced polyester composite. *Proc Inst Mech Eng Part L J Mater Des Appl* 233(10): 2045-2056. https://doi.org/10.1177/1464420718811867
5. Di Bella G, Fiore V, Galtieri G, Borsellino C, Valenza A. 2014. Effects of natural fibres reinforcement in lime plasters (kenaf and sisal vs. polypropylene). *Constr Build Mater* 58: 159-165. https://doi.org/10.1016/j.conbuildmat.2014.02.026
6. Sheeba KJ, Alagarasan JK, Dharmaraja J, Kavitha SA, Shobana S, et al. 2023. Physico-chemical and extraction properties on alkali–treated *Acacia pennata* fiber. *Environ Res* 233: 116415. https://doi.org/10.1016/j.envres.2023.116415
7. Melkamu A, Kahsay MB, Tesfay AG. 2018. Mechanical and water-absorption properties of sisal fiber (*Agave sisalana*)-reinforced polyester composite. *J Nat Fibers* 16(6): 877-885. https://doi.org/10.1080/15440478.2018.1441088
8. Cheung HY, Ho MP, Lau KT, Cardona F, Hui D. 2009. Natural fibre-reinforced composites for bioengineering and environmental engineering applications. *Compos Part B Eng* 40(7): 655-663. https://doi.org/10.1016/j.compositesb.2009.04.014
9. Mohammed L, Ansari MN, Pua G, Jawaid M, Islam MS. 2015. A review on natural fiber reinforced polymer composite and its applications. *Int J Polym Sci* 2015: 243947. https://doi.org/10.1155/2015/243947
10. Premnath AA. 2018. Impact of surface treatment on the mechanical properties of sisal and jute reinforced with epoxy resin natural fiber hybrid composites. *J Nat Fibers* 16(5): 718-728. https://doi.org/10.1080/15440478.2018.1432002
11. Yahaya R, Sapuan SM, Jawaid M, Leman Z, Zainudin ES. 2015. Effect of layering sequence and chemical treatment on the mechanical properties of woven kenaf–aramid hybrid laminated composites. *Mater Des* 67: 173-179. https://doi.org/10.1016/j.matdes.2014.11.024
12. Reddy BM, Reddy YVM, Reddy BCM, Kumar GS, Reddy PV, et al. 2021. A study on mechanical, structural, morphological, and thermal properties of raw and alkali treated *C. dichotoma*-polyester composite. *Polym Compos* 42(1): 309-319. https://doi.org/10.1002/pc.25826
13. Prasad AR, Rao KM. 2011. Mechanical properties of natural fibre reinforced polyester composites: jowar, sisal and bamboo. *Mater Des* 32(8-9): 4658-4663. https://doi.org/10.1016/j.matdes.2011.03.015
14. Sandhanshiv RD, Patel DM. 2020. Carbon fibre reinforced composite material: review of properties and processing for various metal matrix materials. *IOP Conf Ser Mater Sci Eng* 810(1): 012014. https://doi.org/10.1088/1757-899X/810/1/012014
15. Yao SS, Jin FL, Rhee KY, Hui D, Park SJ. 2018. Recent advances in carbon-fiber-reinforced thermoplastic composites: a review. *Compos Part B Eng* 142: 241-250. https://doi.org/10.1016/j.compositesb.2017.12.007
16. MInus M, Kumar S. 2005. The processing, properties, and structure of carbon fibers. *JOM* 57: 52-58. https://doi.org/10.1007/s11837-005-0217-8
17. Prashanth S, Subbaya KM, Nithin K, Sachhidananda S. 2017. Fiber reinforced composites-a review. *J Mater Sci Eng* 6(03): 2-6.
18. Palanikumar K. 2012. Analyzing Surface Quality in Machined Composites. In Hocheng H (ed) Machining Technology for Composite Materials. Woodhead Publishing, pp 154-182.
19. Understanding CFRP Composites. [https://www.thoughtco.com/understanding-cfrp-composites-820393] [Accessed November 24, 2023]
20. Arthanarieswaran VP, Kumaravel A, Kathirselvam M. 2014. Evaluation of mechanical properties of banana and sisal fiber reinforced epoxy composites: influence of glass fiber hybridization. *Mater Des* 64: 194-202. https://doi.org/10.1016/j.matdes.2014.07.058
21. Shahzad A. 2011. Impact and fatigue properties of hemp–glass fiber hybrid biocomposites. *J Reinf Plast Compos* 30(16): 1389-1398. https://doi.org/10.1177/0731684411425975
22. Chou TW. 1992. Microstructural design of fiber composites. NASA STI/Recon Technical Report A, 92, 50452.
23. Prabhushankar N, Balaji N, Kaliappan S. 2023. Effect of sisal/kevlar inter-ply stacking and silane-treatment on mechanical, wear, fracture toughness, drop load impact, and hydrophobicity behavior of cellulose toughened polyester composite. *Biomass Conver Bioref* 1-9. https://doi.org/10.1007/s13399-023-04416-1
24. Shubham SK, Pandey A, Purohit R. 2023. Investigations on mechanical properties and stacking sequence of Kevlar/banana fiber reinforced nano graphene oxide hybrid composites. *Smart Mater Struct* 32: 077001. https://doi.org/10.1088/1361-665X/acda6d
25. Khanam PN, Khalil HPSA, Jawaid M, Reddy GR, Narayana CS, et al. 2010. Sisal/carbon fibre reinforced hybrid composites: tensile, flexural and chemical resistance properties. *J Polym Environ* 18: 727-733. https://doi.org/10.1007/s10924-010-0210-3
26. Murdani A, Hadi S, Amrullah US. 2017. Flexural properties and vibration behavior of jute/glass/carbon fiber reinforced unsaturated polyester hybrid composites for wind turbine blade. *Key Eng Mater* 748: 62-68. https://doi.org/10.4028/www.scientific.net/KEM.748.62
27. Ravikumar P, Rajeshkumar G, Maran JP, Al-Dhabi NA, Karuppiah P.

2022. Evaluation of mechanical and water absorption behaviors of jute/carbon fiber reinforced polyester hybrid composites. *J Nat Fibers* 19(13): 6521-6533. https://doi.org/10.1080/15440478.2021.1924339

28. Assarar M, Zouari W, Sabhi H, Ayad R, Berthelot JM. 2015. Evaluation of the damping of hybrid carbon–flax reinforced composites. *Compos Struct* 132: 148-154. https://doi.org/10.1016/j.compstruct.2015.05.016
29. Tranchard P, Duquesne S, Samyn F, Estebe B, Bourbigot S. 2017. Kinetic analysis of the thermal decomposition of a carbon fibre-reinforced epoxy resin laminate. *J Anal Appl Pyrolysis* 126: 14-21. https://doi.org/10.1016/j.jaap.2017.07.002
30. Yap MGS, Que YT, Chia LHL. 1991. FTIR characterization of tropical wood–polymer composites. *J Appl Polym Sci* 43(11): 2083-2090. https://doi.org/10.1002/app.1991.070431115
31. Nandiyanto ABD, Oktiani R, Ragadhita R. 2019. How to read and interpret FTIR spectroscope of organic material. *Indonesian J Sci Technol* 4(1): 97-118.
32. Fan M, Dai D, Huang B. 2012. Fourier Transform Infrared Spectroscopy for Natural Fibres. In Salih SM (ed) Fourier Transform - Materials Analysis. IntechOpen, pp 45-68.
33. Kumar M, Khatkar SK, Kumar P, Gupta A. 2023. Study of different types of reinforcements in polymer composites - a review. *Nanoworld J* 9(S1): S660-S663. https://doi.org/10.17756/nwj.2023-s1-127
34. Ouarhim W, Zari N, Bouhfid R. 2019. Mechanical Performance of Natural Fibers-based Thermosetting Composites. In Jawaid M, Thariq M, Saba N (eds) Mechanical and Pphysical Testing of Biocomposites, Fibre-reinforced Composites and Hybrid Composites. Woodhead Publishing, pp 43-60.
35. Sreekala MS, Kumaran MG, Thomas S. 2002. Water sorption in oil palm fiber reinforced phenol formaldehyde composites. *Compos Part A Appl Sci Manuf* 33(6): 763-777. https://doi.org/10.1016/S1359-835X(02)00032-5