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Optimization of static and impact mechanical properties for Kenaf-Coir hybrid composite modified with carbon nanotube (CNT)

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ABSTRACT

This decade has observed an upsurge in the eco-friendly materials because of the development of composites using natural fibers. These composites are made from renewable resources and are gaining popularity for their high performance in engineering applications. Industries are increasingly interested in using materials that are sustainable and resource-efficient. This research proposes a new innovative hybrid composite developed using coir and kenaf fibers, carbon nanotubes acting as a nanofiller, and a matrix made up of epoxy resin, detailing how they are fabricated, tested, and optimized based on different weight percentages. The weight percentages considered for CNT nanoparticles are 0, 1, 2, and 3 wt.%, coir, and kenaf fibers are considered in weight percentages of 12, 13, 14, and 15, whereas thickness is regarded as 2,3,4 and 5 mm. This research evaluates the mechanical features of this hybrid composite fabricated using a vacuum bag molding process. The different composite samples are tested using mechanical tests and subsequently optimized using the design of experiment (i.e., Taguchi method) and analysis of variance (ANOVA) method to arbitrate the best weight percent combination of the innovative hybrid composite. On the basis of the optimization results, the best composite sample obtained includes, 3 wt% of CNT, 15 wt% of kenaf, 15 wt% of Coir, and 4mm thickness of the sample, as it yields the highest tensile modulus and strength among all the hybrid composite samples. The outcomes from the research indicate that the hybridization of kenaf fibers into coir fibers, along with CNTs as fillers in the hybrid composite has enhanced the overall tensile strength, and flexural strength of the hybrid composite in comparison to the coir composite and kenaf composite alone, depicting the superiority of natural fiber hybrid composite over synthetic fiber hybrid composite.

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1. Introduction

Composite materials represent one of the most notable advancements in materials science. Recently, they have been observed to have a notable impact on the technological space, mainly because they exhibit the amalgamated characteristics of the matrix and the different types of reinforcements used to make them (Herrera-Franco, & Valadez-Gonzalez, 2004). A hybrid composite is a material made up of a matrix material combined with two or more types of reinforcements. Two or more reinforcements in the hybrid composite replace the limitations of conventional synthetic composites by providing uniform strength to the material (Sharma et al., 2021; Saxena & Chawla, 2021; 2021a; 2022; 2022a; Nagarjun et al., 2022).

Nowadays, nearly all industries are facing new challenges in creating novel, innovative, eco-friendly, and sustainable products developed by utilizing natural fibers derived from the agricultural sector (Treacy et al., 1996; Yang et al., 2007; Faruk et al., 2014; Chanda et al., 2018; Gupta et al., 2022; Yadav & Chawla, 2024; Yadav et al., 2025). For the past ten years, composites have evolved using natural fibers and garnered huge attention due to the existing environmental circumstances and find their application in versatile machine and industrial applications (Treacy et al., 1996; Holbery & Houston, 2006; Arrakhiz et al., 2013; Faruk et al., 2014; Yadav & Chawla, 2025a; 2025b). In addition, they possess high toughness, and low

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abrasion, are processed quickly, have less weight, have high strength, are less expensive, and have outstanding longevity (Ku et al., 2011; Parashar & Chawla, 2021; 2022; 2023; Saxena & Chawla, 2024). To replace synthetic fibers with these fibers in daily life, researchers are eager to learn and study more about these fibers' mechanical and physical attributes (Holbery & Houston, 2006; Parashar & Chawla, 2024). Therefore, observing the physical and mechanical attributes, and overall influence of natural fibers on hybrid composite materials, the present research paper involves using two primary natural fibers on the basis of existing literature: the kenaf and the coir fibers. Kenaf fibers are known for their potential to substitute glass fibers (Parashar & Chawla, 2023; Saba et al., 2015). They are known to possess high strength and excellent durability. Coir fibers are hard and stiff, biodegradable, lignocellulosic materials with high toughness and wear resistance (Lai et al., 2005).

Coir fiber is a renewable, versatile, and rugged natural fiber that is attainable in abundant quantities. The world's production of coir fiber reaches 0.75 million tons per year, and the production of coir fibers in India reaches about 0.16 million tons yearly (Jayabal & Natarajan, 2010). Coir is a lignocellulosic natural fiber with significant importance due to its high elongation features and tensile strength. Natural lignocellulosic fibers offer the following benefits: biodegradability, lesser density and cost, and adequate specific strength characteristics (Bhagat et al., 2013; Sadjadi, 2021).

About 25% of the coconut is made up of coir, a biodegradable, stiff, strong, and lignocellulosic fiber that is extracted from the coconut's mesocarp (Bettini et al., 2010; Zainudin et al., 2014; Zhang & Hu, 2014). Coir fiber's high lignin concentration makes it strong, resilient to weather, waterproof, and amenable to chemical modification (Geethamma et al., 2005). Moreover, due to their high elongation at break, the fibers can be extended without breaking, beyond the elastic limit (Siakeng et al., 2019).

A comprehensive investigation into the thermal, mechanical, thermal, structural, and morphological characteristics of coconut fibers is documented in the previous studies (Arrakhiz et al., 2013; Essabir et al., 2016). Studies have shown that hybridizing coconut composites with kenaf fibers (Islam et al., 2015; Hamidon et al., 2019), bamboo (Yusoff et al., 2016), rice straws (Zhang & Hu, 2014), and glass fibers (Bhagat et al., 2013) can boost the composites' overall characteristics (Zaman & Beg, 2014; Sakthivel et al., 2015; Siddika et al., 2014). According to Sudhakara et al. (2013) and Saw et al. (2014), coir fibers have several beneficial qualities, including availability, high content of lignin, lesser density and cost, high break elongation, and low elastic modulus.

Kenaf fiber is also known to successfully reinforce thermoplastic and thermoset resins, establishing itself as a feasible and innovative augmenting material for polymer composites (Saba et al., 2015). Mossello et al. (2010) conducted a comprehensive review highlighting the various empirical studies on kenaf, emphasizing its utility in pulp production through processes like beating, fractionation, and recycled fiber. Srebrenkoska et al. (2009) conducted a comparative study of kenaf/polypropylene composites developed through compression and injection molding. The research outcomes displayed that the process parameters did not alter the physical characteristics of the composite. Alkalization strengthened the kenaf fiber's elastic attributes for use in structural applications, in accordance with the studies conducted (Symington et al., 2009). Impressively, the fortification of nanoparticles to the matrices of polymer has chiefly augmented the attributes of the polymer materials (Puchy et al., 2013). Because of their low weight, appealing mechanical properties, and superior thermal properties, carbon nanotubes have the potential to emerge as a leading reinforcing material for a novel class of nanostructure composites (Wetzel et al., 2006; Dasari et al., 2009). The primary difficulty, however, lies in transferring the critical characteristics of CNTs, which can only be accomplished in composites by combining the ideal amount of materials with the correct processing method (Zhang & Jiang, 2011; Guadagno et al., 2009).

Adding multi-walled carbon nanotubes (MWCNTs) inculcated outstanding mechanical qualities, high stiffness, hardness, and good thermal properties in composite (Mossello et al., 2010). Zhang & Jiang (2011) discussed that the fortification of carbon nanotubes in the epoxy composites resulted in an enhancement in the wear qualities of the composite material. Kim et al. (2011) conducted the wear test using a ball-on-disc wear analyzer.

Nowadays, high-performance, multifunctional advanced composite materials are being developed using alumina-CNTs as a hybrid component of the polymer resin. A study proposed that the tribology efficacy of epoxy composites, including carbon nanotubes and graphene oxide, decreased the specific wear rate and increased the friction coefficient (Shen et al., 2011). Since hybrid composites have a high specific modulus, low weight ratio, and great strength, they are used as structural materials (Li et al., 2014). Because of their exceptional electrical, mechanical, and thermal qualities, as well as their exceptional high stiffness, strength, and resilience, CNTs are a vital component for reinforcement materials (Abbas et al., 2013; Qian et al., 2010).

Researchers have utilized the Taguchi method to optimize the mechanical properties of various fiber-reinforced composites. The application of the Taguchi method in flax, sisal, and hemp fiber-reinforced composites to achieve optimal performance has been investigated (Navaneethakrishnan & Athijayamani, 2015). Parameters such as coir fiber diameter and length, bone powder content, and particle size have been optimized to improve the properties of bone powder-reinforced coir composites with a polyester resin matrix (Vignesh et al., 2016). Additionally, the Taguchi method has been employed to refine design parameters, including fiber weight fraction and matrix treatment, to enhance the mechanical characteristics of corn fiber-reinforced polypropylene composites (Kumar et al., 2015). Application of this approach was made to optimize critical processing variables such as temperature, time, speed, and fiber size for kenaf fiber-reinforced thermoplastic polyurethane

composites. They concluded that fiber size and processing temperature during melt blending play a crucial role in determining the tensile strength of the composites (El-Shekeil et al., 2013).

All this information affirms that the consolidation of characteristics of different reinforcing materials enhances the attributes of laminates. From the above literature survey following research gaps have been identified.

- It has been noted that research has been carried out on kenaf fibers and coir fibers separately, but a very limited amount of research has been conducted on kenaf fibers in combination with coir fibers.
- A limited amount of investigation is carried out on nanoparticles acting as fillers inside the hybrid nanocomposites to enhance the composite properties. Also, the research on Carbon nanotubes acting as fillers inside composite materials has not been investigated much in previous research.
- The research on evaluating the mechanical characteristics of novel Coir-kenaf fiber hybrid epoxy composite reinforced with Carbon nanotube as filler and epoxy as a matrix, has not been investigated so far. Therefore, the proposed composite is a novel and innovative hybrid composite developed in this research.
- The Taguchi and ANOVA Optimization has also not been performed on the proposed composite.

In view of the above, the proposed research paper derives the following objectives.

- To fabricate the novel kenaf-coir hybrid epoxy composite reinforced with particles of carbon nanotubes using a vacuum bag molding process, with different weight percentages of coir-kenaf fibers, CNT filler, and sample thickness.
- To perform mechanical tests like tensile tests, flexural tests, and impact tests on all the developed hybrid composite samples using ASTM standards.
- To compare and analyze the mechanical attributes namely the tensile modulus of the coir-kenaf hybrid epoxy composite, evaluated by using various analytical models (Parashar & Chawla, 2022) with the experimental results that have been carried out in the present research paper.
- To optimize the different fabricated composite samples using Taguchi, RSM, and ANOVA analysis, and determine the best composite combination out of all the developed composite samples, with different weight percentages of fibers and fillers, having optimum values of all mechanical features.

2. Materials & Methodology

2.1 Materials

As discussed earlier, the proposed research paper focuses on two natural fibers—coir and kenaf—chosen for their beneficial effects in enhancing the elastic properties of fiber composites. In addition to these fibers, nanofillers made of carbon nanotubes have also been included in the study for experimental testing and optimization.

The coir fiber used in this study was sourced from New Paras Textile in New Delhi. This raw fiber has a diameter of 15 µm. The kenaf fiber, sourced from the Fiber Region in Chennai, Tamil Nadu, also in its raw form, has a diameter of 25 µm. The epoxy matrix employed in this research was obtained from Go Green India Pvt. Ltd., located in Chennai, Tamil Nadu, and is of Grade 520, which was used to develop the composite. The carbon nanotubes used in this study is a black powder having a diameter of 20 nm, length- of 20 µm, and Bulk density of 0.16 g/cm^3, with amorphous carbon <0.45%, provided by BTCorp Generique Nano Pvt Ltd., Bangalore, Karnataka.

2.2 Methodology

The approach taken for analyzing the mechanical properties of hybrid composite consists of analytical modeling and experimental analysis. Analytical modeling is performed using many different analytical models namely Nielson Elastic Model, Halpin-Tsai Model, Mori-Tanaka Model, and Chamis Model (Parashar & Chawla, 2022). The basic model on which the above models are based is the Rule of hybrid mixtures model, represented by the below Eq. (1).

$$\textit{Rule of Hybrid Mixtures:} \qquad E_c = V_{f1}E_{f1} + V_{f2}E_{f2} + V_mE_m \tag{1}$$

where, E_c signifies the composite's Elastic Modulus, E_{f1} & E_{f2} signify the fiber's Elastic Moduli, V_{f1} & V_{f2} signify the fiber's volume fractions, V_m illustrates the matrix volume part and E_m illustrates the elastic modulus (Potluri et al., 2018).

Analytical modeling has already been performed for the coir-kenaf hybrid epoxy composites augmented with CNT and results have been carried out for the same using the above different models (Parashar & Chawla, 2022). Results of the kenaf-coir hybrid epoxy composite with 3 wt% of CNT are illustrated in **Table 1**.

Table 1. Properties of coir-kenaf hybrid epoxy composite with 3 wt.% of CNT content (Parashar & Chawla, 2022)

Models/Properties	Nielson-Elastic Model	Mori-Tanaka Model	Halpin-Tsai Model	Chamis Model	RVE
Transverse Modulus (GPa)	11.78	11.81	11.83	11.83	11.99

Longitudinal Modulus (GPa)	36.48	36.37	36.48	36.48	37.86

In the proposed research paper, we are evaluating the hybrid composite's mechanical attributes with the help of fabrication and experimental analysis. The process considered for fabrication of the Carbon nanotubes incorporated kenaf coir hybrid composite is the Vacuum Bag Molding process (Biswas & Anurag, 2019). In this technique initially, a smooth surface mold is considered, made up of Toughened glass, on which the composite is prepared (Biswas & Anurag, 2019). The mold of toughened glass is considered because of its high strength and toughness. Following this, a layer of wax is applied to the glass's surface to give it a glossy appearance. Post this, a Polyvinyl Acetate (PVA) Coat is applied, which acts as the release agent, so as to easily remove the sheet after fabrication. To synthesize pure epoxy samples, the epoxy and hardener are carefully mixed in a 10:1 ratio, using the stirrer. The hardener used in this mixing is LY951, which acts as the curing agent, and transforms the liquified epoxy into a gel state and then into the solid state, gradually. CNT nanoparticles are combined in various weight proportions with the epoxy resin as shown in Table 2. The Carbon Nanotubes mixed with epoxy resin coating are applied on top of the Polyvinyl Acetate Coat with the help of a brush.

After this, the reinforcement layer arranged as unidirectional Kenaf and Coir fibers with distinct weight percentages of both fibers, as observed from Taguchi analysis in **Table 2**, is applied over the epoxy coat employing the hand layup technique. After this, the peel ply is placed over the laminate to give it a smooth surface, followed by the perforated release film and then the breather cloth over it. The complete part is sealed to the mold using a vacuum bag film, which consists of a hole for the vacuum port. The vacuum bag has been attached to the tool using sealant tape.

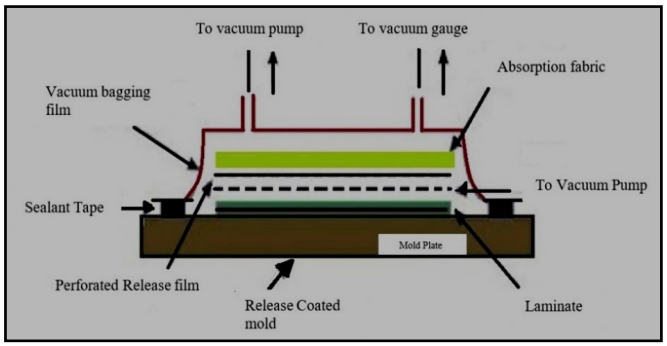


Fig. 1. Diagrammatic Representation of Vacuum Bag Molding Process

A 140 kPa vacuum pressure is supplied to the mold to get rid of extra resin and trapped air. The hybrid composite samples are successfully extracted out of the mold after four hours and can cure for twenty-four hours under ambient conditions (25^{o}C). **Fig. 1** illustrates the diagrammatic representation of the Vacuum Bag Molding process. The process parameters utilized in the fabrication of different samples are illustrated in the below Table. 2. The CNT wt.% is varied between 0,1,2,3 wt.%, the coir percentage is varied between 12, 13, 14, and 15 wt.%, the kenaf weight percentage is varied between 12, 13, 14 15 wt.% and the thickness is varied between 2,3,4,5 mm (Parashar & Chawla, 2022, Peng et al., 2023). The study consists of four different parameters with four different levels of each, therefore a 4×4 matrix has been considered in Taguchi using the different process parameters.

Table 2. Process Parameters for fabrication of hybrid composite

Process Parameters	CNT, wt% (A)	Kenaf, wt% (B)	Coir, wt% (C)	Thickness, mm (D)
Level 1	**0**	**12**	**12**	**2**
Level 2	**1**	**13**	**13**	**3**
Level 3	**2**	**14**	**14**	**4**
Level 4	**3**	**15**	**15**	**5**

Table 3. Samples for experimental analysis of CNT embedded kenaf coir hybrid epoxy composite

S. NO.	CNT (wt%) (A)	COIR (wt%) (B)	KENAF (wt%) (C)	THICKNESS (mm) (D)
1	0	12	15	3
2	0	13	14	2
3	0	14	13	5
4	0	15	12	4
5	1	12	13	4
6	1	13	12	5
7	1	14	15	2
8	1	15	14	3
9	2	12	14	5
10	2	13	15	4
11	2	14	12	3
12	2	15	13	2
13	3	12	12	2

14	3	13	13	3
15	3	14	14	4
16	3	15	15	5

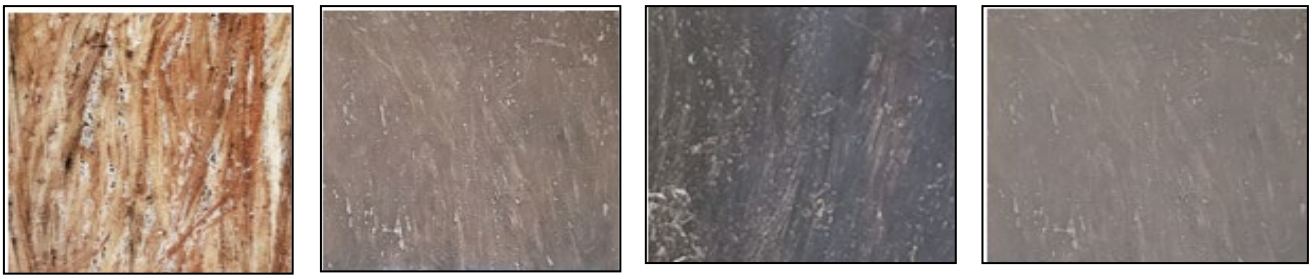
The 16 different samples for CNT embedded kenaf-coir epoxy hybrid composite have been obtained using Taguchi analysis performed on Minitab Statistical Software. A total of 16 samples have been developed with different weight percentages of CNT content, Coir Content, Kenaf content, and thickness. These 16 composite samples have been fabricated in the laboratory using a vacuum bag molding process and then subjected to experimental testing to determine the mechanical attributes of samples. The preceding **Table 3** illustrates the 16 different hybrid composite samples considered for experimental analysis of CNT-embedded kenaf coir hybrid epoxy composite.

Fig. 2. A mixture of CNT and epoxy resin

Fig. 3. Samples placed on the sheet for Vacuum Bag Molding Process

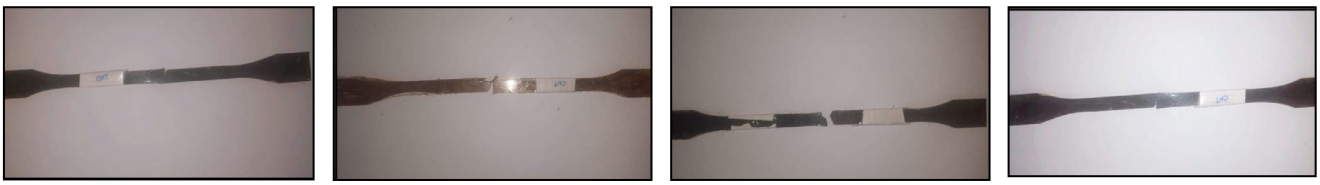
Fig. 2, and **Fig. 3** above represent the different steps during CNT-reinforced kenaf-coir hybrid epoxy composites fabrication.

Below **Fig. 4**, depicts some of the fabricated samples out of 16 for the CNT augmented coir-kenaf hybrid epoxy composites. The dimensions of composite samples developed are 12 inch×12 inches with varying thicknesses of 2mm, 3mm, 4mm, and 5 mm respectively. **Fig. 5**, depicts some of the fabricated samples utilized for tensile testing out of 16 samples for the CNT reinforced coir-kenaf hybrid composites.



(a) (b) (c) (d)

Fig. 4. The different fabricated samples of CNT reinforced kenaf-coir hybrid epoxy composite sample with (a) 0 wt.% of CNT (b) 1 wt.% of CNT (c) 2 wt.% of CNT (d) 3 wt.% of CNT



(a) (b) (c) (d)

Fig. 5. The different Tensile testing samples of CNT reinforced kenaf-coir hybrid epoxy composite sample with (a) 0 wt.% of CNT (b) 1 wt.% of CNT (c) 2 wt.% of CNT (d) 3 wt.% of CNT

3. Mechanical Testing

Mechanical Tests namely flexural tests, tensile tests, impact tests, and hardness tests, have been utilized in the present research to discover the mechanical attributes of the CNT incorporated in kenaf coir epoxy hybrid composites.

The mechanical testing is conducted on the composite in accordance with the ASTM standards.

3.1 Tensile Testing

Tensile test analysis for the Carbon Nanotubes incorporated kenaf coir hybrid epoxy composite specimens is carried out on Universal Testing Machine UTM 5000N, with a maximum capacity of 5000 N. This test is carried out at 5 mm/min of cross-head speed using ASTM standard D638-2014. **Fig. 6** depicts the tensile testing machine used for tensile testing on the

hybrid composite materials. A total of 16 samples have been tested using the tensile testing machine, depicting the lowest tensile strength of 91.5 MPa and the highest tensile strength of 103.5 MPa.

Fig. 6. Tensile Testing Machine

3.2 Flexural Testing

For testing of the proposed Carbon Nanotubes nanofiller incorporated kenaf coir hybrid epoxy composite, the flexural test is being carried out on Universal Testing Machine UTM 5000N, employing a three-point bend fixture. It is employed using ASTM D790-2017 standard, utilizing a 10 KN load cell. **Fig. 6** depicts the flexural testing machine used for flexural test on the hybrid composite materials. A total of 16 samples have been tested using the flexural testing machine, depicting the lowest flexural strength of 114.5 MPa and the highest flexural strength of 123.9 MPa.

3.3 Impact Testing

For testing of the proposed Carbon Nanotubes nanofiller incorporated kenaf coir hybrid epoxy composite, the Impact test is performed on the machine utilized for Izod Impact Testing with ASTM D256 - 2010 standards. The Izod pendulum hammer has an initial potential energy of 2.7 J, at a dropping height of 610 ± 2 mm. **Fig. 7** depicts the Impact testing machine employed for the impact test on the hybrid composite materials. A total of 16 samples have been tested using the flexural testing machine, depicting the lowest impact strength of 7.66 KJ/m^2 and the highest impact strength of 8.75 KJ/m^2.

Fig. 7. Impact testing machine

Fig. 8. Barcol Hardness Tester

3.4 Hardness Testing

For testing the hardness of the proposed Carbon Nanotubes nanofiller incorporated kenaf coir hybrid epoxy composite, this test is carried by utilizing Barcol Hardness Tester, Model No. 934-1, using the ASTM standard D2583-1981. **Fig. 8** depicts the hardness testing machine used for the hardness test on the hybrid composite materials.

4. Modelling and Optimization

Optimization analysis of the samples is performed based on the results of experimental data. Choosing the process parameters is the most crucial step in designing experiments (Patnaik & Bhatt, 2011; Phaneendra & Manoharan, 2021; Shankar et al., 2017). Optimization has been done using Taguchi, RSM and ANOVA analysis.

Taguchi method is considered a Statistical Technique to manage the quality of the product (Patnaik & Bhatt, 2011; Bagci & Imrek, 2013). For the proposed composite four different process parameters are considered namely CNT wt %, Kenaf fiber (wt.%), Coir fiber (wt.%), and thickness(mm) along with their four different levels have been illustrated in **Table 1**. It represents the process parameters and their levels for the CNT-embedded kenaf-coir epoxy hybrid composite respectively. The ANOVA test is employed to assess the critical variables for the flexural, tensile, and impact strength models. It mainly identifies the significant differences in mechanical attributes of different composite combinations.

In the proposed work, four process parameters are the kenaf wt.%, coir wt.%, CNT wt.%, and thickness have been identified and implemented for evaluating the features and attributes of fiber composites. This optimization analysis is primarily to optimize the process parameters before the vacuum bag molding fabrication process, by making use of Minitab Statistical Software, in order to minimize the total number of experiments and get the best optimized sample out of all the composite samples considered in the proposed research. The proposed composite has been fabricated following Taguchi's L16 orthogonal array in the Design of Experiments (Victoria et al., 2023), which requires 16 runs.

5. Results and Discussions

Fabrication of all 16 samples developed according to the Taguchi analysis is carried out for carbon nanotubes incorporated kenaf coir hybrid epoxy composite using a vacuum bag molding process. The composition for all 16 samples with varying percentages of carbon nanotubes, kenaf fiber, coir fiber, and thickness is shown in the previous **Table 2**.

5.1 Results from experimental testing

The fabricated samples are subjected to mechanical testing for performing tests to assess the composite material's performance under different stress conditions. The mechanical testing performed on the composite material includes the Flexural test, Tensile test, and Impact strength test for CNT-reinforced hybrid composites, and outcomes have been predicted for Flexural Strength, Flexural Modulus, Tensile Strength, Tensile Modulus, and Impact Strength as depicted in **Table 4**.

Table 4
Process Parameters and their outcomes for CNT reinforced Composite

S. No	CNT wt% (A)	Coir wt% (B)	Kenaf wt% (C)	Thickness mm (D)	Tensile Modulus (GPa)	Tensile Strength (MPa)	Flexural Modulus (GPa)	Flexural Strength (MPa)	Impact Strength (kJ/m^2)
1	0	12	15	3	9.35	91.5	6.66	114.6	7.66
2	0	13	14	2	9.40	92.3	6.74	115.2	7.74
3	0	14	13	5	9.50	92.9	6.89	114.5	7.81
4	0	15	12	4	9.59	93.2	6.86	115.7	7.88
5	1	12	13	4	10.28	94.8	7.17	117.2	8.04
6	1	13	12	5	10.17	93.9	6.99	116.3	7.97
7	1	14	15	2	10.39	95.2	7.46	118.5	8.13
8	1	15	14	3	10.53	96.6	7.50	118.9	8.21
9	2	12	14	5	10.51	97.6	7.68	121.3	8.48
10	2	13	15	4	10.73	100.5	8.31	123.9	8.71
11	2	14	12	3	10.59	98.5	7.81	122.8	8.66
12	2	15	13	2	10.65	99.8	7.73	121.7	8.53
13	3	12	12	2	10.40	100.2	7.69	121.5	8.52
14	3	13	13	3	10.61	100.9	7.74	121.8	8.63
15	3	14	14	4	10.70	102.6	7.86	122.4	8.68
16	3	15	15	5	10.81	103.5	8.03	123.1	8.75

5.2 Results from ANOVA analysis

The results from ANOVA analysis for all the different composite combinations have been depicted using the two significant plots in statistical analysis which are the Main effects plot and the Interaction plots. These graphs illustrate the mechanical attributes of various composite samples, including tensile strength, flexural strength, flexural modulus, tensile modulus, and impact strength.

5.2.1 Main Effects Plot

To investigate the variations in the level of means for a number of factors, the main effects plot is employed. When a factor has varying effects on the response, there is a main effect. The response mean for each factor level is plotted on a main effects plot and is connected by a line. The different main effect plots have been created for all the mechanical tests and are shown below. These plots are mainly plotted to investigate the differences between level means for one or more than one factor. **Figs. 9-13** depict the Main effects plot of Tensile Strength, Tensile Modulus, Impact Strength, Flexural Strength, and Flexural Modulus, for CNT reinforced kenaf coir hybrid composite respectively.

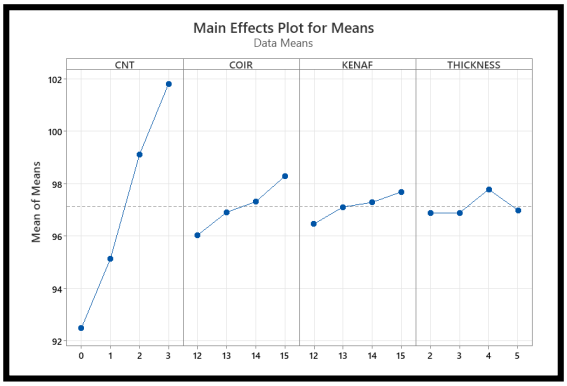


Fig. 9. Main effects plot of Tensile Strength for CNT reinforced kenaf coir hybrid composite

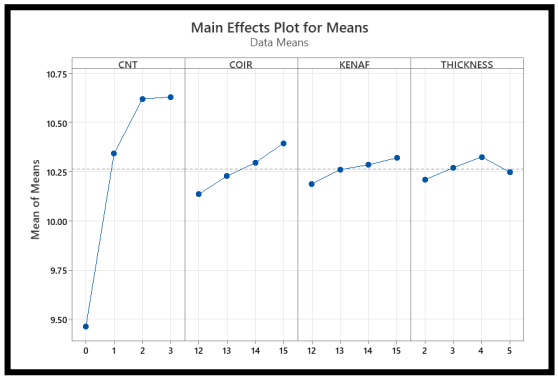


Fig. 10. Main effects plot of Tensile Modulus for CNT reinforced kenaf coir hybrid composite

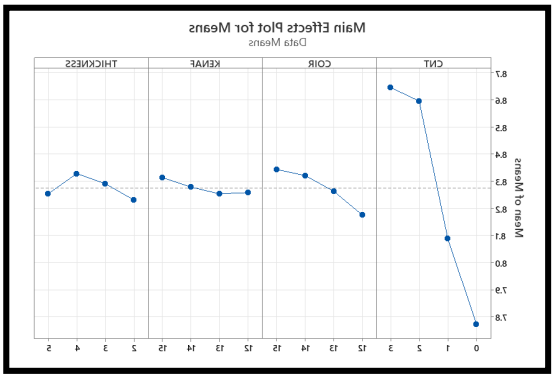


Fig. 11. Main effect plot of Impact Strength for CNT reinforced kenaf coir hybrid composite

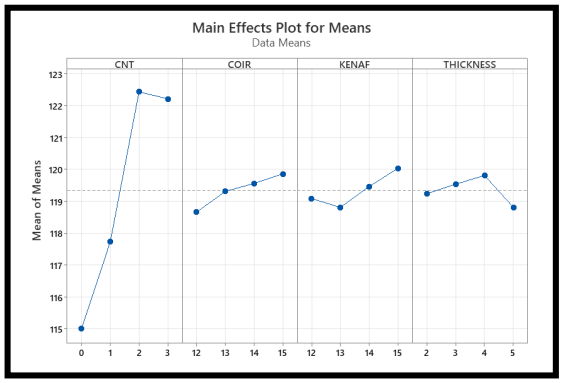


Fig. 12. Main effects Plot of Flexural Strength for CNT reinforced kenaf coir hybrid composite

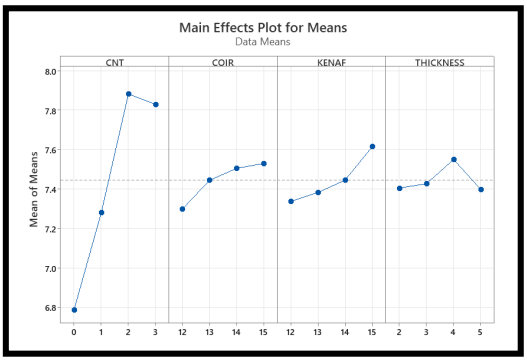


Fig. 13. Main effects plot of Flexural Modulus for CNT reinforced kenaf coir hybrid composite

5.2.2 Interaction Plots

When an interaction effect exists, it depicts that the effect of a particular variable on the outcome depends on the level of the other variable. Interaction plots are mainly employed to analyze a particular variable's behavior based on the other variables' values. These plots are generally carried out in the Design of Experiments and ANOVA analysis. It mainly describes how the variables are related to each other and also assesses the effect of the interaction of the various process parameters along with their different levels. Below are the various Interaction effects plotted for all the different mechanical tests carried out on the CNT-embedded kenaf coir hybrid epoxy composite sample, which basically determines the interaction of one variable with other variables. **Fig. 14** depicts an interaction plot, which represents the interaction effect of carbon nanotubes along with coir fiber, kenaf fiber, and thickness for observation of Tensile Modulus. The overall interaction effect plot depicts that the value of the Tensile Modulus is observed to be highest at 3 % of CNT content, 15 wt % of kenaf, 15 wt % of coir, and 5 mm thickness of the sample, when the interaction effect among all the four variables amongst each other of them is observed. **Fig. 15** depicts an interaction plot that represents the interaction effect of carbon nanotubes along with coir fiber, kenaf fiber, and thickness, for observation of Tensile Strength. The overall interaction effect plot depicts that the Tensile Strength is observed to be highest at 3 % of CNT content, 15 wt % of kenaf, 15 wt % of coir, and 5 mm thickness of the sample, when the interaction effect among all the four variables amongst each other of them is observed.

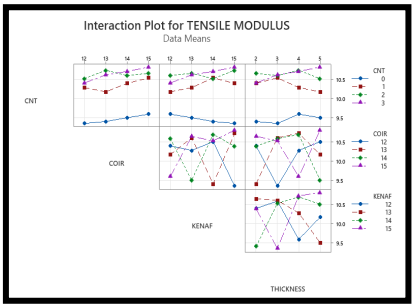


Fig. 14. Interaction Plot of Tensile Modulus for CNT reinforced kenaf coir hybrid composite

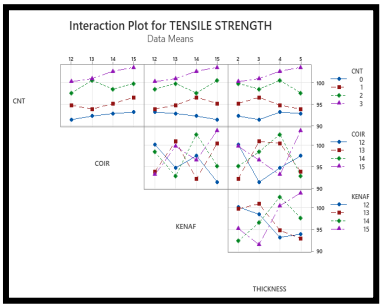


Fig. 15. Interaction plot of Tensile Strength for CNT reinforced kenaf coir hybrid composite

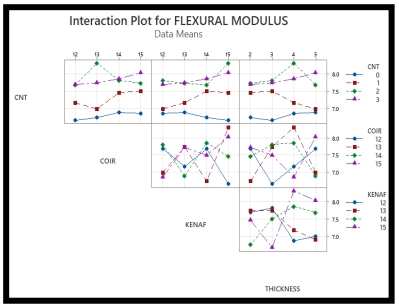


Fig. 16. Interaction plot of Flexural Modulus for CNT reinforced kenaf coir composite

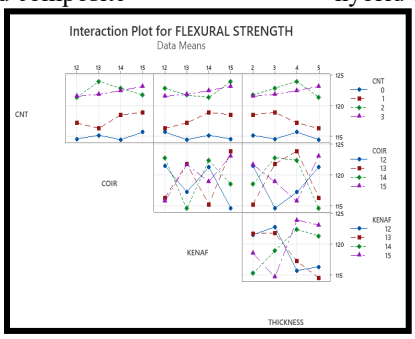


Fig. 17. Interaction Plot of Flexural Strength for CNT reinforced kenaf coir hybrid composite

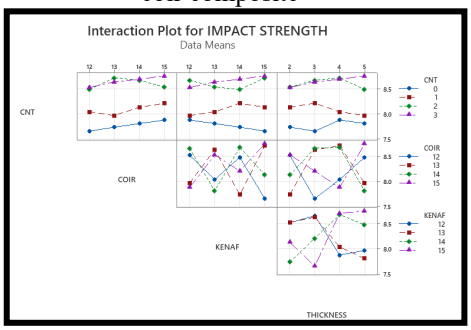


Fig. 18. Interaction Plot of Impact Strength for CNT reinforced kenaf coir hybrid composite

Fig. 16 depicts an interaction plot that represents the interaction effect of carbon nanotubes along with coir fiber, kenaf fiber, and thickness, for observation of Flexural Modulus. The overall interaction effect plot depicts that the value of the Flexural Modulus is observed to be highest at 2 % of CNT content, 15 wt % of kenaf, 13 wt % of coir, and 4 mm thickness of the sample, when the interaction effect among all the four variables amongst each other of them is observed. **Fig.17** depicts an interaction plot that represents the interaction effect of carbon nanotubes along with coir fiber, kenaf fiber, and thickness, for observation of Flexural Strength. The overall interaction effect plot depicts that the value of the Flexural Strength is observed to be highest at 2 % of CNT content, 15 wt % of kenaf, 13 wt % of coir, and 4 mm thickness of the sample, when the interaction effect among all the four variables amongst each other of them is observed. **Fig. 18** depicts an interaction plot that represents the interaction effect of carbon nanotubes along with coir fiber, kenaf fiber, and thickness, for observation of Impact Strength. The overall interaction effect plot depicts that the value of the Impact Strength is observed to be highest at 3 % of CNT content, 15 wt % of kenaf, 15 wt % of coir, and 5 mm thickness of the sample, when the interaction effect among all the four variables amongst each other of them is observed.

Table 5. Results of ANOVA Table for CNT reinforced kenaf coir composite

	Tensile Modulus (GPa)		Tensile Strength (MPa)		Flexural Modulus (GPa)		Flexural Strength (MPa)		Impact Strength (kJ/m2)	
	F value	**P value**	**F value**	**P value**	**F value**	**P value**	**F value**	**P value**	**F value**	**P value**
A	121.2	0.031	263.42	0.007	207.28	0.009	165.43	0.015	181.19	0.011
B	72.91	0.048	146.99	0.020	83.01	0.039	102.15	0.030	62.25	0.030
C	58.62	0.041	38.32	0.039	69.00	0.028	84	0.038	93.35	0.034
D	32.42	0.047	160.22	0.016	6.40	0.387	3.67	0.880	37.75	0.038
A×B	127.31	0.024	14.59	0.074	194.85	0.010	288.3	0.007	32.30	0.046
A×C	131.40	0.023	37.16	0.040	0.72	0.948	2.81	0.892	10.15	0.121
A×D	49.87	0.036	138.15	0.021	2.73	0.902	0.52	0.950	0.41	0.481
B×C	44.80	0.037	40.34	0.039	0.03	1	0.00	0.960	0.18	0.788
B×D	0.36	0.236	170.85	0.015	0.30	0.960	11.19	0.091	0.52	0.487
C×D	0.30	0.284	52.22	0.034	0.34	0.960	11.58	0.091	0.59	0.470
A×B×C	152.18	0.018	13.57	0.080	1.43	0.950	18.46	0.053	9.23	0.098
A×B×D	116.16	0.028	92.41	0.035	167.94	0.014	372.65	0.003	0.14	0.80
A×C×D	11.17	0.092	35.71	0.036	82.88	0.040	154.4	0.017	429.34	0.001
B×C×D	0.16	0.985	162.73	0.017	0.25	0.510	9.34	0.186	0.34	0.490
A×B×C×D	0	1	0	1	0	1	0	1	0	1

where, A = Carbon Nanotubes, B = Coir fibre, C = Kenaf fibre, D = Thickness

The ANOVA (Analysis of Variance) test is used to identify the critical variables for the flexural, tensile, and impact strength models. Parameters with a 95% confidence level are regarded as essential factors. Using p and f values, the main effect and interaction effects of the process variables on the responses are examined. The impact of the

corresponding coefficient terms is demonstrated by the higher f-value in Table 5. The p-values lower than 0.05 imply that each variable has substantially contributed to the models.

5.2.3 Optimization

The optimal conditions with various levels of process parameters in single response optimization, obtained from the main effects plot and interaction plots, have been shown in **Table 5**. The optimal conditions values are illustrated for all the elastic attributes of the composite, including Tensile Strength, Tensile Modulus, Flexural strength, Flexural Modulus, and Impact Strength. The outcomes of combined optimization employing the Multi-response optimization are also shown in **Table 5** below, which finally leads to the determination of the best kenaf coir hybrid composite reinforced with carbon nanotubes, with optimum value of process parameters.

The investigation is associated with the exploration of the optimal selection of process parameters for optimizing the mechanical attributes of CNT nanoparticles augmented kenaf coir epoxy hybrid composites. Several inferences are made in light of the experimental observations, Taguchi & ANOVA analysis, and the Response Surface Methodology.

Table 5. Optimization of Mechanical Attributes

Method	Responses	Optimal Conditions	Optimal Values
Single response optimization	Tensile Modulus	A4 B4 C4 D4	10.81 GPa
	Tensile Strength	A4 B4 C4 D4	103.5 MPa
	Flexural Modulus	A3 B2 C4 D3	8.31 GPa
	Flexural Strength	A3 B2 C4 D3	123.9 MPa
	Impact Strength	A4 B4 C4 D4	8.75 kJ/m^2
Combined optimization	Tensile Modulus		11. 32 GPa
	Tensile Strength		102.13 MPa
	Flexural Modulus	A4 B4 C4 D3	8.86 GPa
	Flexural Strength		121.23 MPa
	Impact Strength		8.27 kJ/m^2

The Taguchi method, ANOVA analysis, and Response Surface Methodology (RSM) are employed to identify the best settings for process parameters in multi-response optimization. The Response Optimizer mainly identifies the combination of predictor values that jointly optimizes one or more fitted processes. The optimal parameters and their levels for individual responses are shown in Table 6. According to Taguchi, ANOVA, and RSM analysis, the optimum combination of process parameters and their levels for the multi-response optimization is A4 B4 C4 D3, which is 3 weight % of CNT, 15 weight % of Kenaf, 15 weight % of Coir, and 4 mm thickness of the sample, represented as shown in the **Table 6** below.

Table 6. Optimum Levels of Process Parameters

Process Parameters	Optimum Levels
Carbon Nanotubes	3 wt%
Kenaf fiber	15 wt%
Coir fibre	15 wt%
Thickness of sample	4 mm

6. Comparison of Mechanical properties for Kenaf-coir hybrid composite

The optimized carbon nanotubes reinforced kenaf coir hybrid epoxy sample, that is the sample with optimal conditions as A4 B4 C4 D3, possessing 3 weight % CNT, 15 weight % kenaf fiber, 15 weight % coir fiber and 4 mm thickness of sample, is again subjected to experimental testing, after the optimization analysis. Hardness testing is now employed on the obtained composite sample and the hardness is obtained in the range of 38-42 Barcol. The results from the optimization analysis have been contrasted with those from the experimental analysis. The results of the comparison between experimental and optimization analysis have been depicted in **Table 7.**

Table 7. Comparison between Optimized and experimental results (CNT Composite)

Properties	CNT-KENAF-COIR-EPOXY COMPOSITE	
	Optimization	Experimental
Tensile Modulus (GPa)	11.32	10.04
Tensile Strength (MPa)	102.13	99.4
Flexural Modulus (GPa)	8.86	8.74
Flexural Strength (MPa)	121.23	112
Izod Impact (kJ/m^2)	8.27	7.9

From the literature survey, it is seen that kenaf fibers are good at tensile strength, whereas coir fibers are better at impact strength in contrast to tensile strength. The hybridization of both of these fibers into a hybrid composite will enhance the attributes of the developed composite material. It is assessed that carbon nanotubes acting as nanofillers in composite materials also possess very good tensile strength. Therefore, an amalgamation of all into a composite will uplift the composite's

mechanical attributes. The results obtained in our research for the hybrid composite determine that the hybridization of kenaf fibers into coir fibers, along with the augmentation of CNT as nanofillers in the hybrid composite has enhanced the overall tensile strength, flexural strength, and impact strength of the hybrid composite in comparison to the coir composite alone.

The optimized composite sample demonstrated exceptional strength, making it suitable for textile applications where durability is crucial. For practical implementation, the best-performing composite identified in this research could be utilized to develop a military-grade luggage bag. This bag would leverage the natural fibers of coir-kenaf, combined with the resin of epoxy and enhanced by carbon nanotube nanoparticles. Such a kenaf-coir-epoxy composite, reinforced with carbon nanotubes, is ideally suited for military applications, where it can efficiently support heavy loads due to its superior strength and durability.

7. Conclusion

The evaluation of mechanical behaviors of CNT nanofiller and kenaf-coir fibers added into the matrix of epoxy composites is studied in the present research work. The effect of the augmentation of CNT nanoparticles on the mechanical attributes of composites is analyzed using experimental analysis, Taguchi, RSM, and ANOVA analysis. The optimization analysis is utilized to minimize the number of experiments and attain the optimum parameters for the composite. The process parameters examined in the study are coir fiber content, kenaf fiber content, CNT content, and sample thickness. The influence of interaction amongst the distinct process parameters is analyzed, and their impact on composite material properties is assessed. The observations made in the current investigation are listed below.

- The samples of novel Carbon nanotubes reinforced kenaf coir hybrid composites have been fabricated through the Vacuum Bag Molding Process.

- The weight percent considered for CNT nanoparticles are 0, 1, 2, and 3 wt.%. Coir and kenaf fibers are considered in weight percentages of 12, 13, 14, and 15, whereas thickness is regarded as 2,3,4 and 5 mm.

- 16 different kenaf coir epoxy hybrid composite samples incorporated by nanofillers of Carbon Nanotube have been developed using Taguchi Analysis, performed on Minitab Statistical Software. 16 different samples of each CNT hybrid composite have been developed.

- The process parameters considered in the present research are the weight % of kenaf, the weight % of coir, the weight % of Carbon Nanotubes, and the thickness of the sample. All four process parameters have been taken at four different levels.

- All 16 samples from both the Carbon Nanotube reinforced hybrid composites have been fabricated using Vacuum Bag Molding and have been subjected to experimental testing for various mechanical tests, namely the Flexural test, Tensile Test, and Impact test, to assess the composite's mechanical attributes.

- The mechanical testing outcomes for all the samples have been fed in the Taguchi Table to optimize the composites and determine the best optimum sample from the CNT-embedded hybrid composites. This has been carried out to minimize the total experiments number and get the best-optimized sample for the study.

- Interaction effects plots and main effects plots have been plotted for the hybrid composites so as to evaluate the effect of distinct interaction parameters and also analyze the influence of this variation on the elastic attributes of both composite materials.

- The interaction effect of various parameters like CNT wt%, Kenaf wt%, Coir wt%, and sample thickness on the composite's attributes has also been determined. From the interaction plots, it has been observed that the interaction effect of CNT*Kenaf, CNT*Kenaf*Thickness, and CNT*kenaf*Coir has been found to provide a substantial effect on the attributes of CNT hybrid kenaf coir composite.

- The Composite samples have been optimized using Response Surface Methodology, and the best optimum samples out of a total of 16 samples have been identified, for Carbon nanotubes embedded Kenaf-Coir composites, which optimizes all the features of the hybrid composites.

- The best optimized composite sample of Carbon nanotubes reinforced kenaf-coir-epoxy hybrid composite incorporates 3 weight % of CNT, 15 weight % of kenaf, 15 weight % of Coir, and 4 mm thickness of the sample with a Tensile Modulus of 11.32 GPa, Tensile Strength of 102.13 MPa, Flexural Modulus of 8.86 GPa, Flexural Strength of 121.23 MPa, and 8.27 KJ/m^2 of Impact Strength.

- The results attained for the hybrid composite determine that the hybridization of kenaf fibers into coir fibers, along with the augmentation of CNT as nanofillers in the hybrid composite has enhanced the overall tensile strength, and flexural strength of the hybrid composite in comparison to the coir and kenaf composite alone. This depicts that the amalgamation of both the kenaf and coir fibers along with the augmentation of CNT as a filler in the epoxy hybrid

composite is effective in enhancing and improving the mechanical characteristics like tensile and flexural strength of both the kenaf epoxy composite as well as the coir epoxy composite.

- In future researches there is a possibility to measure other mechanical behaviors, such as compressive strength, fatigue strength, shear strength, etc., to access the complete behavior of the CNT nanofiller-added Kenaf-coir epoxy hybrid composites. Apart from the Taguchi and Analysis of variance (ANOVA) analysis, other prediction models like ANN, Regression analysis, Genetic algorithm, etc., can be used to discern the mechanical performance of the composite over a wide range of conditions.

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