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EFFECTS OF FIBRE ORIENTATION ON TENSILE PROPERTIES OF JUTE FIBRE REINFORCED COMPOSITES

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Abstract: Natural fibres have many advantages over synthetic fibres such as low cost, low density and biodegradable. Jute fibre is an example of natural fibre that is affordable and easily attainable. In this study, the effects of fibre orientation on the mechanical properties of jute reinforced epoxy composite (JFRC) were analysed. JFRCs were fabricated using hand lay-up method with the fibre orientation of (0°/0°/0°/0°), (0°/45°/0°/45°), and (45°/45°/45°/45°). The tensile strength, yield strength and elongation of the composites were investigated using the universal tensile machine. Samples with 0°/45°/0°/45° orientation shows the highest tensile strength of 32.079 GPa, while the sample with fibre orientation 0°/0°/0°/0° shows the lowest tensile strength of 30.249 GPa.

Keywords: Green composite; Natural fibre; Tensile strength; Orientation

1. Introduction

In recent years, the search for a more sustainable and environmentally friendly material has been an area of interest among many material scientists and engineers (Vinod et al., 2021). Known as the "wonder material" that revolutionized the materials industry, composites offer a remarkable strength-to-weight ratio with remarkable stiffness properties which eventually replaced conventional materials like metal and wood in numerous sectors like construction, electrical, automotive and telecommunication (Gopinath et al., 2014). Composite materials are made out of the combination of two or more materials to obtain a different combination of properties (Mazumdar, 2001). Over the years, composite materials have been increasingly popular among manufacturers and consumers. In order to meet the demand for composite materials while reducing negative environmental impacts, many are looking into the use of natural composite fibres thanks to our ever-developing technological advancements (Praveena et al., 2022).

Natural fibres can be obtained from both plants and animals. The most common types of natural fibres are natural cellulose fibre such as jute, hemp, banana, kenaf, flax, oil palm fruit bunch and sisal (Keya, et al., 2019). These fibres are classified depending on the different part of the plants. It is being extracted from stalk, stem, bast, lead and fruit. Vine, flax, rattan, ramie and jute fibres are examples of bast fibres that are taken out from the outer cell layers of the stems of plants (Jeyapragash et al., 2020). Jute (corchorus-capsularis) is an example of bast fibres that is commonly used reinforcing material in polymer composite (Bindusara et al., 2018). Commonly grown in countries like Vietnam, Thailand, Myanmar, India, China, Taiwan, Cambodia, Nepal and Bangladesh, jute fibre provides good insulation, good strength to weight ratio, good thermal and mechanical properties and high aspect ratio (Keya, et al., 2019). Jute fibre composites are used in many applications like in the automotive industry, doors, windows, floor tiles, packing material like bags and water pipes (Abilash and Sivapragash, 2013).

Although the use of jute fibre in reinforced composite could potentially replace synthetic polymer composites, there are a few disadvantages using natural fibres which could affect the tensile strength of the material. The empty space in jute fibre, known as lumen, could potentially initiate failure in the composite and cause a defect (Hossain et al., 2013). As the mechanical properties of a single layer of jute fibre reinforced composite is weak, several layers of jute fibre laid in different orientation may significantly improve the tensile strength. Therefore, this study is aimed to investigate the effects of woven jute fibre orientation on its tensile properties.

2. Materials and Methods

2.1 Chemical Treatment

Jute fibres used in this study were purchased in plain woven mat form with 0.78 mm thickness. The fibres were chemically treated with 5wt% sodium hydroxide (NaOH) as surface modification to remove lignocellulosic contents. The fibre mats were immersed in the alkaline solution for 24h before being washed and neutralised thoroughly with distilled water. The fibres were then left to dry to remove any moisture from the treatment. **Figure 1** shows the jute fibre mat before and after treatment.

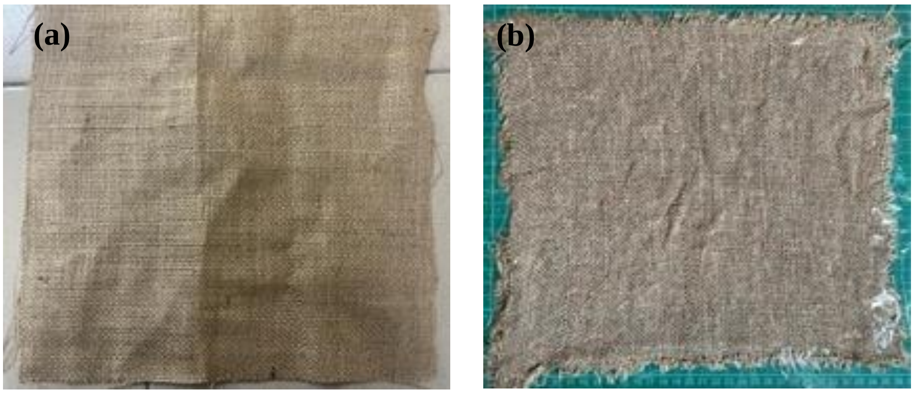
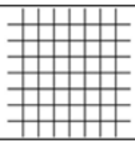
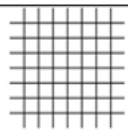
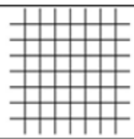
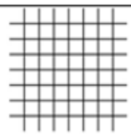
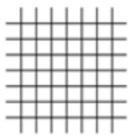
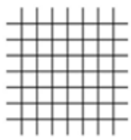


Figure 1. Plain-woven jute fibre mat (a) before and (b) after subjected to NaOH treatment

2.2 Composite Fabrication

Three samples of jute fibre reinforced epoxy composites were fabricated with different orientation: sample A (0°/0°/0°/0°), B (0°/45°/0°/45°), and C (45°/45°/45°/45°) as shown in **Table 1**. Each composite has four layers of plain-woven jute fibre mat and epoxy resin was used as the matrix. Samples were fabricated via hand lay-up method and left to cure at room temperature for 48 hours. The fabricated composites were then cut into 250 mm x 25 mm (length x width) with a thickness of ±4 mm in accordance to ASTM D3039.

Table 1. Orientation and sequence of fibre in composite samples

Sample	Average thickness (mm)	Orientation sequence			
		Ply 1	Ply 2	Ply 3	Ply 4
A (0°/0°/0°/0°)	4.20				
B (0°/45°/0°/45°)	3.98				
D (45°/45°/45°/45°)	4.07				

2.3 Tensile Test

The tensile test was conducted upon the composite samples based on ASTM D3039. An aluminium tab with an area of 25 mm x 25 mm was placed at both ends of the grip area of the specimen to ensure secure gripping and avoid slippage. The tensile test was repeated three times for every sample to obtain an average result.

3. Results and Discussion

3.1. Tensile Strength

Tensile test was conducted to determine the effects of different orientation on the tensile properties of the composite samples. **Figure 2** shows the tensile strength of sample A (0°/0°/0°/0°), B (0°/45°/0°/45°), and C (45°/45°/45°/45°). Sample B (0°/45°/0°/45°) shows the highest tensile strength of 32.079 GPa, followed by sample C (45°/45°/45°/45°) and A (0°/0°/0°/0°), with 30.511 GPa and 30.249 GPa, respectively.

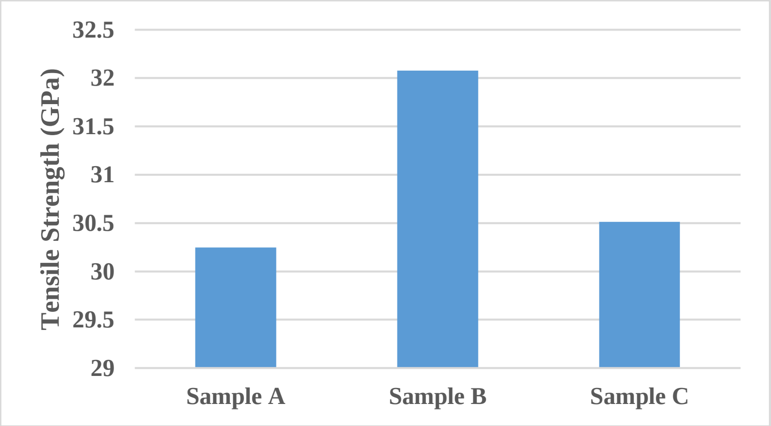


Figure 2. Tensile strength of composite samples as affected by orientation

The high tensile strength in samples aligned at (0°/45°/0°/45°) can be associated with the uniaxial testing condition. Tensile test was conducted uniaxially where the fibres are aligned parallel to the loading condition. When load is applied, the 45° plies of the laminates causes resistance in the 45° direction, whereas the 0° plies cause resistance in the 0° direction. Hence, when combined in a single plate, these plies enhance the tensile strength in both directions. On the other hand, sample C (45°/45°/45°/45°) and A (0°/0°/0°/0°) shows the lowest and similar tensile strength value with percentage difference of 0.9% from each other. The reason for the reduced tensile strength is also due to the physical morphologies of the fibres and the fracture surfaces of the composites. The reason behind the poor tensile strength can also be justified by the fibre-matrix interfaces and defects inside the jute fibre which primarily dominated the tensile strength of the composite. The lack of bonding between the fibre-matrix interface and the voids significantly degrades the strength of the composite (Hossain, et al., 2013).

3.2. Elongation

Ductility is the measure of the amount of deformation a material can withstand without breaking. The percent of elongation describes the permanent plastic deformation of a material before failure and is measured by the total percentage increase in the length of a specimen during a tensile test (Askeland et al., 2003). The extensometer in the universal tensile machine was used to measure the original gauge length and the final gauge length of the specimen after necking. **Figure 3** represents the percentage of elongation of sample A (0°/0°/0°/0°), B (0°/45°/0°/45°), and C (45°/45°/45°/45°).

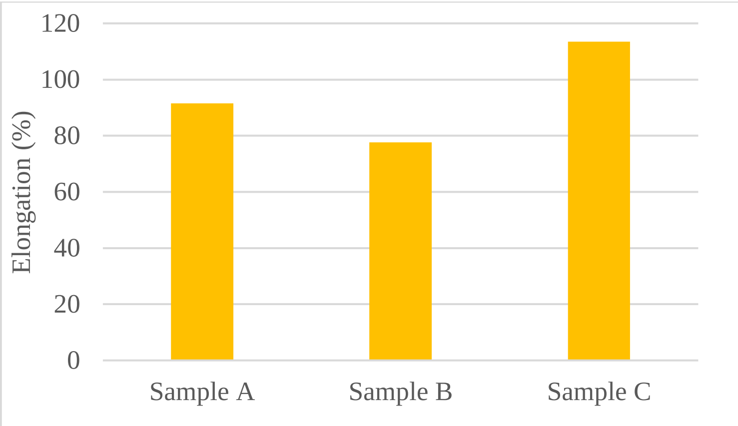


Figure 3. Elongation of composite samples as affected by orientation

Sample A (0°/0°/0°/0°) has the elongation of 91.5%, sample B (0°/45°/0°/45°) has elongation of 77.6%, while sample C (45°/45°/45°/45°) has an elongation of 113.5%. Despite having low tensile strength, sample C shows the highest percentage of elongation. This can be attributed to the poor interfacial bonding between the fibre and matrix that prevent some of the fibres from breaking during the test. Consequently, the sample exhibits a more elastic behaviour (Bindusara et al., 2018). Likewise in a simulation that was done from the literature, the composites with fibre orientation sequence (45°/90°/0°/0°/90°/45°), (45°/-45°/0°/0°/-45°/45°) and (90°/-45°/0°/0°/-45°/90°) had higher percentage of elongation compared to composites with the fibre orientation sequence of (0°/0°/0°/0°/0°/0°) and (90°/0°/90°/0°/90°/0°) (Ahmad & Bajpai, 2018). The high percentage of elongation signifies that there is a low resistance to the applied load offered to the laminate composites. This is also due to the fact that the orientation of the fibre is in a transverse direction which contributes less in the strength of composite in the longitudinal direction.

On the other hand, sample B and A shows lower percentage of elongation, about half the elongation of sample C. This can be associated with the greater longitudinal direction of fibres in sample A and B in comparison to sample C, which results in a maximum resistance that is offered to the fibres in longitudinal direction. The results obtained are similar to a study that was conducted on sisal fibre reinforced epoxy composite, where the specimen with 90° fibre orientation exhibits the highest percentage of elongation, followed by 45° fibre orientation and lastly 0° fibre orientation (Kumaresan, et al., 2015). Therefore, it can be said that the low value in percentage of elongation of a composite represents a high resistance to the applied load.

3.3 Young's Modulus

Young's modulus, also sometimes knows as modulus of elasticity, is the measure of the ability for a material to withstand changes in length under tension or compression. It is used to identify the stiffness of an elastic material and is defined as the ratio of stress applied to strain. Generally, material with a high Young's modulus tend to be brittle whereas material with low Young's modulus tend to be ductile (Chung, 2010). The Young's modulus of sample A with the fibre orientation sequence of (0°/0°/0°/0°) is 31.485 MPa, while sample B (0°/45°/0°/45°) and C (45°/45°/45°/45°) has the Young's modulus of 41.547 MPa and 26.42 MPa, respectively. **Figure 4** shows the results obtained for Young's modulus of all the composite samples.

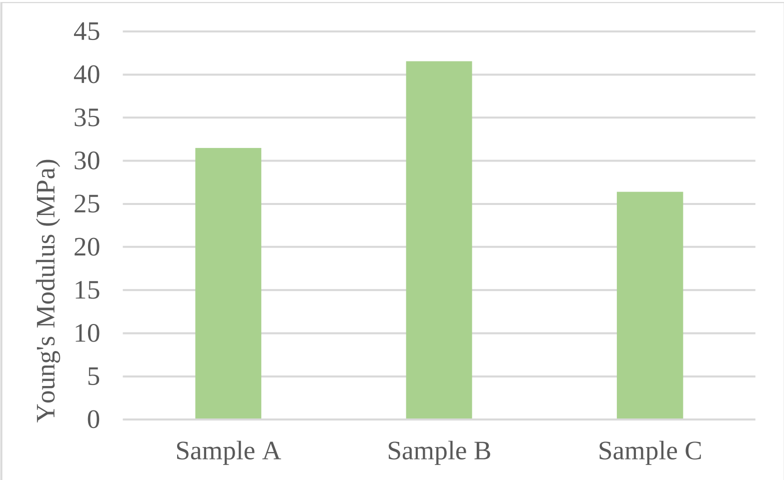


Figure 4. Young's Modulus of composite samples as affected by orientation

The results obtained for the Young's modulus of each composite has a similar trend to the tensile strength results. Sample B has the highest Young's modulus, followed by sample A, and C. This could be associated with the elongation of the samples. Commonly, Young's modulus of a material is inversely proportional to its elongation. In this study, sample B has the lowest percentage of elongation, which is 77.6% which explains the high Young's modulus value. This further indicate sample B with 0°/45°/0°/45° orientation to be stiffer, more brittle and less deformable which breaks at low strain.

Meanwhile, sample C shows the lowest Young's modulus value as it has the highest percentage of elongation. This indicates sample C with 45°/45°/45°/45° orientation to be more elastic than other samples. The sample with the lowest elongation correspondingly have the highest Young's modulus, which is sample B (41.547 MPa) which makes it most brittle in comparison to the other samples where else sample C has the lowest Young's modulus (15.188 MPa) which makes it the most ductile.

4. Conclusion

The objective of this research is to study how the fibre orientation sequence affects the tensile properties of a jute fibre reinforced epoxy composite. The outcome of the tensile test shows that the sample B (0°/45°/0°/45°) had the highest tensile strength at 32.079 GPa followed by sample C and A. One of the greatest advantages of using fibre reinforced composite is that their properties can be tailored to meet different types of loading conditions. Therefore, the jute fibre reinforced epoxy composite with different orientation sequence provides different tensile properties which apply for various types of applications. For instance, in applications where a strong material is needed which does not require the material to be elastic, sample B would be more favourable as it has high tensile strength although it has small elongation. Likewise in applications that focus on the ductility of a material, sample C is preferred due to its ability to stretch before breaking.

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