Research Article

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

Shikha Parashar\textsuperscript{a}, V.K. Chawla\textsuperscript{b}

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

Article Info

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 kenaf and 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\textsubscript{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.

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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 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]

<table>
<thead>
<tr>
<th>S. NO</th>
<th>Properties</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Density</td>
<td>2.7-2.9 g/cm³</td>
</tr>
<tr>
<td>2</td>
<td>Size of Particle</td>
<td>30-50 nm</td>
</tr>
<tr>
<td>3</td>
<td>Absorption of Oil</td>
<td>13-21 g/100g</td>
</tr>
<tr>
<td>4</td>
<td>Specific Surface Area</td>
<td>5-24 m²/g</td>
</tr>
</tbody>
</table>

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 CaCO₃ 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**

### 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]

<table>
<thead>
<tr>
<th>Sample</th>
<th>Epoxy resin fraction (wt%)</th>
<th>Coir fibres (wt%)</th>
<th>Silk Squash (wt%)</th>
<th>Calcium Carbonate (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>84.3</td>
<td>10</td>
<td>5.7</td>
<td>0</td>
</tr>
<tr>
<td>II</td>
<td>82.3</td>
<td>10</td>
<td>5.7</td>
<td>2</td>
</tr>
<tr>
<td>III</td>
<td>80.3</td>
<td>10</td>
<td>5.7</td>
<td>4</td>
</tr>
</tbody>
</table>

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:**

\[
E_1 = E_f S_f + E_m S_m
\]

\[
\nu_C = \nu_f S_f + \nu_m S_m
\]

**Transverse properties:**

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

Where; \(E_1, E_2\) = Composite’s Longitudinal and Transverse modulus; \(E_m, E_f\) = 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.

\[
E_1 = E_K f K_f + E_C f C_f + E_m S_m
\]

\[
E_2 = \frac{E_m}{1 - \left\{ \sqrt{S_K f} \left[ 1 - \left( \frac{E_m}{E_K f} \right) \right] \right\}} + \frac{E_m}{1 - \left\{ \sqrt{S_C f} \left[ 1 - \left( \frac{E_m}{E_C f} \right) \right] \right\}}
\]

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).

\[
E_2 = \frac{S_f}{\sqrt{E_f}} + \frac{1 - \sqrt{S_f}}{E_m} \left[ 1 - \frac{\theta_m^2}{E_m} \right]
\]

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:

\[
E_1 = E_f S_f + E_m S_m
\]
\[ E_2 = E_m \frac{(1 + \varsigma \eta V_f)}{(1 - \eta V_f)} \]  
\[ \eta = \frac{E_f - E_m}{E_f + \varsigma E_m} \]  
\[ \varsigma = \frac{2L}{D} \]

Where, \( \varsigma \) 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 \( \phi_{\text{max}} \) into it [41]. This comes out to be:

\[ E_2 = E_m \frac{(1 + \eta V_f)}{(1 - \eta \phi_{\text{max}} V_f)} \]  

Where, \( \phi_{\text{max}} \), 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).

\[ \frac{1}{E_2} = \frac{\sqrt{S_f}}{E_f \sqrt{S_f} + E_m (1 - \sqrt{S_f})} + \frac{(1 - \sqrt{S_f})}{E_m} \]

### 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 \( R_{\text{hyb}} \) as given by [47] as:

\[ R_{\text{hyb}} = \frac{\bar{\epsilon}_{\text{HEC}}}{\bar{\epsilon}_{\text{LEC}}} = \frac{\sqrt{\bar{\epsilon}_{\text{HEF}}}}{\sqrt{\bar{\epsilon}_{\text{LEF}}}} \left[ \frac{\delta_h (k_h^q - 1)}{\delta (k_q - 1)} \right]^{\frac{1}{2m}} \]

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

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

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

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 CaCo₃ 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 $1.6 \times 10^{-4} \text{m}$ [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 ($V_f$) | 0.10             | 0.057            |
| Diameter ($D_f$)            | 25 µm            | 15 µm            |
| Length ($L$)               | 160 µm           | 160 µm           |
| Width ($W$)                | 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
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

<table>
<thead>
<tr>
<th>S.NO</th>
<th>Composite Material</th>
<th>Experimental Work [35]</th>
<th>Proposed Work</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>1</td>
<td>Epoxy</td>
<td>84.3</td>
<td>82.3</td>
</tr>
<tr>
<td>2</td>
<td>Coir fiber</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>3</td>
<td>Nano Calcium</td>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Carbonate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Silk Squash</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>5</td>
<td>Kenaf fiber</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6. Results for the sample KC1

<table>
<thead>
<tr>
<th>Models/P</th>
<th>Properties</th>
<th>Chamis Model</th>
<th>Morais Model</th>
<th>Halpin Tsai Model</th>
<th>Modified Halpin Tsai Model</th>
<th>Jacquet's Horizontal Model</th>
<th>RVE</th>
<th>Mean</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transve</td>
<td>Modulus (GPa)</td>
<td>5.84</td>
<td>5.75</td>
<td>6.12</td>
<td>5.29</td>
<td>4.98</td>
<td>6.04</td>
<td>5.67</td>
<td>0.36</td>
</tr>
<tr>
<td>Longitud</td>
<td>Modulus (GPa)</td>
<td>7.42</td>
<td>7.42</td>
<td>7.42</td>
<td>7.42</td>
<td>7.42</td>
<td>7.59</td>
<td>7.45</td>
<td>0.048</td>
</tr>
<tr>
<td>Poisson's</td>
<td>Ratio (µ)</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.32</td>
<td>0.35</td>
<td>0.32</td>
<td>0.270</td>
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</tbody>
</table>

Table 7. Results for the sample KC2

<table>
<thead>
<tr>
<th>Models/P</th>
<th>Properties</th>
<th>Chamis Model</th>
<th>Morais Model</th>
<th>Halpin Tsai Model</th>
<th>Modified Halpin Tsai Model</th>
<th>Jacquet's Horizontal Model</th>
<th>RVE</th>
<th>Mean</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transve</td>
<td>Modulus (GPa)</td>
<td>6.18</td>
<td>6.01</td>
<td>6.28</td>
<td>5.99</td>
<td>5.93</td>
<td>6.42</td>
<td>6.14</td>
<td>0.16</td>
</tr>
<tr>
<td>Longitud</td>
<td>Modulus (GPa)</td>
<td>7.92</td>
<td>7.92</td>
<td>7.92</td>
<td>7.92</td>
<td>7.92</td>
<td>7.98</td>
<td>7.93</td>
<td>0.016</td>
</tr>
<tr>
<td>Poisson's</td>
<td>Ratio (µ)</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.35</td>
<td>0.38</td>
<td>0.36</td>
<td>0.012</td>
</tr>
</tbody>
</table>

The different samples that have been used in this composite are the Kenaf Coir composite (KC1), the Kenaf Coir composite with 2% of CaCO3 (KC2), and the Kenaf Coir composite with 4% of CaCO3 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.
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.

### Table 8. Results for the sample KC3

<table>
<thead>
<tr>
<th>Properties</th>
<th>Chamis Model</th>
<th>Morais Model</th>
<th>Halpin Tsai Model</th>
<th>Modified Halpin Tsai Model</th>
<th>Jacquet’s Horizontal Model</th>
<th>RVE</th>
<th>Mean</th>
<th>Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transverse Modulus</td>
<td>6.73</td>
<td>6.47</td>
<td>6.84</td>
<td>6.24</td>
<td>6.17</td>
<td>6.96</td>
<td>6.57</td>
<td>0.275</td>
</tr>
<tr>
<td>(GPa)</td>
<td>0.16</td>
<td>0.1</td>
<td>0.27</td>
<td>0.33</td>
<td>0.4</td>
<td>0.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitudinal Modulus</td>
<td>8.22</td>
<td>8.22</td>
<td>8.22</td>
<td>8.22</td>
<td>8.22</td>
<td>8.34</td>
<td>8.24</td>
<td>0.033</td>
</tr>
<tr>
<td>(GPa)</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>0.39</td>
<td>0.373</td>
<td>0.005</td>
</tr>
</tbody>
</table>

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

Different Composite Samples

Chamis Model
Morais Model
Halpin Tsai Model
Modified Halpin Tsai Model
Jacquet’s Horizontal Model
RVE

KC1 KC2 KC3
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 CaCO₃ 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 CaCO₃ 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

\( \nu_f, \nu_m \)  
Poisson’s ratio of fiber and matrix, respectively

\( E_{kf}, E_{cf}, E_m \)  
Modulus of kenaf fiber, coir fiber, and matrix, respectively.

\( S_{kf}, S_{cf}, S_{cm} \)  
The volume fraction of kenaf fiber, the Volume fraction of coir fibers.

\( \phi_{max} \)  
Packing fraction

\( \zeta \)  
Reinforcing Efficiency Factor

\( L, D \)  
Length and diameter of fibers, respectively.

\( \text{RVE} \)  
Representative Volume Element

\( \text{NR} \)  
Natural Rubber Composite

\( \text{NFCs} \)  
Natural Fiber Composites

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