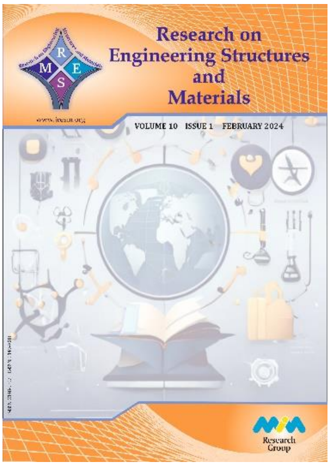
Research on Engineering Structures & Materials

www.jresm.org

Research Group



Effect of calcium carbonate nanoparticles on mechanical properties of coir-kenaf based epoxy hybrid composites: An analytical and simulation study

Shikha Parashar, V.K.Chawla

Online Publication Date: 20 December 2023

URL: http://www.jresm.org/archive/resm2023.33me1020rs.html

DOI: http://dx.doi.org/10.17515/resm2023.33me1020rs

Journal Abbreviation: *Res. Eng. Struct. Mater.*

To cite this article

Parashar S, Chawla VK . Effect of calcium carbonate nanoparticles on mechanical properties of coir-kenaf based epoxy hybrid composites: An analytical and simulation study. *Res. Eng. Struct. Mater.*, 2024; 10(2): 819-838.

Research on Engineering Structures & Materials
www.jresm.org

Research Article

Effect of calcium carbonate nanoparticles on mechanical properties of coir-kenaf based epoxy hybrid composites: An analytical and simulation study

Shikha Parashar[*a], V.K.Chawla[b]

Department of Mechanical and Automation Engineering, IGDTUW, Kashmere Gate, Delhi, India

Article Info

Article history:

Received 20 Oct 2023
Accepted 16 Dec 2023

Keywords:

Hybrid fibre composite;
Kenaf;
Coir;
Epoxy;
Calcium carbonate nanoparticles;
Mechanical properties

Abstract

The manufacturing sector is presently in search of sustainable materials that are lighter in weight, readily available, biodegradable, and cost-friendly. Natural fibers are observed to bring unblemished advancement in composite materials. In this research, a novel hybrid composite material has been analyzed. The composite comprises two different natural fibers, kenaf and coir fiber, reinforced in epoxy matrix with nanofillers of calcium carbonate particles. The weight percent of kenafand coir fibers is maintained at 5.7% and 10%, whereas nanofillers is varied as 0%, 2%, and 4%, respectively, in all three samples. The elastic characteristics like the Longitudinal Modulus, and Transverse Modulus, are evaluated for the proposed composite utilizing five different analytical models, and are also interpreted using Representative Volume Element (RVE) analysis. The analytical results of the proposed composite are correlated with the experimental work in the earlier research. The influence of nanofiller is investigated and it has been observed that the composite with a higher filler content of 4 percent attains enhanced strength than a sample with a lower filler content of 0 and 2 wt. percent. The transverse modulus is noticed to uplift by 16.88%, and the longitudinal modulus by 11.14% on the mixing of $CaCO_3$ particles in coir kenaf composite. Also, the composite is analyzed for hybridization effect, which proves to be one of the most promising ways to improve the features of the hybrid composite.

1. Introduction

Since the past decade, reviewers have faced many challenges to environmental problems caused by using synthetic fibers that are not sustainable, non-biodegradable, and harmful to the surrounding environment. To overcome this problem, scientists have introduced natural fiber-made composites because of their environmental friendliness, less weighty than synthetic fibers, easy availability, meager cost compared to other fibers, etc. [1-5,49-56]. Because of these cons, natural fiber composites are increasing their utilization for industrial applications. Taking into consideration the mechanical, chemical, and physical attributes of natural fiber composites, they are utilized in several applications. Some fibers like hemp, pineapple, sisal, and kenaf show similar properties compared to steel and aluminum [6, 57-61]. Because of the innumerable and positive characteristics of natural fibers, the utilization of composites made by these fibers shows their wide range of uses in areas of vehicle, construction, aircraft, and marine industries [7-11, 62-68]. Despite these numerous pros of NFCs, some cons need to be observed, such as low impact strength, high rate of water absorption, and lower heating capacity. To bridle these cons, scientists have

[*]Corresponding author: shikha001phd18@igdtuw.ac.in
[a] orcid.org/0000-0003-0768-2545; [b] orcid.org/0000-0001-7386-1838
DOI: http://dx.doi.org/10.17515/resm2023.33me1020rs

mixed and hybridized this natural fiber with small percentages of synthetic fibers to boost their mechanical attributes, thermal strength, reduce water absorption, etc. [12,69-74]. The investigation has been done on the mechanical attributes of cellulose nanofibers fortified composite at varying weight percentages of nanocellulose, which predicted that 0.75 weight percent of epoxy composite reinforced with nanocellulose resulted in improved thermal properties and modulus in comparison to 0.5 weight percent and 1 weight percent of the composite [13]. Due to the firm synergy between fibers and matrix, the natural rubber composite incorporated with oil palm fibers showed a rise in the modulus, enhancing the total fibers in the composite [14]. A study is made on the jute-sisal reinforced epoxy hybrid composite's thermal properties and dynamic performance. The outcomes showed that the hybrid effect of fibres, positively impacts the improvement of dynamic mechanical and thermal features. It has been discovered that hybrid composites with a higher proportion of jute fibers had higher modulus of storage, and modulus of loss [15]. The investigation is done on the different banana fiber forms, and the conclusion has been made that fiber composites incorporated with plain weave fibers ensued in improved mechanical attributes of the composite. Incorporating more fibers enhanced the modulus and reduced damping behavior [16]. All the attributes of treated and untreated coir composite are considered. The research concludes that chemically treated coir fiber composite showed enhanced properties compared to untreated composites [17]. In the case of jute and palm leaf composites, it is noticed that hybridizing the fibres, improved flexural and tensile strength by 56 percent and 46 percent [18]. Also, it is remarked that an increment in jute volume enhanced the composite’s modulus. The mechanical attributes of coconut and bagasse reinforced fibre hybrid composite are examined. A conclusion has been made that composite with three layers of fibers inculcated better characteristics than two-layered fiber composites [19]. The dielectric and mechanical features of hybrid composites incorporated with banana and glass fibers, are studied. The conclusion is drawn that glass fiber aggregation in composite reduced the damping properties and the modulus [20]. The mechanical properties of coconut and nano clay composite have been explored by differing the filler content between 1-5 wt. percent, which resulted in enhanced properties at 3 percent of filler material in the composite [21]. Comparisons between composites with filler and without filler are made with composites having pure matrix for studying the mechanical attributes of the composite. The impact of the volume and length of fiber is also observed on the dynamic mechanical attributes, and related application areas were explored [22]. Also, damping properties are investigated to foresee the component’s lifetime. It is noticed that as the weight percent of sisal fibres increases, it reduces the damping behavior of the composite [23]. Moreover, the review is prolonged to evaluate the outcomes of the above-stated factors on the mechanical performance of developed composites. Outcomes depict that both the volume content of fiber and orientation afflicted the composite’s mechanical features. The hybrid composite is studied to predict water absorption and mechanical features with differing weight percent of fiber content [24]. It is also observed that the hybrid effect of fibers enhanced the overall performance and composite attributes [26, 68]. Composite with two different fibers, used in the proportion of 25 percent Coir and 75 percent Kevlar, inculcated good impact, flexural, and water absorption properties. According to the results, it has been ratified that the fabricated composite may find its application in the defense sector. Work is done on polymer composite reinforced with piassava fiber, and the composite's mechanical analysis has been done as a function of temperature [25]. Outcomes show that, in comparison to polyester composites, the fortification of fibers improves the modulus of the composite. Three composites with varying content of kenaf and bamboo fibers are considered, showing that equal content of both fibers resulted in dimensional stability and improved properties [26].

Investigation is done on coir-luffa fiber composite to study the mechanical characteristics of the composite, which shows that alkali-treated fiber results in enhanced properties [27]. An exploration is made on the composite reinforced with abutilon indicum fiber to predict the outcome of alkali treatment and a varying number of fibres on mechanical and thermal characteristics. Outcomes predicted that composite fibres treated with alkali possessed improved mechanical features [28]. The conclusion is made that composite properties improved by up to 20 percent of fiber content and decreased afterward. Scientists have revealed that incorporating fillers into the composite resulted in better and improved properties [29-33]. The investigation is made on Coir and Luffa cylindrica fibres incorporated with calcium carbide nanofillers. Outcomes predicted that mechanical properties of composites with incorporated nanofillers resulted in higher characteristics [31]. Also, the discussion was done on filler's impact on the mechanical attributes of hybrid composites incorporated using prosopis juliflora fibers [32]. Study has been done on palm fibre nanofiller reinforced ABS composites to explore the filler's effect on the attributes of composite. Results depicted that the addition of palm fiber nanofiller enhanced the absorption property of the materials [33]. Despite several advantages, research on natural fibers and fillers have some drawbacks and limitations when employed as reinforcement for composites, including weak interfacial adhesion, a processing temperature range of only around 200 °C, low dimensional stability, and low moisture absorption resistance.

The above reported literature has been reviewed using papers from relevant fields which have been identified from the Science Citation Index Database, Scopus Database, Web of Science, and other reputed International Journals.

In the proposed paper, the mechanical attributes of a calcium carbonate nanofiller incorporated in a kenaf coir composite have been evaluated. Based on an extensive literature review, it is found that a very limited amount of work is performed on Kenaf-coir epoxy composite.

Table 1. Attributes of Calcium Carbonate nanofiller [34]

S. NO	Properties	Values
1	Density	2.7-2.9 g/cm^3
2	Size of Particle	30-50 nm
3	Absorption of Oil	13-21 g/100g
4	Specific Surface Area	5-24 m^2/g

The kenaf-coir epoxy composite added with Calcium carbonate is a novel composite that has not been studied earlier. The novel composition of kenaf-coir epoxy composite filled with $CaCO_3$ particles has not been analyzed earlier, using various mathematical, empirical models and RVE modeling to evaluate their elastic properties. Also, an earlier study has not evaluated the influence of the hybrid effect on the proposed composite. Therefore, to address the aforementioned gaps in the literature, this research addresses the problems listed below.

- A novel kenaf coir hybrid epoxy matrix composite, with varying weight percentages of calcium carbonate nanoparticles, is modeled in ABAQUS CAE version 6.14, and Representative Volume Element Analysis has been performed on it.
- The elastic attributes of the novel proposed composite are evaluated by applying the Chamis Model, Morais Model, Halpin Tsai Model, Jacquet's Horizontal Model, and Modified Halpin Tsai Model.

- The strength and Young's modulus of the analyzed composite incorporated with 0%, 2%, and 4% of calcium carbonate nanoparticles are analyzed at different fiber percentages using the analytical model and RVE analysis.
- The composite is also evaluated for the hybridization effect to analyze and calculate the tensile failure strain for the proposed novel composite.
- The impact of filler content on the composite's behavior and characteristics, has been determined. The properties and attributes of calcium carbonate are depicted in Table 1 [34].

The flowchart of the proposed research is shown as shown in figure 1.

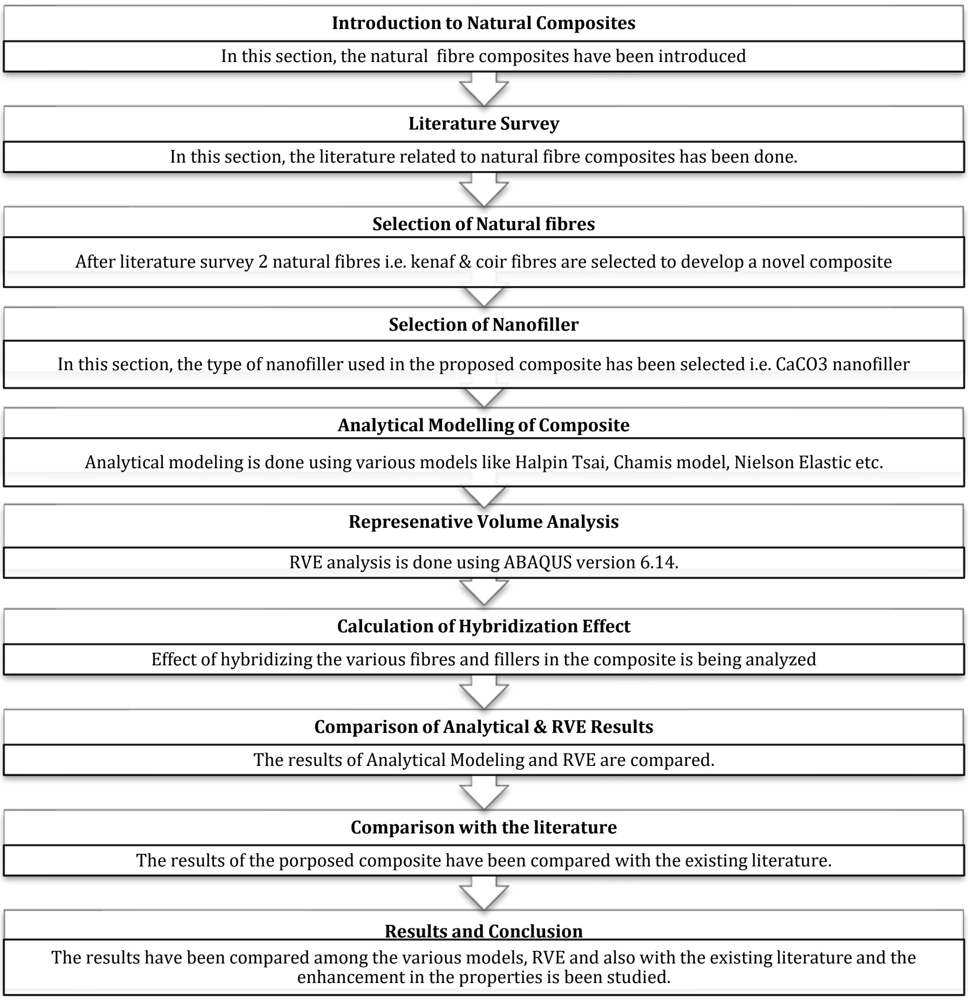


Fig. 1. Flowchart of the proposed research

2. Methodology

The original objective of incorporating mineral fillers into polymers had been predominantly cost diminution; however, in the past few years, the fillers have increasingly been employed to carry out a useful role, such as boosting the stiffness or improving the dimensional stability of the polymers. Calcium carbonate is a type of new high-grade capability filler with low cost, that is utilized extensively in plastics, rubber, paint, and numerous other applications in industry. The form, size, and amount of calcium carbonate can all have an impact on the general attributes of composites. Because inorganic fillers are significantly smaller in size than wood fibers, they can readily be injected into polymeric matrix within wood fibers. Other attributes of Calcium Carbonate particles are shown in Table 1.

The composite analyzed in previous literature comprises Coir, Calcium carbonate, and silk squash with epoxy as a matrix element [35]. The composition used in previous literature is shown in Table 2.

Table 2. Composite sample from existing literature [35]

Sample	Epoxy resin fraction (wt%)	Coir fibres (wt%)	Silk Squash (wt%)	Calcium Carbonate (wt%)
I	84.3	10	5.7	0
II	82.3	10	5.7	2
III	80.3	10	5.7	4

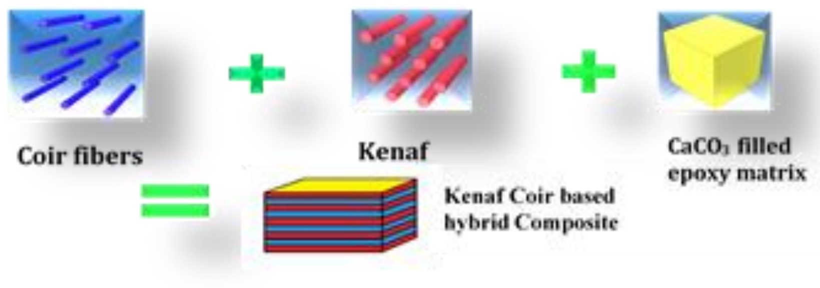


Fig. 2. Portray of hybrid composite

Table 3. Varying sample composition of the proposed composite

Sample	Description	Epoxy resin fraction (wt%)	Coir fibres (wt%)	Kenaf (wt%)	Calcium Carbonate (wt%)
I	Coir Kenaf fibers in epoxy matrix	84.3	10	5.7	0
II	Coir and kenaf fibers along with CaCO3 Particles (2 wt%)	82.3	10	5.7	2
III	Coir and kenaf fibers along with CaCO3 Particles (4 wt%)	80.3	10	5.7	4

The results derived from the above combination of composite signify that the enforcement of calcium carbonate particles increased the composite's mechanical characteristics. The tensile modulus is observed to be 5000 MPa in the sample SP1. In the second sample, SP2 the tensile modulus is observed to be 6000 MPa, whereas, in the third sample, SP3, it is observed to increase to 6700 MPa [35].

The composite considered in the present research consists of coir fiber, calcium carbonate particles, and kenaf fiber in place of silk squash embedded in epoxy resin, in the same weight percent as in previous literature. The weight percentages of different fibers utilized in the proposed composite are shown in Table 3. The hybrid effect of kenaf, coir, and calcium carbonate nanoparticles has been depicted in figure 2.

3. Analytical Models

The analytical models employed use numerical equations and expressions to count on the mechanical attributes of the composite [36, 37]. These models provide good results based on some presumptions. Therefore, in this paper, several analytical models are considered, such as the Morais model, Chamis model, Halpin Tsai model, Hirsch Model, Modified Halpin Tsai model, and JaH & JaV model, to evaluate the elastic properties of the developed composite.

3.1. Chamis Model

Chamis model is a semi-empirical model designed for outlining the composite's elastic features. In the proposed research, this model is a modified form of the rule of mixtures, replacing the fiber fraction with the square root of the function [38].
Longitudinal properties:

$$E_1 = E_f S_f + E_m S_m \tag{1}$$

$$\nu_C = \nu_f S_f + \nu_m S_m \tag{2}$$

Transverse properties:

$$E_2 = \frac{E_m}{1 - \left\{\sqrt{S_f}\left[1 - (\frac{E_m}{E_f})\right]\right\}} \tag{3}$$

Where; $E_1, E_2, =$ Composite's Longitudinal and Transverse modulus; $E_{m,} Ef =$ Young's modulus of matrix and fiber; $S_m, S_f =$ The volume fraction of matrix and fibres; $\nu_{m,}\ \nu_C, \nu_f =$ Poisson's ratio of matrix, composite, and fibers. The above model is evaluated as equation (4) and (5), for the proposed composite in this research.

$$E_1 = E_{Kf} S_{Kf} + E_{Cf} S_{Cf} + E_m S_m \tag{4}$$

$$E_2 = \frac{E_m}{1 - \left\{\sqrt{S_{Kf}}\left[1 - (\frac{E_m}{E_{Kf}})\right]\right\}} + \frac{E_m}{1 - \left\{\sqrt{S_{Cf}}\left[1 - (\frac{E_m}{E_{Cf}})\right]\right\}} \tag{5}$$

3.2. Morais Model

Morais Model is an interpretation observed mechanically at a micro level, derived in a closed form, to anticipate the representative volume element as a square for calculating its transverse modulus [39]. Morais Model is an extension of previous models by considering Poisson's ratio of the matrix in the model as shown by equation (6).

$$E_2 = \frac{S_f}{\frac{\sqrt{S_f}}{E_f} + \frac{(1-\sqrt{S_f})(1-2\vartheta_m^2)}{E_m}} + \left(1 - \sqrt{S_f}\right)\frac{E_m}{1 - \vartheta_m^2} \tag{6}$$

3.3. Halpin Tsai Model

Halpin Tsai Model is developed to calculate the longitudinal and transverse modulus of the composites [40]. The longitudinal and transverse modulus can be seen as:

$$E_1 = E_f S_f + E_m S_m \tag{7}$$

$$E_2 = E_m \frac{(1 + \varsigma\, \eta\, V_f)}{(1 - \eta V_f)} \tag{8}$$

$$\eta = \frac{E_f - E_m}{E_f + \varsigma E_m} \tag{9}$$

$$\varsigma = \frac{2L}{D} \tag{10}$$

Where, ς is the reinforcing efficiency factor mainly influenced by the packing geometry and the cross-section of fibers. The value is observed to lie between 1 and 2, as predicted by various authors.

3.4. Modified Halpin Tsai Model

The equation (7) and (8) has been modified by introducing the maximum packing fraction ϕ_{max} into it [41]. This comes out to be:

$$E_2 = E_m \frac{(1 + \varsigma \eta V_f)}{(1 - \eta \phi_{max} V_f)} \tag{11}$$

Where, ϕ_{max} depicts the packing fraction (0.81 is taken for randomly oriented fibers, 0.906 is observed for a hexagonal array, 0.785 is observed in the case of a square array).

3.5 Jacquet's Horizontal Model

The transverse modulus in the case of composite material is evaluated with the use of this novel model, namely Jacquet's horizontal model [42]. Jacquet's Horizontal Model (JA-H) is shown in eq (12).

$$\frac{1}{E_2} = \frac{\sqrt{S_f}}{E_f \sqrt{S_f} + E_m (1 - \sqrt{S_f})} + \frac{(1 - \sqrt{S_f})}{E_m} \tag{12}$$

4. Hybridization Effect

Hybridization is mainly employed to ameliorate the composite material's functional characteristics and mechanical properties [43-46]. It is one of the most essential tools for analyzing the characteristics of a composite. This is evaluated to fathom the behavior of fibers in the composite. In the present case, the fibers used are Coir, which is a low elongation fiber, and Kenaf, which is a high-elongation fibers. The hybridization effect is calculated as proportion of the composite's failure strain to the low-elongation composite's failure strain [45]. The hybrid effect R_{hyb} as given by [47] as:

$$R_{hyb} = \frac{\overline{\varepsilon_{HEC}}}{\overline{\varepsilon_{LEC}}} = \sqrt{\frac{\overline{\varepsilon_{HEF}}}{\overline{\varepsilon_{LEF}}}} \left[\frac{\delta_h (k_h^q - 1)}{2\delta (k_q - 1)}\right]^{\frac{-1}{2m}} \tag{13}$$

Simplifying the above equation (13), we get the reduced equation:

$$R_{hyb} = 2^{\frac{1}{2q}} \left[\frac{\bar{\epsilon}_2}{\bar{\epsilon}_1}\right]^{1/2} \left[\frac{m}{m_h}\right]^{1/2} \left[\frac{\omega}{\omega_h}\right]^{1/2q} \tag{14}$$

Now according to the hybridization effect calculated in [47], the hybridization effect for the current composite fiber combination comes out to be: $R_{hyb} = 1.19$

This effect depicts the consequence of mixing filler in the fiber composites on the elastic and mechanical characteristics. In the case of the Kenaf coir fiber-fortified composite, it is noticed that the tensile failure strain is 1.19 times higher in comparison to the coir composite alone. Therefore, this portrays the benefits of fiber hybridization in composite materials.

5. Representative Volume Element Analysis

In the field of composite materials, the Representative Volume Element analysis is the smallest volume on which any assessment is done that will produce a quantity depictive of the whole volume. This technique of homogenization has proved to be one of the key aspects in determination of the characteristics of composite material [48]. The assumptions taken during this analysis are:

- The bond existing between the matrix and fibers is taken to be perfect.
- The composite is free from any inclusions.
- Even the distribution of fibers inside the composite.
- The composite utilized is a 3-dimensional system with unidirectional fibers.

In this paper, Representative Volume Element analysis of the Kenaf Coir epoxy-fortified calcium carbonate nanoparticles composite has been done to examine the features of the hybrid composite using ABAQUS CAE version 6.14.

5.1 Modeling Steps

- STEP 1: Initially the coir fibers are designed in ABAQUS. Post this the kenaf fibres are stacked above it.
- STEP 2: After this a volume element of epoxy matrix reinforced with $CaCo_3$ nanofillers is designed.
- STEP 3: The kenaf and coir fibres of diameter shown in table 4 are integrated into the volume element of epoxy matrix. The volume element possesses a length, breadth, and height of 1.6 x 10^{-4}m [48].
- STEP 4: The mechanical properties of respective fibres and matrix are assigned in ABAQUS.
- STEP 5: Meshing used is hexahedra meshing while performing RVE analysis with the help of the Sweep tool. 0.00005 is the mesh size used in this research modeling.
- STEP 6: The Pre boundary Condition parameters are shown in Table 4.
- STEP 7: RVE is then subjected to respective loads and conditions.
- STEP 8: After this, the RVE analysis is done for Longitudinal and Transverse Modulus.

Table 4. PBC Criterion for RVE

Criterion	Kenaf fibers	Coir fibers
The volume fraction of fibers ($\boldsymbol{V_f}$)	0.10	0.057
Diameter ($\boldsymbol{D_f}$)	25 µm	15 µm
Length ($\boldsymbol{L}$)	160 µm	160 µm
Width ($\boldsymbol{W}$)	80 µm	80 µm

The model for the above-considered composite has been developed in ABAQUS, as shown in figure 3.

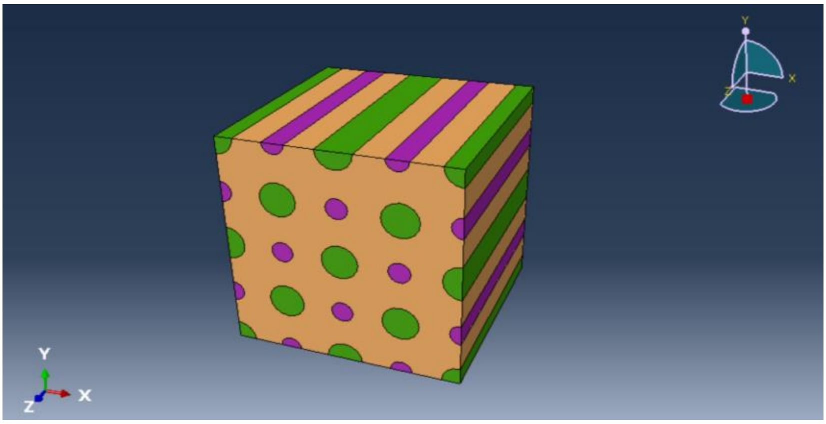


Fig. 3. RVE model

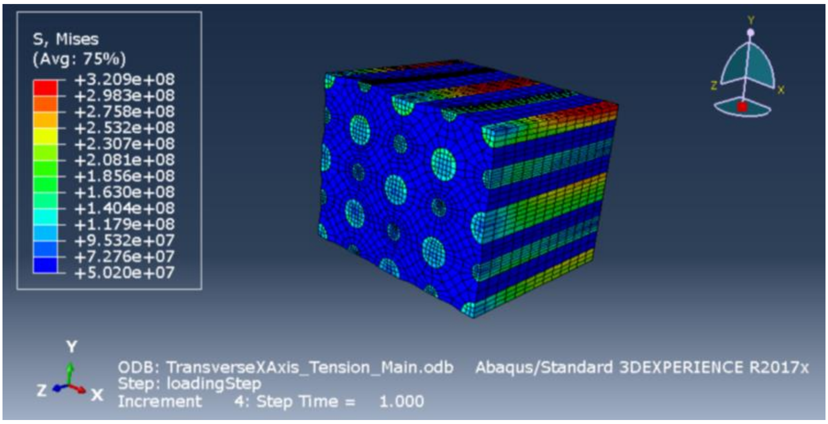


Fig. 4. Postprocessing of transverse modulus

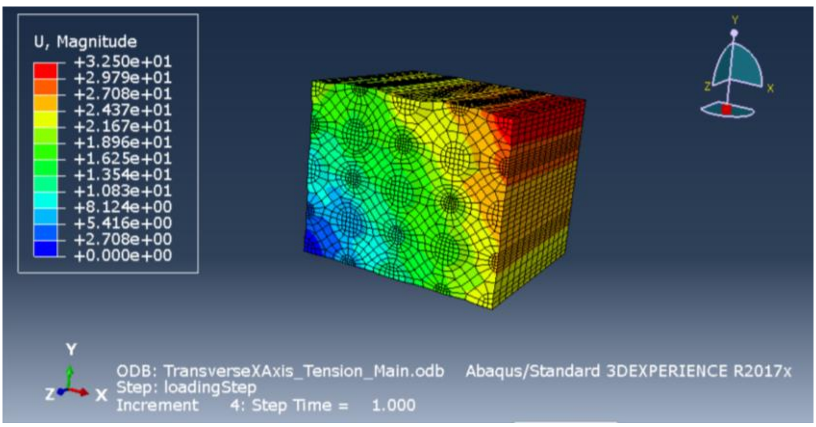


Fig. 5. Resultant displacement on implementation of transverse stress

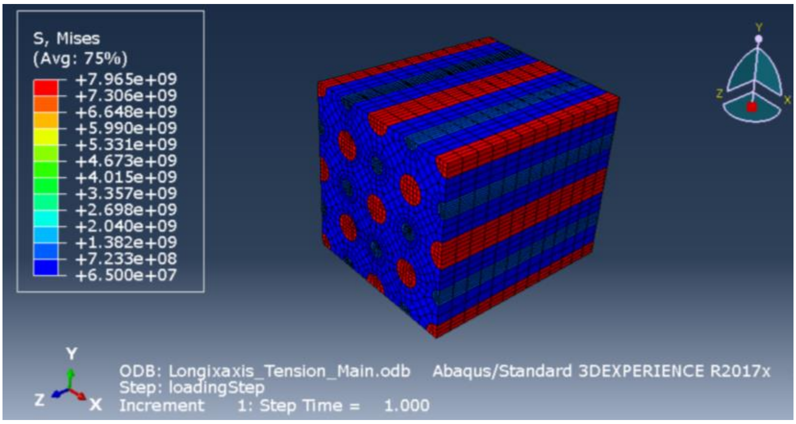


Fig. 6. Postprocessing of longitudinal modulus

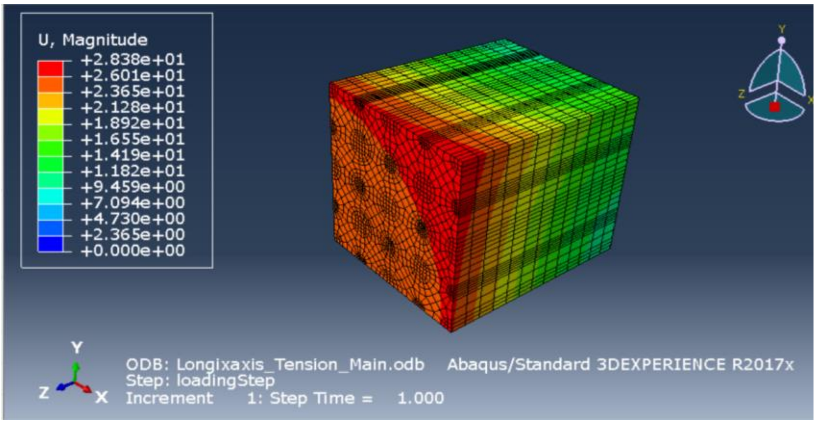


Fig. 7. Resultant displacement on implementation of longitudinal stress

Figures 4,5, 6 and 7 illustrate the results plotted for the stress in the case of longitudinal and transverse fiber composite. Figure 4 and 5 manifest the postprocessing three-dimensional results and resultant displacement that depict the damage criteria, on implementation of transverse stress, respectively. Figures 6 and 7 manifest the three-dimensional postprocessing results and the resultant displacement that depict the damage criteria, after the implementation of longitudinal stress, respectively.

6. Results from Analytical Modelling and RVE Analysis

Table 5 compares the weight percentages of the composite materials analyzed in the existing literature with the fiber material used in the proposed work. In the existing literature work, Coir, Silk Squash, epoxy, and calcium carbonate particles are used in different weight percentages. Whereas in the proposed composite, the sample composition evaluated is the same, just by replacing the silk squash fiber with the kenaf fibers. In the proposed composite, three samples of the composite with varying content of kenaf, coir fiber, and calcium carbonate particles, have been analyzed for longitudinal modulus and transverse modulus, as well a comparison is made with the existing literature [35].

Table 5. The weight percent of materials used in existing literature and proposed work

S.NO	Composite Material	Experimental Work [35]			Proposed Work		
		I	II	III	I	II	III
1	Epoxy	84.3	82.3	80.3	84.3	82.3	80.3
2	Coir fiber	10	10	10	10	10	10
3	Nano Calcium Carbonate	0	2	4	0	2	4
4	Silk Squash	5.7	5.7	5.7	0	0	0
5	Kenaf fiber	0	0	0	5.7	5.7	5.7

Table 6. Results for the sample KC1

Models/ Properties	Chamis Model	Morais Model	Halpin Tsai Model	Modified Halpin Tsai Model	Jacquet's Horizontal Model	RVE	Mean	Deviation
Transverse Modulus (GPa)	5.84	5.75	6.12	5.29	4.98	6.04	5.67	0.36
Longitudinal Modulus (GPa)	7.42	7.42	7.42	7.42	7.42	7.59	7.45	0.048
Poisson's Ratio (μ)	0.32	0.32	0.32	0.32	0.32	0.35	0.32	0.270

Table 7. Results for the sample KC2

Models/ Properties	Chamis Model	Morais Model	Halpin Tsai Model	Modified Halpin Tsai Model	Jacquet's Horizontal Model	RVE	Mean	Deviation
Transverse Modulus (GPa)	6.18	6.01	6.28	5.99	5.93	6.42	6.14	0.16
Longitudinal Modulus (GPa)	7.92	7.92	7.92	7.92	7.92	7.98	7.93	0.016
Poisson's Ratio (μ)	0.35	0.35	0.35	0.35	0.35	0.38	0.36	0.012

The different samples that have been used in this composite are the Kenaf Coir composite (KC1), the Kenaf Coir composite with 2% of $CaCO_3$ (KC2), and the Kenaf Coir composite with 4% of $CaCO_3$ content (KC3). Results have been analyzed using five different analytical and empirical models Jacquet's Model, H-T Model, Chamis Model, Morais Model, and Modified H-T Model. The outcomes from all three samples KC1, KC2, and KC3 have been shown in Tables 6, 7 and 8, respectively. The graphical results for transverse and longitudinal modulus have been shown in Figures 8, 9, and 10 respectively.

Table 8. Results for the sample KC3

Models/ Properties	Chamis Model	Morais Model	Halpin Tsai Model	Modified Halpin Tsai Model	Jacquet's Horizontal Model	RVE	Mean	Deviation

Transverse Modulus (GPa)	6.73 0.16	6.47 0.1	6.84 0.27	6.24 0.33	6.17 0.4	6.96 0.39	6.57	0.275
Longitudinal Modulus (GPa)	8.22	8.22	8.22	8.22	8.22	8.34	8.24	0.033
Poisson's Ratio (μ)	0.37	0.37	0.37	0.37	0.37	0.39	0.373	0.005

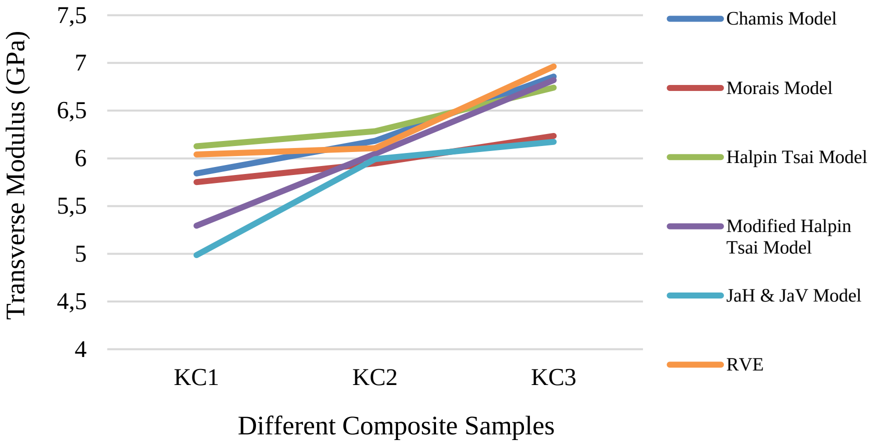


Fig. 8 Transverse modulus for different samples (KC1, KC2, KC3)

Figures 8, 9 and 10 depict the mechanical attributes of varying samples of composite. On uplifting the volume of the calcium carbonate in the composite, the modulus is observed to see a rise. The Transverse Modulus in sample KC1 is observed to be 5.67 GPa, which increases to 6.13 GPa in sample KC2 and to 6.56 GPa in sample KC3. The Longitudinal modulus is reported to increase from 7.45 GPa to 7.93 GPa to 8.24 GPa in KC1, KC2, and KC3 samples, respectively. Therefore, an enhancement of 11.14% is noticed in the case of longitudinal modulus, whereas an advancement of about 15.69% is noticed in the case of transverse modulus on the addition of calcium carbonate nanofiller to the kenaf coir epoxy composite.

To verify that the properties of the proposed composites are better than the composite taken from the previous literature, a comparison of the properties has been made for all the three samples of the composites. Comparison based on existing literature depicts that the elastic modulus displayed an increase from 4.2 GPa to 7.45 GPa in the first sample KC1. In the second sample, KC2, the modulus is remarked to uplift from 5.3 GPa to 7.93 GPa [35]. The relative increment is noticed in the third sample, KC3, where the modulus of 6.7 GPa has uplifted to 8.24 GPa. The results are portrayed in Figure 11 [35]. From figure 11, it is observed that the proposed composite has enhanced properties in comparison to the previous literature, which uses silk squash fibre in place of kenaf fibres for all the three samples.

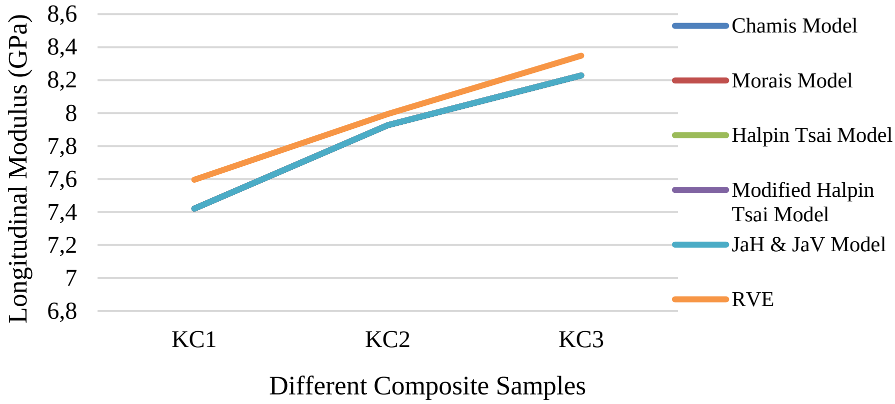


Fig. 9. Longitudinal modulus for different samples (KC1, KC2, KC3)

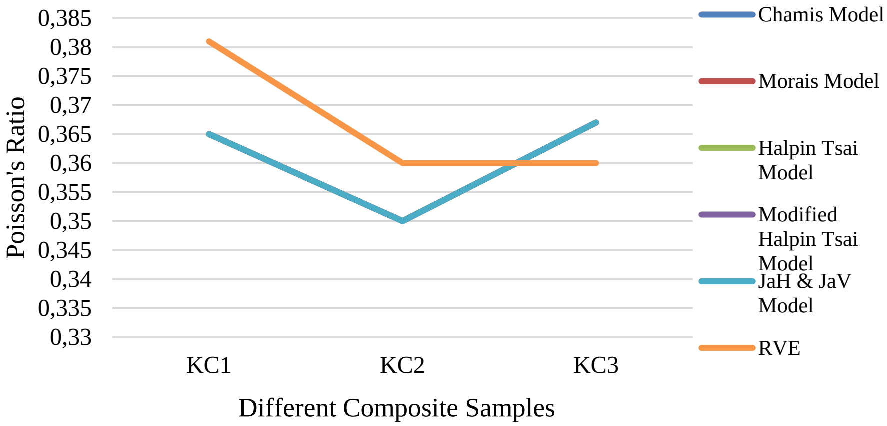


Fig. 10 Poisson's ratio for different samples (KC1, KC2, KC3

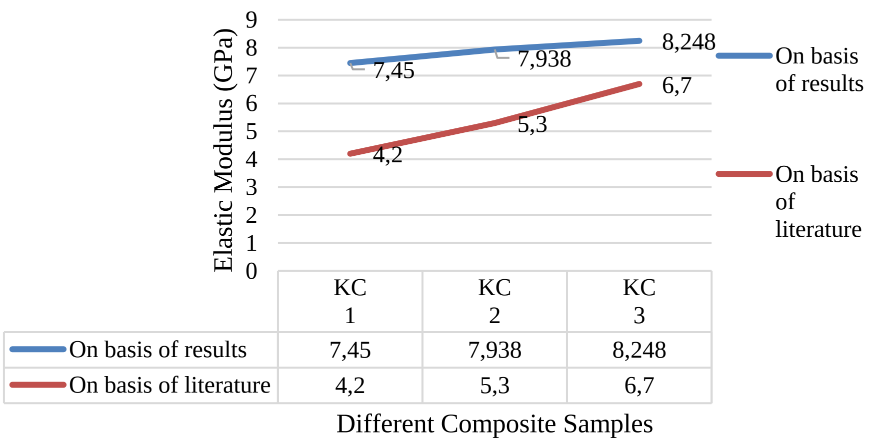


Fig. 11. Comparison of results for elastic modulus for proposed composite with existing literature [35]

7. Conclusions

The kenaf coir epoxy composite with the incorporation of calcium carbonate nanoparticles is analyzed in the present paper, using five different analytical models and using RVE analysis. This is carried out to examine the effect of fortification of nanofiller in the composite on the elastic features and performance of coir kenaf epoxy composites. The outcomes of the research are delineated as follows:

- Based on the extensive literature survey, it has been found that the proposed Kenaf-Coir-Calcium carbonate nanoparticle reinforced epoxy composite is a novel and unique composite, not researched before and thereby cherishing superior elastic characteristics.
- The elastic characteristics of the composite are accomplished by employing mathematical analytical modeling using five different models, particularly Chamis Model, Morais model, Jacquet's Horizontal Model, Halpin Tsai Model, Modified Halpin Tsai Model.
- The composite outcomes have also been analysed using Representative Volume Element analysis that has been carried out using software ABAQUS CAE version 6.14.
- An observable increment is detected on the mixing of calcium carbonate nanoparticles with coir and kenaf fibers. The transverse modulus is noticed to uplift by 16.88%, and the longitudinal modulus is observed to uplift by 11.14% on the mixing of CaCO3 particles in coir kenaf composite.
- The hybridization effect is calculated as 1.19, which represents that tensile failure strain in CaCO3 fortified composites is 1.19 times greater as compared to pure kenaf coir epoxy composite.
- The outcomes of RVE are noticed to be in synergy with the outcomes gained through analytical modeling, as illustrated in Tables 5, 6, and 7.
- The silk squash fibers in the existing literature are replaced with kenaf fibers in the proposed literature, and the influence of this replacement is observed in terms of its mechanical attributes. Comparison made with existing literature shows the upliftment of modulus by 76.66 % in the KC1 sample, an increment of 49.77% in the KC2 sample, and a growth of 23.10% in the KC3 sample. This represents enhanced tensile strength in in contrast to $CaCO_3$ incorporated coir and luffa cylindrica hybrid composite used in literature, is found to be in a superior state in terms of its mechanical properties.
- Analyzing the practical implications of this composite, we conclude that the above proposed novel composite having immense attributes, will be of great help and usefulness in development of light weight textile items such as a lady's purse or bag. This purse has been developed and analyzed in this research on ANSYS.

8. Recommendation

The above proposed composite with enhanced properties is recommended for further analysis using fibre modification, matrix modification etc. In future, in order to solve issues including moisture absorption, insufficient toughness, and decreased long-term stability for outdoor application, more study and investigation is needed. Additionally, research can be done to improve the properties of nanofillers and fibers by combining more than one of them. As of right now, natural fiber composites offer a wide range of applications that do not necessitate extremely high load bearing or high temperature functioning capacities. the proposed composite. Therefore, the $CaCO_3$ incorporated kenaf coir hybrid composite

Abbreviations

E_1, E_2	Longitudinal and Transverse modulus of composite
E_f, E_m	Elastic Modulus of fibers and matrix, respectively
S_f, S_m	Volume fraction of the fibers and matrix, respectively
v_f, v_m	Poisson's ratio of fiber and matrix, respectively
E_{kf}, E_{cf}, E_m	Modulus of kenaf fiber, coir fiber, and matrix, respectively.
S_{kf}, S_{cf},	The volume fraction of kenaf fiber, the Volume fraction of coir fibers.
ϕ_{max}	Packing fraction
ς	Reinforcing Efficiency Factor
L, D	Length and diameter of fibers, respectively.
RVE	Representative Volume Element
NR	Natural Rubber Composite
NFCs	Natural Fiber Composites

Acknowledgement

The author would like to express deep thanks to the editorial team and anonymous reviewers for their positive comments for previous version of this research paper.

References

[1] Sanjay MR, Madhu P, Jawaid M, Senthamaraikannan P, Senthil S, Pradeep S. Characterization and properties of natural fiber polymer composites: A comprehensive review. J Clean Prod. 2018;172:566-581. https://doi.org/10.1016/j.jclepro.2017.10.101

[2] Anbukarasi K, Kalaiselvam S. Thermal and mechanical behaviors of biorenewable fibers-based polymer composites. In: Handbook of composite from renewable materials: Functionalization. Wiley-Scrivener. 2016;4(19):491-520. https://doi.org/10.1002/9781119441632.ch81

[3] Sumesh KR, Kanthavel K, Vivek S. Mechanical/thermal/vibrational properties of sisal, banana, and coir hybrid natural composites by the addition of bio synthesized aluminum oxide nano powder. Mater Res Express. 2019;6(4):045318. https://doi.org/10.1088/2053-1591/aaff1a

[4] Guimaraes JL, Frollini E, Silva CGD, Wypych F, Satyanarayana KG. Characterization of banana, sugarcane bagasse, and sponge gourd fiber of Brazil. Indus Corp Prod. 2009;30(3):407-415. https://doi.org/10.1016/j.indcrop.2009.07.013

[5] Kumar R, Anand A. Fabrication and mechanical characterization of Indian ramie reinforced polymer composites. Mater Res Express. 2019;6(5):055303. https://doi.org/10.1088/2053-1591/aaff12

[6] Saba N, Paridah MT, Jawaid M. Mechanical properties of kenaf fiber reinforced polymer composite: a review. Constr Build Mater. 2015;76:87-96. https://doi.org/10.1016/j.conbuildmat.2014.11.043

[8] Matykiewicz D, Barczewski M, Knapski D, Skorczewska K. Hybrid effects of basalt fibers and basalt powder on thermomechanical properties of epoxy composites. Compos Part B Eng. 2017;125:157-164. https://doi.org/10.1016/j.compositesb.2017.05.060

[9] Balan AK, Parambil SM, Vakyath S, Velayudhan JT, Naduparambath S, Etathil P. Coconut shell powder reinforced thermoplastic polyurethane/natural rubber blend-composites: effect of silane coupling agents on the mechanical and thermal properties

of the composites. J Mater Sci. 2017;52:6712-6725. https://doi.org/10.1007/s10853-017-0907-y

[10] Siqueira G, Bras J, Follain N, Belbekhouche S, Marais S, Dufresne A. Thermal and mechanical properties of bio-nanocomposites reinforced by luffa cylindrica cellulose nanocrystals. Carbo Polym. 2013;91(2):711-717. https://doi.org/10.1016/j.carbpol.2012.08.057

[11] Satapathy S, Kothapalli RV. Mechanical, dynamic mechanical and thermal properties of banana fiber/recycled high-density polyethylene bio composites filled with flyash cenospheres. J Polym Environ. 2018;26:200-213. https://doi.org/10.1007/s10924-017-0938-0

[12] Saba N, Paridah MT, Abdan K, Ibrahim NA. Dynamic mechanical properties of oil palm nano filler/kenaf/epoxy hybrid nanocomposites. Constr Build Mater. 2016;124:133-138. https://doi.org/10.1016/j.conbuildmat.2016.07.059

[13] Saba N, Safwan A, Sanyang ML, Mohammad F, Pervaiz M, Jawaid M, Sain M. Thermal and dynamic mechanical properties of cellulose nanofibers reinforced epoxy composites. Int J Biol Macromol. 2017;102:822-828. https://doi.org/10.1016/j.ijbiomac.2017.04.074

[14] Joseph S, Appukuttan SP, Kenny JM, Puglia D, Thomas S, Joseph K. Dynamic mechanical properties of oil palm microfibril-reinforced natural rubber composites. J Appl Polym Sci. 2010;117:1298-1308. https://doi.org/10.1002/app.30960

[15] Gupta MK. Thermal and dynamic mechanical analysis of hybrid jute/sisal fiber reinforced epoxy composite. Proc Inst Mech Eng Part L. 2018;232:743-748. https://doi.org/10.1177/1464420716646398

[16] Venkateshwaran N, Elaya Perumal A, Raj RA. Mechanical and dynamic mechanical analysis of woven banana/epoxy composite. J Polym Environ. 2012;20:565-572. https://doi.org/10.1007/s10924-011-0410-5

[17] Kumar SS, Duraibabu DA, Subramanian K. Studies on mechanical, thermal, and dynamic mechanical properties of untreated (raw) and treated coconut sheath fiber reinforced epoxy composites. Mater Des. 2014;59:63-69. https://doi.org/10.1016/j.matdes.2014.02.013

[18] Shanmugam D, Thiruchitrambalam M. Static and dynamic mechanical properties of alkali-treated unidirectional continuous Palmyra Palm Leaf Stalk Fiber/jute fiber reinforced hybrid polyester composites. Mater Des. 2013;50:533-542. https://doi.org/10.1016/j.matdes.2013.03.048

[19] Saw SK, Sarkhel G, Choudhury A. Dynamic mechanical analysis of randomly oriented short bagasse/coir hybrid fiber-reinforced epoxy novolac composites. Fibers Polym. 2011;12:506. https://doi.org/10.1007/s12221-011-0506-5

[20] Pothan LA, George CN, John MJ, Thomas S. Dynamic mechanical and dielectric behavior of banana-glass hybrid fiber reinforced polyester composites. J reinf Plast Compos. 2010;29:1131-1145. https://doi.org/10.1177/0731684409103075

[21] Rajini N, Jappes JW, Rajakarunakaran S, Jeyaraj P. Dynamic mechanical analysis and free vibration behavior in chemical modifications of coconut sheath/nano-clay reinforced hybrid polyester composite. J Compos Mater. 2013;47:3105-3121. https://doi.org/10.1177/0021998312462618

[22] Saba N, Jawaid M, Alothman OY, Paridah MT. A review on dynamic mechanical properties of natural fiber reinforced polymer composites. Constr Build Mater. 2016;106:149-159. https://doi.org/10.1016/j.conbuildmat.2015.12.075

[23] Krishnudu DM, Sreeramulu D, Reddy PV. Optimization of the mechanical properties of coir-luffa cylindrica filled hybrid composites by using Taguchi method. AIP Conference Proceedings. 2018. https://doi.org/10.1063/1.5032020

[24] Boujmal R, Kakou CA, Nekhlaoui S, Essabir H, Bensalah MO, Rodrigue D, Qaiss AEK. Alfa fibers/clay hybrid composites based on polypropylene: Mechanical, thermal, and

structural properties. J Thermoplast Compos Mater. 2018;31(7):974-91. https://doi.org/10.1177/0892705717729197
[25] Senthilkumar K, Saba N, Rajini N, Chandrasekar M, Jawaid M, Siengchin S, Alothman OY. Mechanical properties evaluation of sisal fiber reinforced polymer composites: a review. Constr Build Mater. 2018;174:713-729. https://doi.org/10.1016/j.conbuildmat.2018.04.143
[26] Naveen J, Jawaid M, Zainudin ES, Sultan MTH, Yahaya R. Mechanical and moisture diffusion behavior of hybrid Kevlar/Cocos nucifera sheath reinforced epoxy composites. J Mater Res Technol. 2019;8:1308-1318. https://doi.org/10.1016/j.jmrt.2018.07.023
[27] d'Almeida JR, Aquino RC, Monteiro SN. Dynamic mechanical behavior of piassava fibers (Attalea funifera) reinforced polyester composites. Int J Polym Mater. 2007;56:397-403. https://doi.org/10.1080/00914030600873527
[28] Chee SS, Jawaid M, Sultan MTH, Alothman OY, Abdullah LC. Thermomechanical and dynamic mechanical properties of bamboo/woven kenaf mat reinforced epoxy hybrid composites. Compos B Eng. 2019;163:165-174. https://doi.org/10.1016/j.compositesb.2018.11.039
[29] Krishnudu DM, Sreeramulu D, Reddy PV. Optimization the mechanical properties of coir-luffa cylindrica filled hybrid composites by using Taguchi method. AIP Conference Proceedings, AIP Publishing. 2018. https://doi.org/10.1063/1.5032020
[30] Reddy PV, Prasad PR, Krishnudu DM, Hussain P. Influence of fillers on mechanical properties of prosopis juliflora fiber reinforced hybrid composites. Materials Today Proceedings. 2019.
[31] Krishnudu DM, Sreeramulu D, Reddy PV. Synthesis and characterization of coir and Luffa Cylindrica filled with CaCo3 hybrid composites. Int J Integrated Eng. 2019;11:290-298. https://doi.org/10.30880/ijie.2019.11.01.029
[32] Prado NS, da Silva ISV, de Morais LC, Pasquini D, Otaguro H. Effects of surface modifications of kraft wood pulp cellulose fibers on improving the mechanical properties of cellulose fiber/latex composites. J Polym Environ. 2019;1-9. https://doi.org/10.1007/s10924-019-01516-w
[33] Saba N, Paridah MT, Abdan K, Ibrahim NA. Effect of oil palm nano filler on mechanical and morphological properties of kenaf reinforced epoxy composites. Constr Build Mater. 2016;123:15-26. https://doi.org/10.1016/j.conbuildmat.2016.06.131
[34] Dante RC, Arevalo FMS, Ramos PM. Composite fiber based on Sisal fiber and Calcium Carbonate. J Nat Fibers. 2014;11(2):121-135. https://doi.org/10.1080/15440478.2013.849644
[35] Krishnudu DM, Sreeramulu D, Reddy PV, Prasad PR. Influence of filler on mechanical and dielectric properties of coir and luffa cylindrica fiber reinforced epoxy hybrid composites. Journal of Natural fibers. 2020;19(1):339-348. https://doi.org/10.1080/15440478.2020.1745115
[36] Parashar S, Chawla VK. Kenaf-Coir based hybrid nano-composite: An analytical and representative volume element analysis. Engineering Solid Mechanics. 2023;11(1):103-118. https://doi.org/10.5267/j.esm.2022.8.001
[37] Parashar S, Chawla VK. A systematic review on sustainable green fiber reinforced composite and their analytical models. Materials Today: Proceedings. 2021;46:6541-6546. https://doi.org/10.1016/j.matpr.2021.03.739
[38] Chamis CC, Sendeckyj GP. Critique on theories predicting thermoelastic properties of fibrous composites. J Compos Mater. 1968;2(3):332-358. https://doi.org/10.1177/002199836800200305
[39] Alfredo BM. Transverse moduli of continuous fiber reinforced polymers. Compos Sci Technol. 2000;60:997-1002. https://doi.org/10.1016/S0266-3538(99)00195-5
[40] Halpin JC, Tsai SW. Environmental factors in composite materials design. US Air Force Technical Report AFML TR. 1967;67423.

[41] Osaka E, Onukwuli OD. A Modified Halpin Tsai model for estimating the modulus of natural fiber reinforced composites. Int J Eng Sci Invention. 2018;7(5):63-70.
[42] Jacquet E, Trivaudey F, Varchon D. Calculation of the transverse modulus of a unidirectional composite material and of the modulus of an aggregate: Application of rule of mixtures. Compos Sci Technol. 2000;60:345-350. https://doi.org/10.1016/S0266-3538(99)00128-1
[43] Essabir H, Bensalah MO, Rodrigue D, Bouhfid R, Qaiss A. Structural, mechanical and thermal properties of bio-based hybrid composites from waste coir residues: Fibers and shell particles. Mech Mater. 2016;93:134-144. https://doi.org/10.1016/j.mechmat.2015.10.018
[44] Thwe MM, Liao K. Effects of environmental aging on the mechanical properties of bamboo-glass fiber reinforced polymer matrix hybrid composites. Compos Part A Appl Sci Manufact. 2002;33(1):43-52. https://doi.org/10.1016/S1359-835X(01)00071-9
[45] Jacob M, Thomas S, Varughese KT. Mechanical properties of sisal/oil palm hybrid fiber reinforced natural rubber composites. Compos Sci Technol. 2004;64(7-8):955-965. https://doi.org/10.1016/S0266-3538(03)00261-6
[46] Joseph S, Sreekala MS, Oommen Z, Koshy P, Thomas S. A Comparison of the mechanical properties of the phenol formaldehyde composites reinforced with banana and glass fibers. Compos Sci Technol. 2002;62(14):1857-1868. https://doi.org/10.1016/S0266-3538(02)00098-2
[47] Zweben C. Tensile strength of hybrid composites. J Mater Sci. 1977;12(7):1325-1337. https://doi.org/10.1007/BF00540846
[48] Adeniyi AG, Adeoye AS, Ighalo JO. FEA of effective elastic properties of banana fiber reinforced polystyrene composites. Mech Adv Mater Struct. 2020;28(18):1869-1877. https://doi.org/10.1080/15376494.2020.1712628
[49] Pol A, Malagi R, Munshi G. Identification of mechanical properties of an araldite LY556 blended with DNR composite and polyacetal: A comparative study for a sustainable future. Journal of Future Sustainability. 2022;2(4):149-156. https://doi.org/10.5267/j.jfs.2022.10.005
[50] Sadjadi S. A survey on the effect of plastic pollution in the Great Lakes. Journal of Future Sustainability. 2021;1(1):5-8. https://doi.org/10.5267/j.jfs.2021.1.002
[51] Tekletsadik S. Selection of best leather item using an FAHP method to launch new leather industry in Ethiopia: A case study. Journal of Future Sustainability. 2023;3(2):85-96. https://doi.org/10.5267/j.jfs.2022.11.008
[52] Chawla VK, Chanda AK, Angra S. Coexistent scheduling in the tandem flow path configuration of a flexible manufacturing system by using an advanced grey wolf optimizer. Scientia Iranica. 2020. https://doi.org/10.24200/sci.2020.54152.3618
[53] Chawla VK, Bhargava P, Verma S. Design, stimulation, and fabrication of chassis of an FSAE female-driven vehicle. Materials Today: Proceedings. 2021;43:36-41. https://doi.org/10.1016/j.matpr.2020.11.202
[54] Gupta P, Chawla VK, Jain V, Angra S. Green operations management for sustainable development: An explicit analysis by using fuzzy best-worst method. Decision Science Letters. 2022;11(3):357-366. https://doi.org/10.5267/j.dsl.2022.1.003
[55] Parashar S, Chawla VK. Evaluation of fiber volume fraction of kenaf-coir-epoxy based green composite by finite element analysis. Materials Today: Proceedings. 2022; 50: 1265-1274. https://doi.org/10.1016/j.matpr.2021.08.14 7
[56] Saxena T, Tomar P. Constitutive Performance Characterization of Diversified Bamboo Material-A Green Technology. Proceedings of International Conference on Sustainable Computing in Science, Technology and Management (SUSCOM), Jaipur-India; 2019. https://doi.org/10.2139/ssrn.3358200
[57] Parashar S, Tomar P. Synergy of sustainable bio-composite bamboo material in green technology-an explicit report. Proceedings of International Conference on Sustainable

Computing in Science, Technology, and Management (SUSCOM) Jaipur-India; 2019. https://doi.org/10.2139/ssrn.3357290
[58] Saxena T, Chawla VK. Banana leaf fiber-based green composite: A detailed review report. Materials Today: Proceedings. 2021; 46: 6618-6624. https://doi.org/10.1016/j.matpr.2021.04.099
[59] Faghidian SA. Flexure mechanics of nonlocal modified gradient nano-beams. Journal of Computational Design and Engineering. 2021; 8(3): 949-959. https://doi.org/10.1093/jcde/qwab027
[60] Saxena T, Chawla VK. Evaluation of mechanical properties for banana-carbon fiber reinforced nano-clay epoxy composite using analytical modeling and simulation. Research on Engineering Structures and Materials. 2022; 8(4): 773-798. https://doi.org/10.17515/resm2022.403me0219
[61] Yadav E, Chawla VK. An explicit literature review on bearing materials and their defect detection techniques. Materials Today: Proceedings. 2022; 50: 1637-1643. https://doi.org/10.1016/j.matpr.2021.09.132
[62] Faghidian SA. Two-phase local/nonlocal gradient mechanics of elastic torsion. Mathematical Methods in the Applied Sciences. 2020; 1-17. https://doi.org/10.1002/mma.6877
[63] Yadav E, Chawla VK. Fault detection in rotating elements by using fuzzy integrated improved local binary pattern method. Journal of the Brazilian Society of Mechanical Sciences and Engineering. 2022; 44(12): 596. https://doi.org/10.1007/s40430-022-03916-x
[64] Pothan LA, George CN, John MJ, Thomas S. Dynamic mechanical and dielectric behavior of banana-glass hybrid fiber reinforced polyester composites. Journal of Reinforced Plastics and Composites. 2010; 29(8): 1131-1145. https://doi.org/10.1177/0731684409103075
[65] Chawla VK, Yadav E. Defect detection in rotating machine elements by using an improved image segmentation technique. IOP conference series: materials science and engineering. 2022; 1228(1): 012009. https://doi.org/10.1088/1757-899X/1228/1/012009
[66] Bhatia S, Khan S, Angra S. Effect of the content of silane-functionalized boron carbide on the mechanical and wear performance of B4C reinforced epoxy composites. High Performance Polymers. 2021; 33(10): 1165-1180. https://doi.org/10.1177/09540083211031129
[67] Sadjadi S. A survey on the effect of plastic pollution in the Great Lakes. Journal of Future Sustainability. 2021; 1(1): 5-8. https://doi.org/10.5267/j.jfs.2021.1.002
[68] Gupta R, Rout V, Rajput K, Chawla VK, Fouad H, Akhtar MS. A Sustainable Method to Convert Waste Heat Energy to Electricity by Using Thermo-Electric Generators. Journal of Nanoelectronics and Optoelectronics. 2023; 18(4): 502-509. https://doi.org/10.1166/jno.2023.3410
[69] Faghidian SA. Higher order mixture n onlocal gradient theory of wave propagation. Mathematical Methods in the Applied Sciences. 2020; 1-23. https://doi.org/10.1002/mma.6885
[70] Saxena T, Chawla VK. Effect of fiber orientations and their weight percentage on banana fiber-based hybrid composite. Materials Today: Proceedings. 2022; 50: 1275-1281. https://doi.org/10.1016/j.matpr.2021.08.149
[71] Balcioglu HE, Ozmen HB. The fracture behaviour of pure and hybrid intraply knitted fabric reinforced polymer composites. Fracture Mechanics Applications. 2019; 1-22.
[72] Faghidian SA. Contribution of nonlocal integral elasticity to modified strain gradient theory. The European Physical Journal Plus. 2021; 136(5): 559. https://doi.org/10.1140/epjp/s13360-021-01520-x

[73] Chawla V, Chanda AK, Angra S, Bonyadi Naeini A. Coexistent scheduling in the tandem flow path configuration of a flexible manufacturing system by using an advanced grey wolf optimizer. Scientia Iranica. 2020. https://doi.org/10.24200/sci.2020.54152.3618
[74] Chawla VK, Chhabra D, Gupta P, Naaz S. Evaluation of green operations management by fuzzy analytical hierarchy process. Materials Today: Proceedings. 2021; 38: 274-279. https://doi.org/10.1016/j.matpr.2020.07.200