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# An extensive analysis of mechanical, thermal and physical properties of jute fiber composites with different fiber orientations

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A R T I C L E I N F O

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A B S T R A C T

The study is aimed to find the effect of orientation of the woven jute fiber on the composites with epoxy matrix on the mechanical properties, thermal properties with different orientations (0°, 15°, 30°, 45°, 60° & 75°) of jute fiber. The mechanical properties such as tensile strength, flexural strength, and impact strength of the prepared composites are obtained with ASTM standard specimens. The composite prepared with 30° orientation fiber has shown better properties compared to the other orientation directions. Differential Scanning Calorimetry (DSC) and Thermogravimetric Analysis (TGA). The work has been carried out to predict the thermal properties of the prepared jute fiber composite specimens. DSC analysis revealed volatilization of the molecules induced the endothermal reaction, and the charring development caused the exothermal reaction. TGA curve peaks showed the removal of hemicellulose, decomposition of cellulose and lignin.

## 1. Introduction

Composite materials are comprised of one or more physically or chemically dissimilar elements on macro/micro/nano-scale irregular phases embedded in a continuous phase to produce a composite. The reinforcement is generally an irregular phase, and it is usually harder and tougher than the matrix material [1]. Three matrix materials are generally used, and they can be polymer, metal, and ceramic. In a polymer matrix composite (PMC), a polymer is a matrix material. In PMC, the discontinuous strengthening phase can

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**Nomenclature**

| | |
|---|---|
| ° | Degree |
| GPa | gigapascal |
| MPa | Megapascal |
| % | Percentage |
| $kg/m^3$ | Kilogram per cubic meter |
| $g/m^2$ | Gram per square meter |
| $mm^3$ | Cubic millimetre |
| mm | Millimetre |
| *kN* | Kilo newton |
| $^\circ C$ | Degree Celsius |
| $^\circ C/min$ | Degree Celsius per minute |
| *mg* | Milli gram |
| *mm/min* | Millimetre per minute |
| *Kg* | Kilogram |
| J | Jules |

*Abbreviations*

| | |
|---|---|
| DSC | Differential Scanning Calorimetry |
| PMC | Polymer Matrix Composite |
| FRP | Fiber-reinforced polymers |
| HY | Hardener |
| LY | epoxy resin |
| UTM | Universal Testing Machine |
| ASTM | American Society for Testing and Materials |
| TGA | Thermogravimetric analysis |

either be particulates or fibrous with high strength and modulus embedded with polymer. The PMC has good mechanical properties and corrosion resistance because fibers are the major weight-carrying elements, while the polymers retain their position and orientation of the fiber.

The fibers which are not man-made or synthetic are called natural fibers. The natural fibers can be extracted from animals or plants. Jute, banana, kenaf, sisal and hemp are natural fibers. Jute is eco-friendly and one of the most important natural, renewable, biodegradable, and non-abrasive fibers [2]. In addition, they exhibit excellent strength, thermal conductivity, inexpensive and low density. This good eco-friendly feature material is widespread in engineering applications like structural and automotive applications. This motivated researchers to examine jute fiber strengthened composites thermal and mechanical properties with different fiber orientations.

The production of natural fibers from jute, flax, sisal have gained quite attention in recent years. Fiber-reinforced polymers (FRP) have been widely applied to different fields of engineering [3]. These materials have also been used in several technical applications, particularly with less weight and high strength and stiffness. Comparing composite materials made of jute and bamboo fibers, jute fiber composites have larger Young's modulus, while bamboo reinforced composites have higher tensile strength values. The length of fiber has a significant role in the tribological behavior of jute fiber composites. The maximum impact, flexural and tensile strengths are found for the 50/50 wt ratio of banana and jute fiber strengthened composites [4]. Mechanical behaviors of Jute-polyester composites are studied with mechanical properties; jute composites record greater flexural stiffness and tensile modulus compared with jute-polyester composite laminates. Natural fiber composites are used due to their susceptibility to moisture absorption and the effect of their thermal and mechanical properties [5]. De-bonding of fiber-matrix at its interface due to outstanding moisture absorption and inadequate adhesion among fiber and polymer. In order to improve the properties of epoxy composites, natural fibers must be reinforced [6].

Munikenche Gowda et al. evaluated the mechanical properties of woven jute fabric-reinforced composites. This study reported the ultimate tangent modulus and tensile strength of the 'as received' jute fiber as 3.75 GPa and 120 MPa. Jute composites fabricated by the vacuum aided resin penetration method were examined [7]. Jute fiber preforms were stacked by following the combination (0/0/0/0), 0/+45°/-45°/0 and 0/90°/90°/0. The volume fraction maintained in all the specimens was 25%. The experimental tensile properties have been compared with the theoretical values. The longitudinal tensile strength of 0/0/0/0 and 0/+45/-45/0 appeared higher than the other directions, i.e., transverse direction. The tensile strength of the 0/90/90//0/laminate composites showed the equivalent tensile properties in both directions [8]. The single screw extrusion molding method was used to prepare polypropylene composites with short jute fibers. The optimization of jute fiber content was followed by concerning the mechanical properties, and the higher mechanical properties were obtained for the composite with 20% fiber content [9].

The mechanical and thermal properties of the jute and glass fiber impregnated epoxy composite was predicted. The jute fibers were mixed with the glass fibers with the expectation of improving the mechanical properties. The various properties such as density, tensile, impact, and flexural properties were found more in the hybridized composites. Short jute fiber reinforced polypropylene (PP) composites were prepared using a single screw extrusion molding. The jute fiber content in the composites is optimized with the extent of mechanical properties and composites with 20% jute showing higher mechanical properties [10]. This research deals with the study of the effect of fiber orientation on mechanical properties.

## 2. Materials and methods

### 2.1. Materials

This study uses epoxy resin (LY-556) as the matrix material to prepare the composites. Hardener (HY-951) is used as a curing agent for epoxy resins. It is also called a catalyst, and it initiates curing. The selection and combination of the hardener and epoxy resins determine the characteristics and fitness of the epoxy composites. Fiber strengthened polymer composites have served a prominent role in a variety of applications for quite a long period for their great specific strength and modulus. Jute fibers are primarily used and economically efficient as all fibers. Cross-plied jute fibers are strengthened with epoxy resin. The resin has a modulus of about 3.42 GPa, and jute fibers have a modulus of about 55 GPa [11]. The resin and jute fibers have a density of 1100 kg/m$^3$ and 1300 kg/m$^3$ correspondingly. The resin and hardener are blended in the weight ratio of 10:1. Jute fabric with an aerial density of 320 g/m$^2$ was used in the composite specimen preparation. Four layers of jute fabric were used for the experiments of all the specimens.

### 2.2. Composite preparation

The resin and hardener are blended by manual stirring in order to dispense the mix in the matrix. Each layer of cross-plied jute fiber mat is cut to the size of 260 mm × 260 mm. The hand-lay-up technique and compression molding process are adopted to produce the composite slabs. The dimensions of the molding are 280 × 280 × 3 mm$^3$ and are made of stainless steel. At first, the releasing agent is applied on the surface of the mold to enable easy removal of the prepared composites after curing the mold.

Jute cross plies are placed one by one in the mold, and the resin with hardener solution is applied to the mold. Subsequently, another five layers of jute cross plies are placed on attaining a 3 mm thickness plate. The resin mixer is used between the layers. Finally, the mold is cured with a load of 20 kg for a day before being taken from the mold. After that, this prepared composite plate is placed in the free air for another day (24 h) after being taken from the mold. The process is repeated for different orientations of the cross plied jute fibers of 0°, 15°, 30°,45°, 60°, and 75°. The prepared composite plates are cut into specimens of the required size suitable for different mechanical and thermal studies.


**Fig. 1.** UTM machine.

### 2.3. Mechanical studies

The samples were tested for mechanical properties as per ASTM standards. The tensile test was conducted at room temperature and with a humidity of 60%. Once the composites are prepared, the samples are subjected to different mechanical studies as per ASTM standards. The testing standards used in this work are ASTM D638 for a tensile test by utilizing Universal Testing Machine (UTM) at a speed of 5 mm/min [12]. The flexural test was conducted at room temperature in the composite specimens and humidity of 60% according to ASTM D790. The flexural strength of the specimen is obtained by using the standard of ASTM D790, and a three-point bending test is carried out [13,14].

The result includes flexural displacement and strength. The test procedure includes placing the test specimen in the UTM and applying load on the specimen until it breaks. Fig. 1 shows the DTRX-30kN model UTM machine with maximum head travel of 600 mm. The impact strength of the specimen is obtained by using an Izod testing machine as per the standard of ASTM D256 with a range of measurement as 0–25 J, as shown in Fig. 2. The prepared test specimens as per ASTM standards are shown in Fig. 3. The specimen is placed on the Izod testing machine and allows the pendulum to break or crack the specimen during the test. The toughness and yield strength of the material are identified using the energy needed to break the specimen.

### 2.4. Thermal studies

The thermal properties of jute fiber composites are analyzed by Differential Scanning Calorimetry (DSC) and Thermogravimetric analysis (TGA) tests. The thermogravimetric analysis identifies the change in the material weight with respect to time or temperature function in a controlled atmosphere. The method can differentiate materials that show the loss or gain of weight due to oxidation or decomposition. The thermal stability of the specimens is determined by increasing the temperature up to 600 °C. This technique characterizes the materials that show the gain or loss of weight due to dehydration, oxidation, and decomposition.

## 3. Results and discussion

### 3.1. Mechanical studies

Mechanical studies include the prediction of the tensile properties, flexural properties, and impact properties. All the tests were conducted in accordance with the ASTM standards.

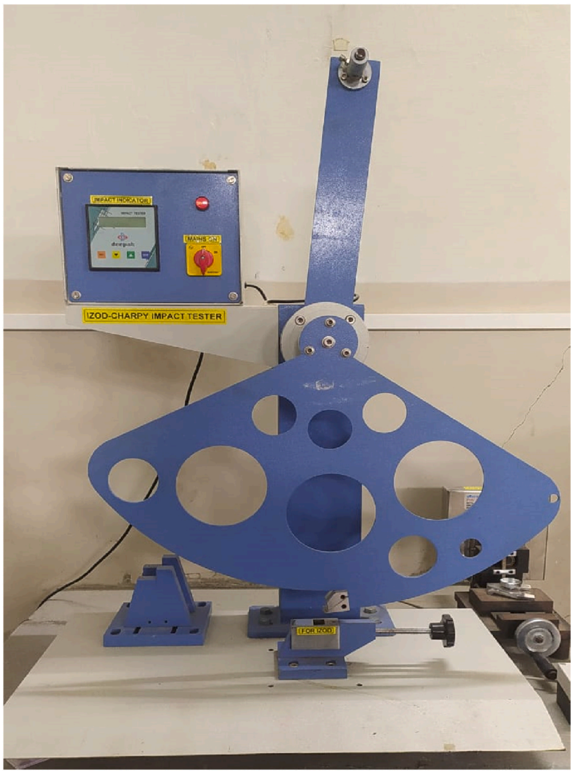


**Fig. 2.** Impact test machine.

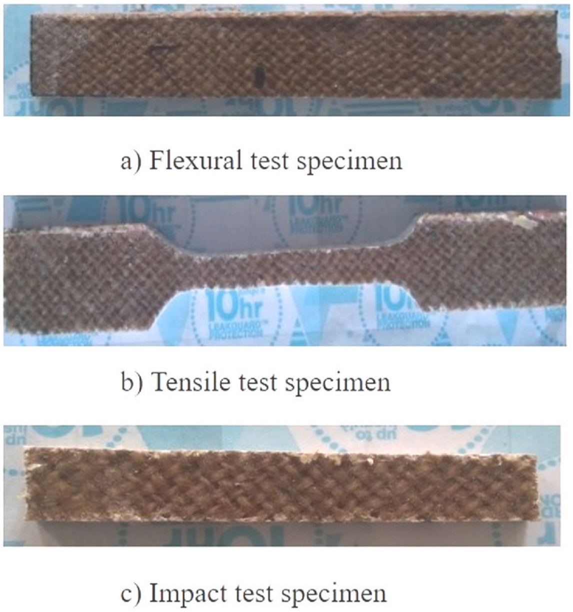


**Fig. 3.** Mechanical test specimens.

**Fig. 4.** DSC set up for thermal analysis of the specimen DSC test is done on NETZSCH STA 449F3 in the range of 30 °C–550 °C as shown in Fig. 4. Dynamic scanning is done by increasing the temperature of the prepared sample at the rate of 10 °C/min. Dynamic scans are performed to come up with the average of the total heat of reaction values. The sample size taken for the analysis is 3.3 ± 1 mg [1].

#### 3.1.1. *Effect of orientation of jute fiber on tensile properties*

The prepared samples are subjected to a tensile test in UTM with a speed of 5 mm/min, which is normally followed for the jute fabric composites by many researchers. The readings are plotted in a graph as shown in Fig. 5. The graph is plotted against applied load in kg and elongation in mm for the various orientation of the specimens. Fig. 6 shows the Flexural strength of jute fiber composites.

Table 1 shows the Comparison of the results of the different orientations of specimens; the maximum load obtained is 270.8 kg in a 30° specimen with an elongation of 2.06 mm. The maximum elongation of 2.48 mm is recorded with an applied load of 162.6 kg in a 75° orientation specimen. The lowest elongation value of 1.42 mm is obtained in a 45° orientation specimen with an applied load of 117.4 kg. It is due to the orientation of the cross-plied jute fiber. It is being observed that the 30° orientation specimen has the highest tensile strength, whereas the 45° specimen has less strength and lesser elongation. The tensile load is decreased, and elongation is increased for the 75° specimen. Because in the cross plied jute fiber composite specimens, longer fibers are subjected to higher tensile load, and shorter fibers are subjected to lesser load.

#### 3.1.2. *Effect of orientation of jute fiber mat on flexural properties*

The flexural strength of the composite plates prepared is shown in Fig. 3. The flexural strength for different orientations of the prepared specimen shows that the 75° orientation gives improved flexural strength than other specimens. The values of flexural strength are gradually increasing up to 75° jute fiber. Further, the jute fiber composite with an orientation of 45° and 60° shows a higher reduction in the flexural strength. The jute fiber with a 75° orientation composite has the largest flexural load. The minimum flexural load is reduced to 53.8 kg. Table 2 shows the comparison of flexural test values of different specimens. The flexural strength of the 30° orientation fibers is appeared to be 45.92 MPa which is the highest value among other combinations. It may be attributed to the reason that fiber pulls out is less in this case. The 30° orientation fiber composite specimen has the higher flexural strength values. The lowest value was recorded for the 45° specimen because the cross-plied fibers deviate from the point loads.

#### 3.1.3. *Effect of orientation of jute fiber mat on impact properties*

An impact test is conducted on the jute fiber composite specimens, and the unexpected load-carrying capacity of the prepared samples is determined by breaking down the specimen. The energy loss prepared composites specimens of different orientations are found using the Charpy test machine. The performance of impact load on prepared composites depends upon the mechanical bonding between the matrix and fiber. The impact load of different specimens is shown in Fig. 7. The recorded impact strength values are shown in Table 3. The 0° orientation specimen withstands the impact load of 0.422 J, and the 30° orientation specimen withstands the impact load of 0.814 J. The cross plies placed at 30° orientation withstand the high impact loads.

### 3.2. *Thermal studies*

#### 3.2.1. *Thermogravimetric analysis*

The TGA provides information on the weight loss of composites as a function of increasing temperature. The weight loss in composites happens due to the decomposition of cellulose, hemicellulose, and lignin constituents during heating. Higher decomposition temperatures provide greater thermal stability. The TGA results of different orientation jute fiber composites are illustrated in Fig. 8. In the 0° oriented jute fiber composite, initial weight loss occurs at the low temperature of 73 °C corresponds to the solvent removal in the jute matrix composites. The heaviest weight loss (81.6%) happens at 336.31 °C due to the degradation of epoxy resin. Higher temperatures are required for subsequent degradation. At the temperature of 547.31 °C final degradation occurs (17.58%).

In the 15° oriented jute fiber composite, initial weight loss occurs at the low temperature of 63.6 °C corresponds to the solvent

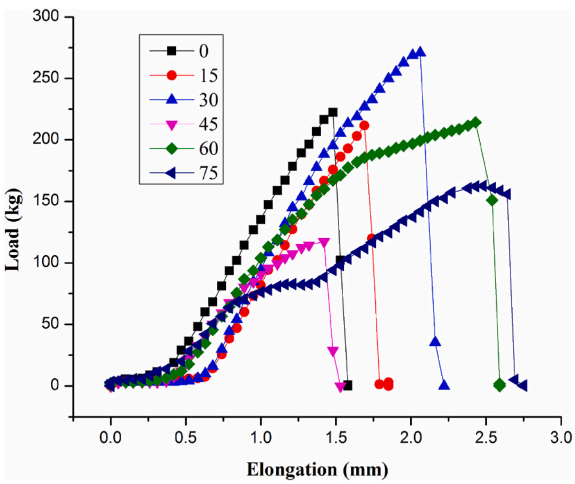


**Fig. 5.** Load versus elongation of jute fiber composite.

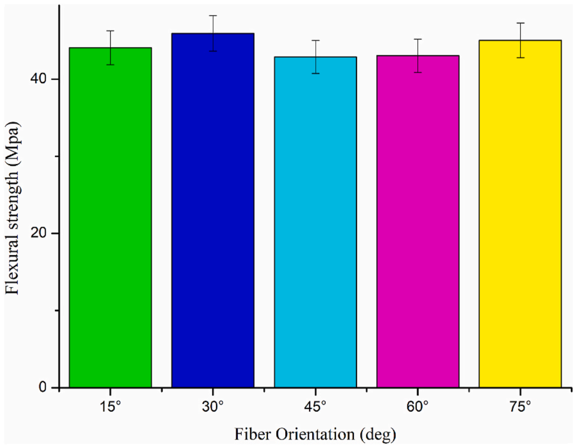


**Fig. 6.** Flexural strength of jute fiber composites.

**Table 1**
Comparison of tensile test results.

| Fiber Orientation | Maximum Elongation (mm) | Applied Load (kg) |
|---|---|---|
| 0° | 1.48 | 222.4 |
| 15° | 1.69 | 211.6 |
| 30° | 2.06 | 270.8 |
| 45° | 1.42 | 117.4 |
| 60° | 2.43 | 214.1 |
| 75° | 2.48 | 162.6 |

**Table 2**
Comparison of flexural test values.

| Fiber Orientation | Maximum Displacement (mm) | Maximum Load (kg) | Flexural Strength (MPa) |
|---|---|---|---|
| 15° | 4.86 | 55.1 | 44.08 |
| 30° | 4.92 | 57.4 | 45.92 |
| 45° | 5.02 | 53.6 | 42.88 |
| 60° | 5.6 | 53.8 | 43.04 |
| 75° | 5.97 | 56.3 | 45.04 |

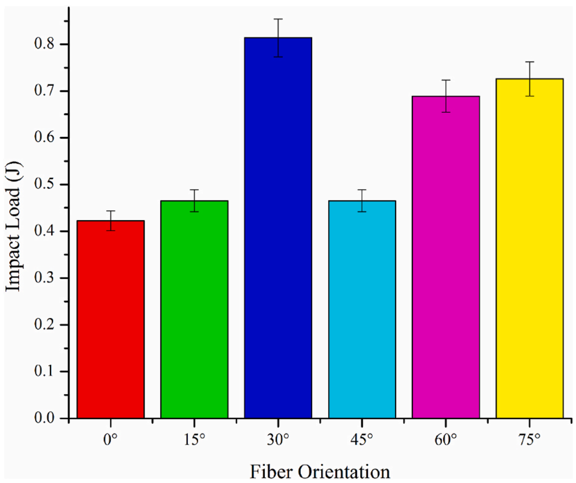


**Fig. 7.** Impact Strength of different orientations of jute fiber.

**Table 3**
Comparison of impact strength of different specimens.

| Fiber Orientation | Impact Load (J) |
|---|---|
| 0° | 0.422 |
| 15° | 0.465 |
| 30° | 0.814 |
| 45° | 0.465 |
| 60° | 0.689 |
| 75° | 0.726 |

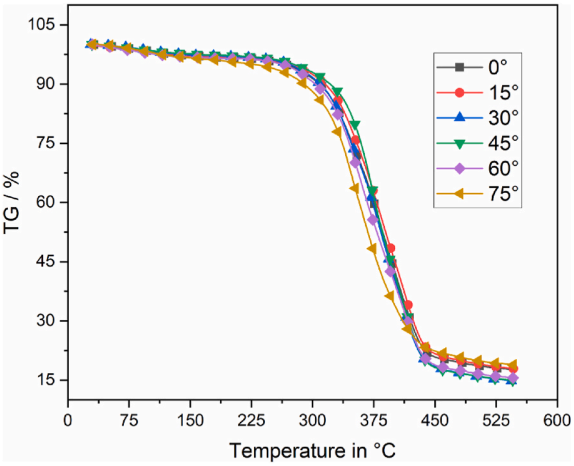


**Fig. 8.** Comparison of Weight (%) versus Temperatures of jute fiber composites.

removal in the jute matrix composites. The significant weight loss (81.21%) happens at 342.37 °C due to the degradation of epoxy resin. Higher temperatures are required for subsequent degradation. At the temperature of 547.46 °C final degradation occurs (17.84%).

In the 30° oriented jute fiber composite, initial weight loss occurs at the low temperature of 83.17 °C corresponds to the solvent removal in the jute matrix composites. The heavier weight loss (80.9%) happens at 336.77 °C due to the degradation of epoxy resin and jute fibers. Higher temperatures are required for subsequent degradation. At the temperature of 547.39 °C final degradation occurs (14.74%).

In the 45° oriented jute fiber composite, initial weight loss occurs at the low temperature of 79.25 °C corresponds to the solvent removal in the jute matrix composites. The significant weight loss (80.19%) happens at 351.27 °C due to the degradation of epoxy resin and jute fibers. At the temperature of 547.15 °C final degradation occurs (14.89%).

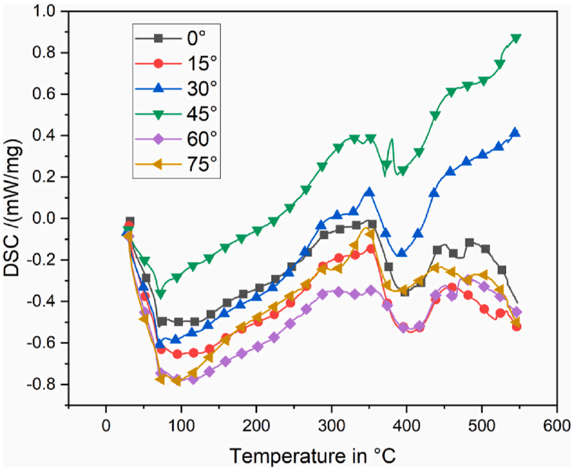


**Fig. 9.** DSC curves for jute fiber composites.

In the remaining specimens (60° & 75° orientation), fibers have the initial weight loss at 60.1 °C & 72.41 °C corresponds to the solvent removal in the jute matrix composites. Higher temperatures are required for subsequent degradation. At the temperature of 547.68 °C final degradation occurs (15.58% & 18.78%). Among the six different types of specimens, the 30° orientation specimen has the highest degradation at the highest temperature. The highest degradation temperature is more or less equal in all types of specimens because the compositions are the same. With respect to the orientation, the thermal behavior of composites will change due to the volume of the matrix occupied in the fiber mat.

### 3.2.2. DSC analysis

The heating of the fiber in fiber-reinforced composites releases or absorbs thermal energy. This phenomenon is analyzed by doing a DSC analysis. Decomposition of fibers at various temperatures causes a series of endothermic and exothermic reactions. The thermal phase change of the fiber is observed with the peaks of the endothermic and exothermic. An endothermic reaction absorbs heat, whereas an exothermic reaction releases heat. Composite melting, phase change, evaporation, dehydration, and pyrolysis evidences are obtained in endothermic reactions. Exothermic reactions explain crystallization, oxidation, combustion, and decomposition. The thermograms of the different orientations of prepared specimens are shown in Fig. 9. From Fig. 9, it is seen that all samples make one broad endothermic peak between the temperatures of 10–120 °C. This peak was matched to the release of moisture by the fiber.

The region between 120 and 250 °C displays no exothermic or endothermic reactions, revealing thermally steady composites. It also shows a sharp endotherm at 394.31 °C for 0° orientation specimen and a corresponding melting temperature of 73.89 °C because of additives present in the matrix. In the 30° orientation specimen, a sharp endotherm at 392.65 °C and corresponding melting temperature of 72.14 °C. In a 75° orientation specimen, a sharp endotherm moved to 384.39 °C, and the corresponding melting temperature moved to 75.48 °C. Slight changes in the temperatures are noticed because only the orientation of cross plies changes, and composition is the same. The exothermic peak appeared between the temperature ranges of 300–400 °C. The exothermic peak disappeared in the 0° and 75° orientation specimen. The previous research has testified that lignin degrades at a temperature around 200 °C. Therefore, hemicellulose and cellulose decay at higher temperatures. Hence the exothermic peak is higher than 200 °C because of the thermal degradation of lignin, hemicellulose, and cellulose constituents.

## 4. Conclusion

- The jute fiber fabric reinforced epoxy laminated composites are fabricated by changing the orientation of jute fiber.
- A maximum tensile load of 270.8 kg is found for laminated composites with 30° orientation when compared to other composites. It is due to the load distribution of the fiber in the prepared composites being uniform.
- Maximum flexural strength is obtained for laminated composites with 30° orientation when compared to other composites. It is due to the fibers transferring the load evenly in the entire composites, and fibers absorb a higher bending load.
- The fibers are placed in a composite with respect to each other, and they can bear a larger flexural load. The fiber with 30° oriented laminated composites possesses the high impact work done of 0.814 J. The jute fiber orientation is highly influencing the impact properties.
- The thermal properties are analyzed with TGA and DSC. The degradation temperature is more or less the same for all the specimens due to the compositions, which are the same in all the specimens. A slight variation of the endotherm temperatures is noted across all the specimens.

## Future scope

The hybridization of the jute fabric composite with different artificial fabrics such as glass fiber, carbon fiber, Kevlar fiber, etc., may be tried for better mechanical properties of the composites. Changing the density of the jute fabric for enhanced property may be conducted. The addition of abrasive particles into the matrix may be tried for better mechanical properties.

## Author statement

**Gukendran Rangasamy**: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing – review & editing; **Sambathkumar Mani**: Conceptualization, Investigation, Resources, Data curation, Writing - review & editing, Supervision, Project administration; Funding acquisition; **Sasikumar Kondayampalayam Senathipathygoundar Kolandavelu**: Conceptualization, Methodology, Writing - review & editing, Supervision, **Mohammad S. Alsoufi**: Methodology, Data curation, Writing - review & editing; **Ahmed Mohamed Mahmoud Ibrahim**: Methodology, Data curation, Writing - review & editing; **Suresh Muthusamy**: Methodology, Data curation, Writing - review & editing. **Hitesh Panchal**: Methodology, Data curation, Writing - review & editing; **Kishor Kumar Sadasivuni,** Methodology, Data curation, Writing - review & editing **Ammar H. Elsheikh**: Methodology, Data curation, Writing - review & editing;

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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