FIBRE SELECTION VIA ANALYTIC HIERARCHY PROCESS AND FIBRE ORIENTATION IN KENAF/GLASS THERMOPLASTIC COMPOSITES FOR FRUIT PICKER POLE

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ABSTRACT

This study preliminarily investigates suitable natural fibres for blending with glass fibres to create durable, high-performance hybrid composites. The analytical hierarchy process (AHP) was used to select the best fibre for enhancing hybrid natural/synthetic composites designed for fruit picker poles. Flexural tests were conducted on kenaf/glass fibre mesh-reinforced Acrylonitrile Butadiene Styrene (ABS) composites to evaluate bending performance under different stacking sequences. The composites, prepared by hot press compression molding, featured stacking sequences of 0°/90°/0°/90°, 0°/+45°/-45°/0°, 0°/+45°/90°/-45°, and 0°/0°/0°/0°. Results showed that stacking sequence significantly influences flexural properties, allowing tailored material design for engineering applications. The 0°/0°/0°/0° sequence exhibited the highest bending strength and modulus, 65.76 MPa and 1657.57 MPa, respectively, while the 0°/+45°/90°/-45° sequence showed the lowest, at 52.05 MPa and 908.69 MPa. These findings highlight stacking sequence optimization as a practical method to improve performance and sustainability in fruit picker poles. The stacking sequence impacts flexural properties because fibres aligned at 0° carry bending loads more effectively, resulting in higher strength and stiffness. The 0°/0°/0°/0° sequence maximizes fibre alignment with the load, hence the best flexural performance. Mixed angles distribute stress in multiple directions but reduce load-bearing efficiency along the bending axis, lowering strength and modulus. Optimizing the stacking sequence is therefore key to tailoring composite performance for specific engineering applications like durable fruit picker poles.

Keywords: *AHP; Fibre stacking sequence, flexural behaviour, thermoplastic, hybrid biocomposites*

1.0 INTRODUCTION

Acrylonitrile Butadiene Styrene (ABS) [1] exhibits exceptional mechanical characteristics and reduced weight owing to the amalgamation of co-monomers, playing a crucial role in enhancing its overall properties [2]. The inclusion of polyacrylonitrile components promotes polar interactions among polymer chains, leading to enhanced mechanical strength compared to pure polystyrene. The presence of polybutadiene components imparts toughness, attributed to their elastomeric nature. Furthermore, the polystyrene content provides a glossy finish and enhances electrical insulating properties. This combination of characteristics makes ABS well-suited for use in automotive parts, electronic devices, and urban infrastructure. In addition, ABS offers further benefits, including better chemical resistance, high toughness, dimensional stability, and ease of manufacturing [3].

However, while ABS provides strength and toughness, it does not inherently address the need for lightweight and eco-friendly materials [4]. Natural fibres present a promising alternative due to their low density, high economic value, and renewable nature, but they suffer from limitations, including inconsistent mechanical strength, stiffness, and poor performance in harsh environments [5]. Furthermore, multiple investigations have demonstrated that inadequate mechanical strength and stiffness of natural fibres have become limitations that retard the broad applications of such materials [6,7]. Poor performance in harsh environments and exceeding load safety factors were additional causes of mechanical failure in material design [8]. Due to these demerits, early failure would occur significantly below their expected service life. Today, efforts have been made to tackle the demerits of natural fibres. Optimising fibre stacking sequence and hybridising fibres in composites could be one of the viable ways to overcome these problems [9]. Due to concerns regarding mechanical performance, availability, and density, the study aims to select the most suitable natural fibre material from seven options to combine with glass fibre mesh and create eco-friendly hybrid FRP composites for a fruit picker pole. By combining the advantages of both natural and glass fibres, researchers can develop lightweight, durable, and eco-friendly hybrid fibre-reinforced polymer composites [10]. Furthermore, optimizing fibre orientation and stacking sequences, particularly in kenaf fibre-reinforced ABS composites, is essential to achieving balanced flexural properties in multiple directions [11]. Despite the recognized potential of natural fibres like kenaf, there remains a research gap concerning the effects of different fibre stacking arrangements on the flexural performance of these composites [5]. This investigation seeks to fill that gap and contribute to the design and engineering of high-performance, eco-friendly composites for practical applications such as fruit picker poles [12]. The study employed the analytical hierarchy process (AHP) methodology to evaluate and determine the most suitable natural fibre for combining with glass fibre in the automotive component applications. The software "Expert Choice 11.5" was employed to determine the optimal natural fibre for hybrid composites. The selection process was based on six criteria: tensile strength, Young's modulus, density, and availability. Five natural fibres were evaluated as alternatives, and a pairwise comparison matrix (PCM) was created to assess their performance based on the established criteria. The proposed materials were ranked based on several factors, and an overall ranking was determined by synthesising the PCM data. The consistency ratio was ensured to be below 0.10 (10%) to justify the judgments. Sensitivity analysis was conducted to simulate results and adjust the weight of each criterion. With these viable solutions, researchers may create an ideal composite structure with decent mechanical performance.

Hybridisation with glass fibre mesh, which is composed of interwoven glass fibre strands, is a durable and flexible material that can be utilised in thermoplastic composites [13,14]. Considerations regarding the positioning of the glass fibre mesh, whether on the top or bottom side during fabrication, are crucial to optimise its performance. This effort could provide numerous advantages in composite development, making it a favoured choice for reinforcing surfaces and ensuring the long-lasting performance of fibre-reinforced polymer composite in fruit picker poles [14]. Additionally, fibre orientation has been identified as a factor that affects the material properties. Reiner [15] found that the highest strength in orthotropic composites is reached with a balanced fibre orientation of ±45°, 0°, and 90°. Quasi-isotropic is a term used in the context of composite materials to describe a layup or arrangement of reinforcing fibres that provides similar mechanical properties in multiple directions [16]. In a quasi-isotropic composite, the reinforcing fibres are oriented in a way that offers comparable strength and stiffness characteristics in several principal directions [17]. The mechanical properties are the same in all directions in a truly isotropic material. Achieving isotropy in composite materials can be challenging due to the anisotropic nature of the reinforcing fibres. However, a quasi-isotropic layup seeks to approximate isotropy by strategically arranging the fibres in different orientations, often at 0°, 90°, and ±45 ° angles [18]. This configuration provides the composite materials with balanced material properties in multiple directions. This ideal quasi-isotropic pattern provides composites with equal and balanced strength and stiffness, regardless of the loading direction.

According to literature studies, it can be postulated that the orientation and hybridisation of fibre and glass fibre mesh in composite materials have a significant impact on their flexural properties. This investigation builds upon a vast corpus of research in the field of composite materials, encompassing studies on various fibre types, hybrid composites, and layering sequences. The investigation is supported by a comprehensive range of scholarly works [19–22] that collectively emphasise the high potential of kenaf fibre as a reinforcing material for composite materials, providing a firm foundation for this research investigation. Although natural fibres such as kenaf have demonstrated significant potential, their structural applications remain limited due to inconsistent mechanical performance. Until today, the effect of different fibre stacking sequences and orientations on the flexural properties of kenaf fibre-reinforced ABS composites has not been reported. Therefore, this study aims to conduct a thorough analysis of how various stacking arrangements affect the flexural performance of these composites. It is anticipated that the findings will contribute to enhancing composite design and engineering, particularly for use in fruit picker poles.

2.0 MATERIAL AND METHODOLOGY

2.1 Applications of the AHP for Fibre Selection

Material selection is a critical process that involves identifying the most suitable fibre to fulfil the specific requirements of a given application. This process ensures that the chosen material aligns with the desired properties necessary for optimal performance. One of the most effective methods for evaluating and comparing material options is the AHP. It is a systematic decision-making framework designed to simplify complex choices by decomposing them into a clear hierarchical structure. This approach is especially valuable for selecting materials in natural fibre composite applications, as it enables a comprehensive evaluation of multiple criteria such as mechanical strength, environmental impact, cost-effectiveness, and sustainability in an organised and methodical manner.

As depicted in Figure 1, the evaluation is arranged in a hierarchical model. The top tier represents the overall decision goal or objective. The middle tier comprises the criteria, which are the crucial factors influencing the decision; each criterion is assigned a relative weight to signify its importance. The bottom tier contains the alternatives, which are evaluated against each criterion. Decision makers perform pairwise comparisons among the criteria, systematically assessing each factor relative to the others. These comparisons can be based on subjective inputs, such as expert opinions, or objective measurements derived from data. This structured process fosters a rigorous, transparent, and consistent prioritisation, ultimately facilitating the selection of the most suitable alternative.

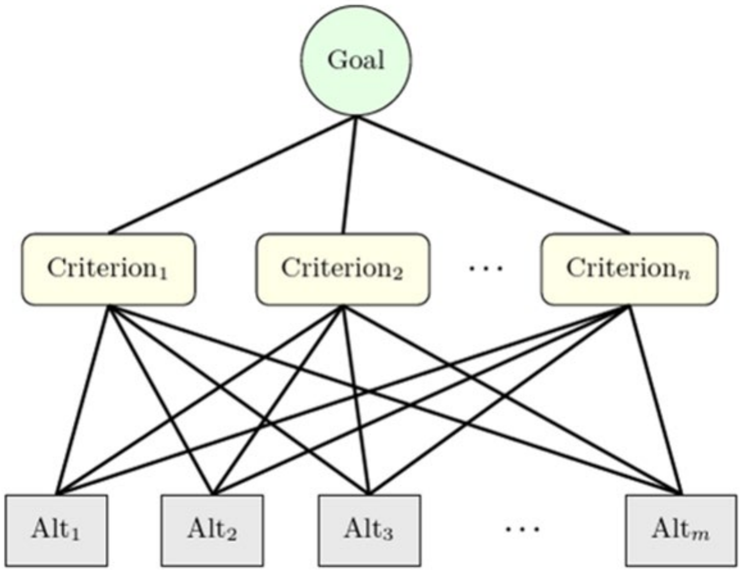


Figure 1: An example of a Generic Three-Layer AHP Hierarchy

The first step in applying the AHP is to clearly articulate the goal or objective and identify a set of alternatives, each defined by specific criteria or attributes for evaluation. Once this hierarchical framework is established with the goal at the top, criteria at the intermediate levels, and alternatives at the bottom in order the decision makers can conduct systematic pairwise comparisons. These comparisons involve evaluating two elements at a time based on their influence on the element above them in the hierarchy. Such evaluations may rely on objective data or subjective judgments reflecting the relative importance of each element. Given the potential biases and uncertainties in subjective assessments, conducting sensitivity analysis is crucial to verify the stability and reliability of the results.

AHP translates subjective judgments into numerical values, facilitating consistent and quantitative analysis across diverse, often incomparable criteria. This process generates priority weights for every element within the hierarchy, enabling logical and coherent comparisons. Ultimately, a numerical priority score is calculated for each alternative, indicating its relative effectiveness in achieving the overall goal. This creates a transparent and structured framework to evaluate options and identify the best course of action.

AHP is highly versatile, suitable for individuals making straightforward decisions as well as interdisciplinary teams tackling complex challenges. It proves especially valuable when decision factors are difficult to quantify or compare directly, or when collaboration involves differing viewpoints, terminologies, or expertise. By assigning weighted priorities to various criteria, AHP allows for rigorous quantitative comparison of material alternatives, ensuring that decisions are informed and balanced across technical and economic dimensions.

In the context of natural fibre materials, AHP further enhances the selection process by accounting for the intrinsic variability of these fibres. This ensures the optimal combination of properties is identified for a specific application, supporting sustainable and high-performance outcomes. Overall, AHP stands as a powerful and effective tool for addressing complex material selection problems, particularly in industries striving for sustainability and excellence in material performance.

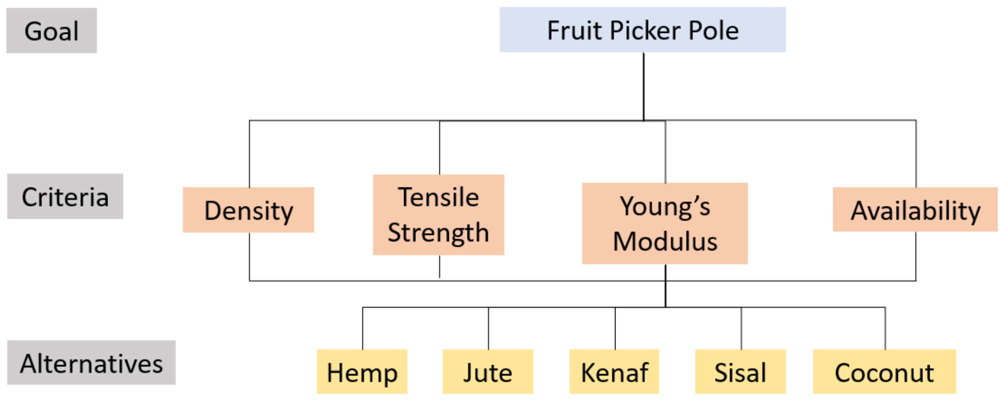


Figure 2: Hierarchical structure used in the AHP process for selecting natural fibres based on mechanical, physical, technical, and environmental criteria.

The primary objective of this project is to design a structural pole using natural fibre materials. To ensure the selection of the most suitable natural fibre, four key evaluation criteria have been identified, as illustrated in Figure 2. These criteria encompass mechanical, physical, technical, and environmental properties, each of which plays a crucial role in determining the feasibility and performance of the selected fibre material. Based on the defined selection criteria, six natural fibres have been identified as the most promising candidates for this application, including hemp, flax, kenaf, jute, sisal, and coconut. Each of these fibres possesses unique characteristics that make them viable contenders for structural applications, particularly in lightweight, high-strength composite materials. The next phase of this project involves evaluating these fibres in greater detail to determine the optimal choice for the proposed pole design.

There are four primary clusters or groups: Goals, Criteria, Sub-Criteria, and Alternatives. In the Goal cluster, the variable is the pole. The Criteria cluster comprises four primary attributes. Simultaneously, the Sub-Criteria cluster encompasses all variables pertinent to the primary qualities within the Criteria cluster, in addition to the Alternatives cluster, which describes the six most recommended natural fibres. By structuring the decision-making process into these hierarchical clusters, the evaluation becomes more systematic, and data driven. This approach ensures that each material alternative is assessed based on multiple performance factors, leading to an optimal and well-balanced selection for the pole application. The next step involves applying the AHP process to quantitatively compare these materials, ensuring a structured and objective process for material selection.

A PCM was constructed to evaluate the criteria related to the objective, using a relative intensity scale. This scale ranges from 1 to 9, indicating different levels of importance among the criteria as shown in Table 1. The scale was applied to represent and assess the relative importance of one criterion in comparison to another [23].

Table 1 Pairwise comparison in PCM for selection in AHP [24,25].

Relative intensity/score	Definition	Explanation
1	Equal importance	Both requirements are considered equally important.
3	Slightly more important	One requirement is preferred slightly over the other.
5	Clearly more important	One requirement is strongly prioritised over the other by several individuals.
7	Very strongly more important	One requirement is highly favoured, with clear practical evidence of its value.

9	Extremely more important	Strong evidence overwhelmingly supports one requirement over the other.
2, 4, 6, 8	Intermediate importance	Represents a compromise between two adjacent levels of judgement.
Reciprocal values	Inverse comparison	Used to express the inverse of comparisons when the second item is more important.

The PCM data was utilised to ascertain the relative priority vector for each attribute. Upon inputting all values for each criterion, sub-criterion, and material alternative, the pairwise comparison can be expressed by equation (1).

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & \cdots & w_1/w_n \\ \vdots & \ddots & \vdots \\ w_n/w_1 & \cdots & w_n/w_n \end{bmatrix} \quad (1)$$

The w or also known as the priority vector, was determined based on Eq. (2):

$$w = \frac{1}{n}\sum_{i=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{a} a_{ij}} \qquad i,j = 1,2,\ldots,n \quad (2)$$

Where w is the eigenvector, i and j are the judgement scale, and n is the number of criteria. The assessment of judgement can be conducted by either a questionnaire or a direct method. The questionnaire method is used to assess judgement. The assessment of these qualities will determine which aspect has the greatest influence on the selection of the natural fibre. Consequently, the study determined that mechanical performance are the crucial factor in selecting the appropriate natural fibre.

PCM for the alternative materials was established based on all the criteria in the fourth step. The priority vector for alternative materials, denoted as (w), was calculated for each criterion. The PCM for the alternative materials was determined based on existing research data about the mechanical and physical properties of each natural fibre type, as shown in Table 2.

Table 2 Mechanical and physical properties of natural fibres [7,26,27].

Fibre	Density (g/cm^3)	Elongation at break (%)	Young's Modulus (GPa)	Tensile Strength (MPa)	World Production (x 10^3 tonnes)	Countries
Hemp	1.4-1.6	1.6-6	30-80	550-900	214	China, France, Philippines
Jute	1.3-1.46	1.5-1.8	10-55	393-800	2300	India, China, Bangladesh
Kenaf	0.6-1.5	1.6–6.9	2.86-60	215.4-1191	970	India, Bangladesh, Malaysia
Sisal	1.3-1.5	2.0-2.5	9-38	80–840	378	Tanzania, Brazil, Kenya
Coconut	1.1–1.6	14.21–59.9	1.27–6	106–593	100	India, Sri Lanka, Philippines, Malaysia

The global priority vector was obtained by multiplying the PCM of the alternative materials by the priority vector of the criteria. This evaluation indicates the most suitable material based on the analysis. The alternative with the highest priority vector is considered the most appropriate natural fibre for producing hybrid FRP composites, which will be subjected to flexural testing (ASTM D790) using different fibre orientations [28].

2.2 Materials

Roving kenaf and glass fibre wire mesh were used as reinforcements in the hybrid composites. The roving kenaf (Average diameter of 1mm) was supplied by the Center of Advanced Composite Material (CACM) lab, Universiti Teknologi Malaysia, Skudai, Johor. glass fibre wire mesh (10 m x 10 m) was purchased from Chemrex Corporation Sdn. Bhd, Cheras Jaya, Selangor. ABS in natural colour was purchased from OPC Resources SD Bhd, Simpang Ampat, Pulau Pinang. The material properties and proportion of composite samples are summarised in Table 3.

Table 3: Material properties and proportion for fabrication of the composites retrieved from Supian et al. [29]

Material	Density (g/cm^3)	Tensile Strength (MPa)	Young Modulus, E (GPa)	Proportion in Composite (%)
ABS	1.10	13.7	-	72.0
Kenaf fibre	1.5	320-500	40	25.4
Glass fibre	2.6	2000	76	2.6

Figure 3 shows the arrangement of fibre layers in the composite laminates. The composites consisted of a total of six fibre layers: four layers of kenaf fibre and two layers of glass fibre. The glass fibre mesh remained as the top and bottom layers, whereas the kenaf layers were the core components of the composite laminates. In this study, four different composite stacking orientations were fixed, and they are summarised in Table 4. The fibre stacking sequences investigated in this research study are denoted as UD, CP, QI-1 and QI-2. The flexural properties of composite laminates with varying stacking orientations were identified and compared to determine the optimal fibre layer arrangement.

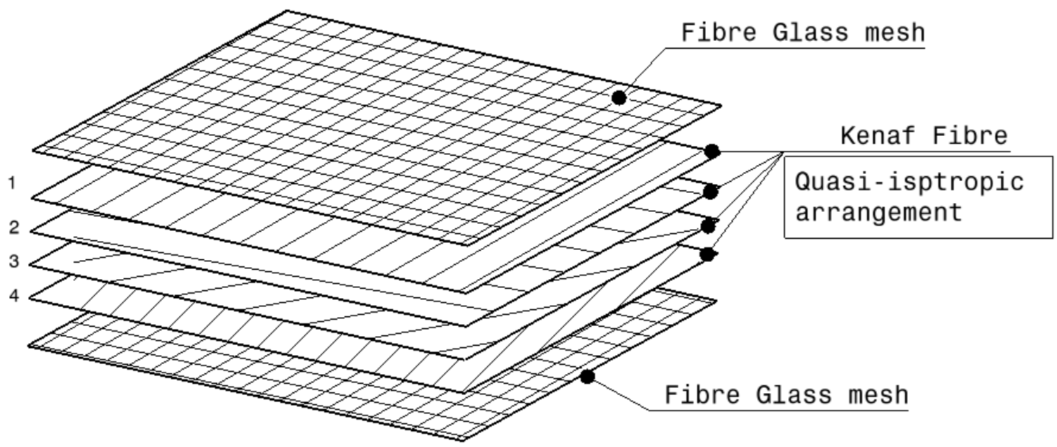


Figure 3: Lamination of kenaf/glass fibre mesh-reinforced ABS composites

Table 4: Fibre stacking orientations of composite laminates

Sample Label	Sample Name	Sample Configuration	Flexural Test Specimens	Kenaf Fibre Orientation
UD	Unidirectional	0/0/0/0	1F1, 1F2, 1F3, 1F4, 1F5	0°,0°,0°,0°
CP	Cross-ply	0/90/0/90	2F1, 2F2, 2F3, 2F4, 2F5	0°,90°,0°,90°
QI-1	Quasi-isotropic 1	0/+45/-45/0	3F1, 3F2, 3F3, 3F4, 3F5	0°,45°,-45°,0°
QI-2	Quasi-isotropic 2	0/+45/90/-45	4F1, 4F2, 4F3, 4F4, 4F5	0°,45°,90°,-45°

2.3 Fabrication of Composites

The kenaf/glass fibre mesh-reinforced composites were fabricated through the hot moulding compression method. Figure 4 shows the fabrication process of kenaf/glass fibre mesh-reinforced ABS composites. The fibre content of all the composites was identified to be around 50 wt%. The fabrication process was initiated by thoroughly cleaning the mould with acetone to remove any impurities from the mould surfaces. Mould wax was applied to the mould surfaces to prevent the composite laminates from sticking after hot compression. Subsequently, the kenaf fibre and glass fibre mesh were carefully arranged in the mould, which had a dimension of 300 mm x 300 mm. ABS was sprinkled on the middle, top, and bottom of the fibre layers to ensure optimum fibre impregnation. The composite laminates were then preheated at 180°C and 2 MPa for 10 minutes to ensure the ABS was completely melted before the full compression process. After the preheating process, the composite laminates were compressed at the same temperature and pressure of 4 MPa for 15 minutes. After that, the composite laminates were cooled to room temperature.

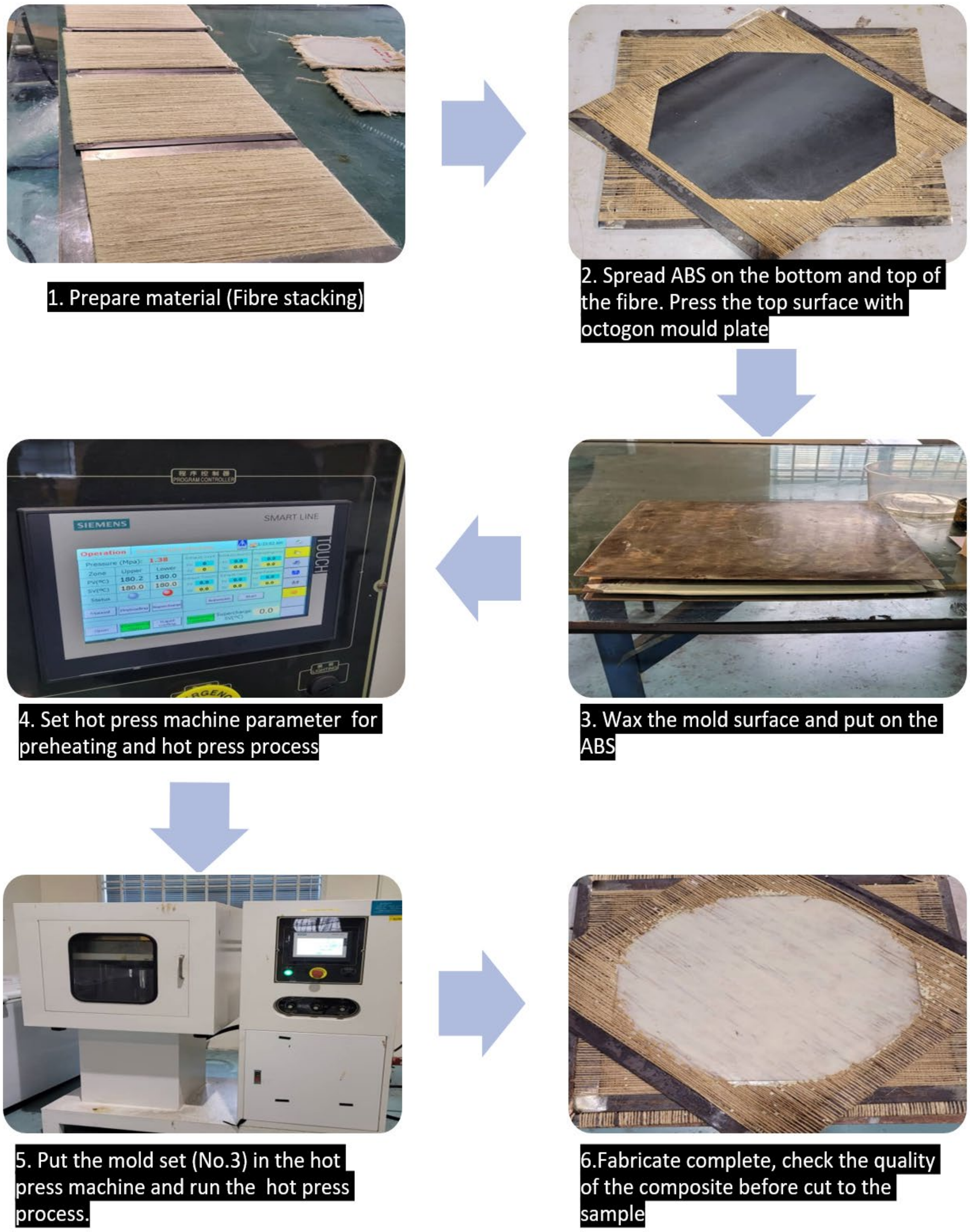


Figure 4: Hot compression moulding procedure.

2.4 Experimental Procedures

Flexural testing was performed to evaluate the flexural strength and modulus of kenaf/glass fibre mesh-reinforced ABS composites arranged in different stacking sequences. The specimens used for this test were rectangular. As outlined in Table 5, the test parameters were established in accordance with ASTM D790 standards.

Table 5: Flexural Test Specification

Test Method	Single
Test Speed	0.76mm/min
No of Batches	4
Test Type	3 Point Bend
Sample Shape	Plate
Number of Sample	5

The testing procedure was carried out using a Shimadzu Universal Testing Machine equipped with a 20-kN load cell. The crosshead operated at a constant speed of 0.76 mm/min, and a span-to-depth ratio of 16:1 was applied. Each specimen was tested until either a 5% strain threshold was reached or structural failure occurred. To ensure reliability, each sample type was tested five times, and the average values were recorded.

The calculations for ultimate flexural strength (σ_f), maximum flexural strain (ε_f), and flexural modulus (E_f) were based on the following equations:

$$\sigma_f = \frac{3PL}{2bd^2} \quad (3)$$

Where σ_f (MPa) is the ultimate flexural strength, P (N) is the load at the maximum point of the stress-strain curve, L (mm) is the span length between supports, b (mm) is the width of the specimen, and d (mm) is the thickness of the specimen.

$$\varepsilon_f = \frac{6Dd}{L^2} \quad (4)$$

Where ε_f is the maximum flexural strain, D (mm) is the maximum deflection at mid-span, d (mm) is the thickness of the sample, and L (mm) is the support span.

$$E_f = \frac{L^3 m}{4bd^2} \quad (5)$$

Where E_f (MPa) is the flexural modulus, L (mm) is the support span, m is the gradient of the stress-strain curve, b (mm) is the width of the sample, and d (mm) is the thickness of the sample.

3.0 RESULTS AND DISCUSSION

3.1 Results of Material Selection using AHP

The AHP was performed utilising "Expert Choice" version 11.5 software to identify the most suitable natural fibre for reinforcing hybrid Fibre Reinforced Polymer (FRP) composites in the context of fruit picker pole applications. The variance in the evaluation of all criteria and alternatives is below 0.1% [30]. A reduced level of inconsistency signifies enhanced accuracy in judgements.

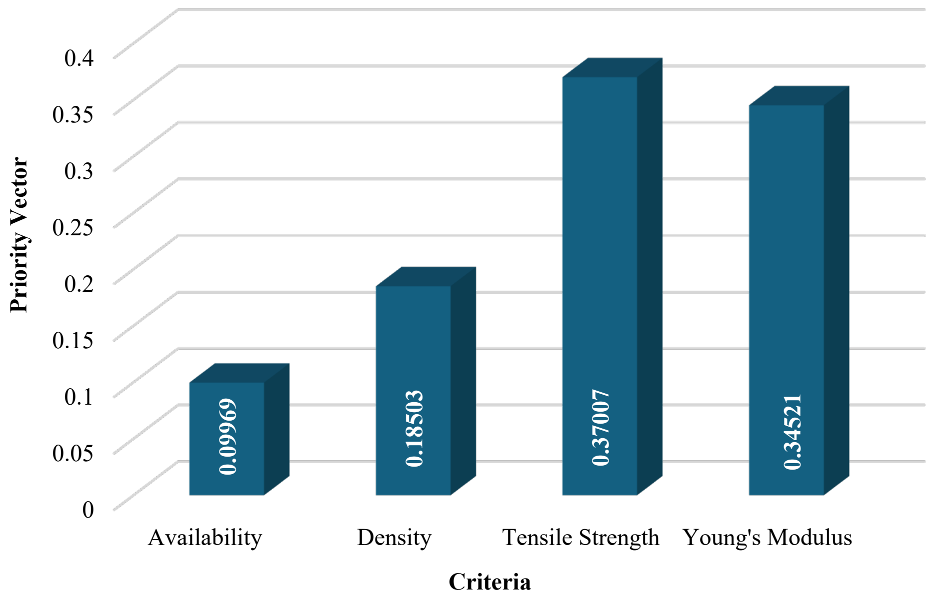


Figure 5: Priority vector values for criteria used in AHP analysis.

The initial stage involved developing a PCM for the four criteria, followed by constructing separate PCMs for the seven alternatives concerning each criterion. The criteria were prioritised in the following order: tensile strength ranked highest, followed by Young's modulus, then density, and lastly availability, as depicted in Figure 5. In selecting natural fibres for structural applications, the key factors considered are tensile strength, Young's modulus, and density. Generally, materials with greater tensile strength and lower density are favoured for manufacturing structural components, as they offer improved strength-to-weight and stiffness-to-weight ratios [8,31]. When utilising natural fibres in structural contexts, their strength becomes a critical factor. Hence, fibres with high tensile strength are primarily chosen for structures that require resistance to impact.

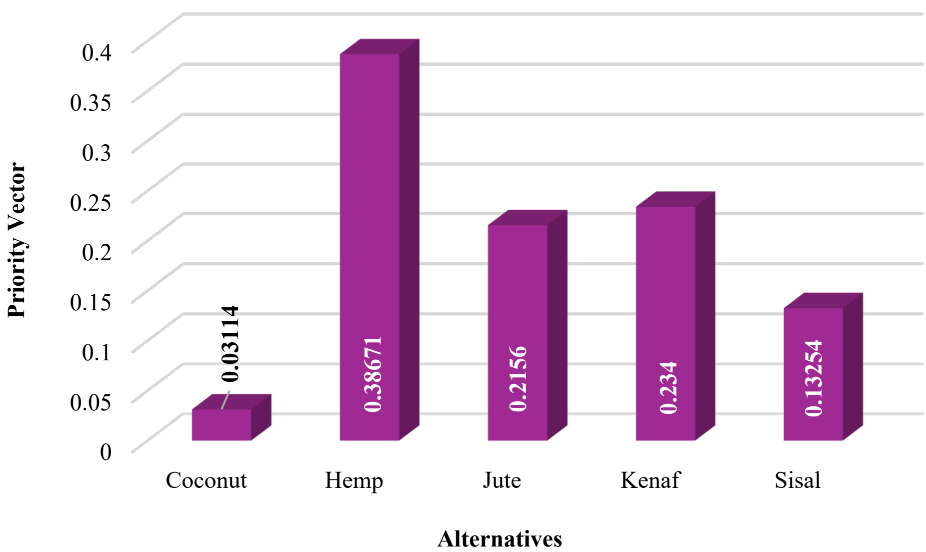


Figure 6: Priority vectors of alternatives due to the Young's modulus. A higher value is considered more favourable or important in terms of its stiffness or ability to resist deformation.

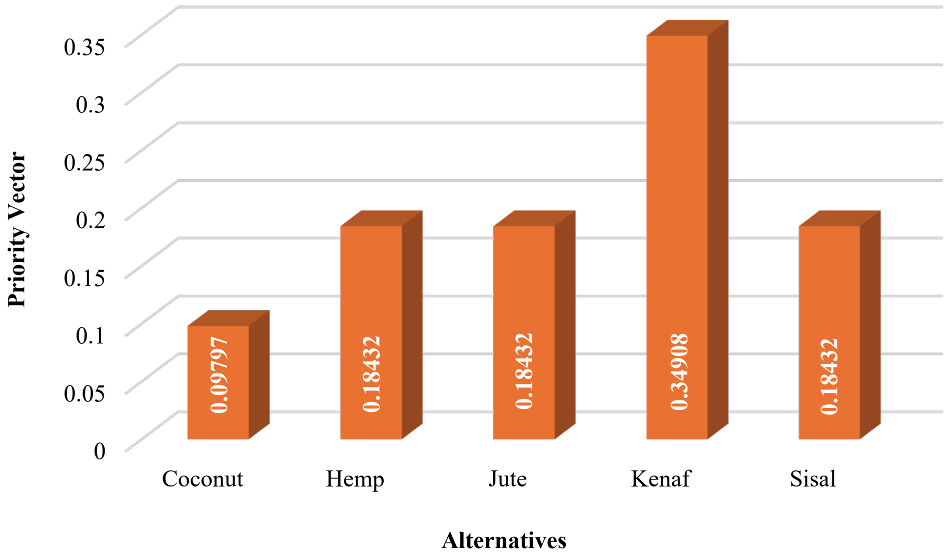


Figure 7: Priority vectors of alternatives due to the tensile strength. Higher values indicate that an alternative has greater tensile strength and is therefore more favourable or preferred for applications requiring strong resistance to tension.

Figures 6 and 7 depict the synthesis of the natural fibres concerning tensile strength and Young's modulus. The alternatives of Young's modulus were ranked as follows: hemp > kenaf > jute > sisal > coconut. In terms of Young's modulus, hemp fibre had the highest weightage, followed by kenaf fibre, whereas coconut fibre had the lowest weightage. For alternative tensile strength, kenaf fibre depicts the highest weightage. In this case, kenaf fibre shows the most preferable fibre for reinforcement in ABS composites, even though it has lower mechanical properties compared to the glass fibres used in high-load-bearing structures. This is because kenaf fibre has moderate mechanical properties, making it suitable for developing cost-effective, moderately load-bearing structural applications with better sustainability terms [7,32]. Structural products, such as fruit picker poles, can be made strong using the hybridisation of kenaf and glass fibre mesh-reinforced hybrid thermoplastic composites.

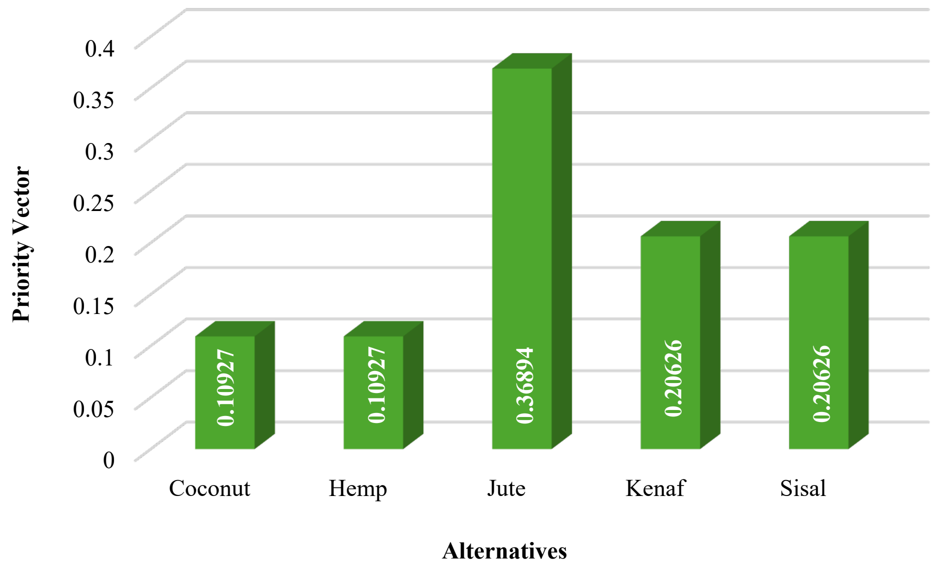


Figure 8: Priority vectors of alternatives due to the density. A higher value indicates a greater relative importance or preference for alternatives with specific density characteristics.

Figure 8 illustrates the synthesis of alternatives regarding density, where the fibres were ranked as follows: jute > kenaf, and sisal > coconut and hemp. The ranking indicates that the values assigned to the priority vector by the alternatives are similar, with only slight deviations. Coconut and hemp fibres have the lowest density compared to the average densities of other candidate natural fibres. The reduced fibre density is crucial for creating profiles with significantly less weight. Kenaf demonstrates the capability to produce profiles with higher strength-to-weight and stiffness-to-weight ratios compared to other materials, as shown in Figures 6 and 7.

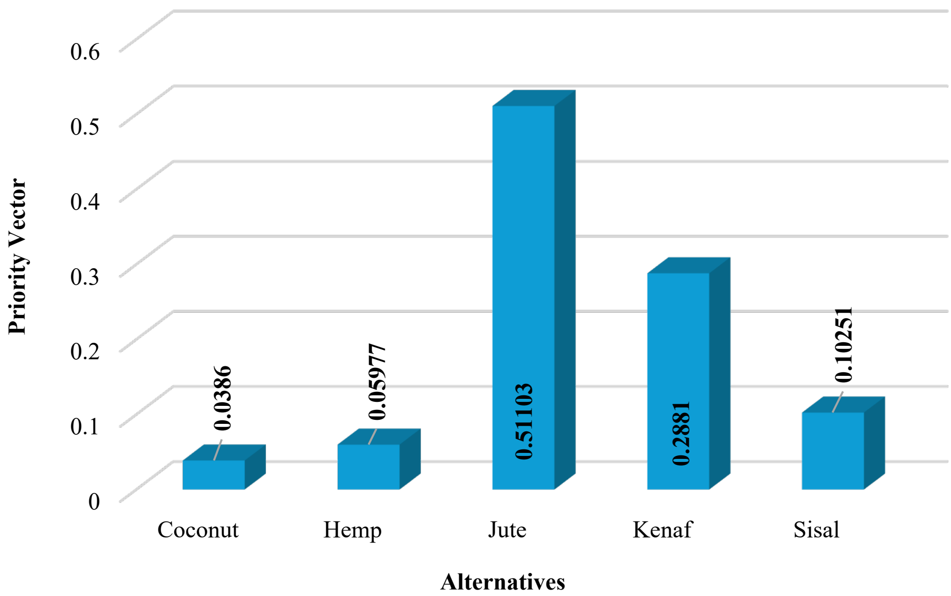
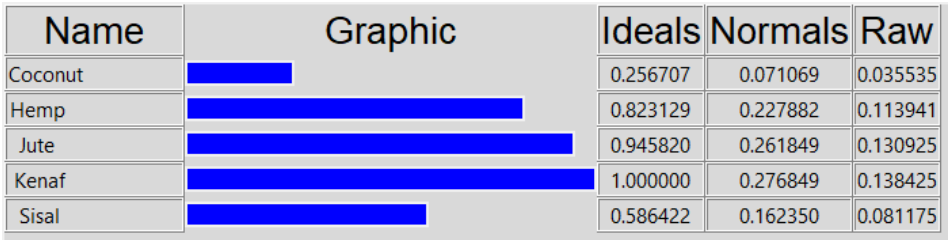


Figure 9: Priority vectors of alternatives due to the availability. A higher value means that the alternative is more readily available or easier to obtain, making it a more favourable option in the decision-making process.

The synthesis of fibres concerning availability was evaluated as shown in Figure 9. For availability, questionnaire judgements were used, as neither has an exact quantity value. Thus, by using questionnaire judgements, the natural fibres were rated based on their yearly world production rate in metric tons. The same logical approach was applied to government support.

A sensitivity analysis was performed to verify and validate the overall results of the AHP process. Figure 10 displays the performance chart, illustrating the priority vector of the natural fibres in relation to the criteria.



Name	Graphic	Ideals	Normals	Raw
Coconut		0.256707	0.071069	0.035535
Hemp		0.823129	0.227882	0.113941
Jute		0.945820	0.261849	0.130925
Kenaf		1.000000	0.276849	0.138425
Sisal		0.586422	0.162350	0.081175

Figure 10: Normals and Ideals value for AHP method

Figure 10 displays the ideal values calculated using the AHP approach. It is employed as a structured technique to systematically evaluate multiple criteria through a hierarchical framework. In this study, four criteria, which are tensile strength, Young's modulus, density, and availability are considered to determine the most suitable natural fibre for structural applications. While tensile strength alone indicates that kenaf is superior, all criteria are accounted for via their priority vectors. For example, in terms of Young's modulus, kenaf is ranked second after hemp, and similar rankings are observed for density and availability. The overall decision is made by calculating the aggregate score across all criteria, which confirms kenaf as the best natural fibre among those evaluated.

It is believed that this comprehensive AHP approach offers a robust and balanced assessment by addressing the importance of all relevant factors rather than relying on a single criterion. The optimal option is kenaf fibre, with an ideal value of 1, indicating that it is the most suitable material for this project. Globally, the availability of one of the most widely produced crops is a key factor, with kenaf scoring the highest in both production and availability. Conversely, coconut fibre has the lowest index value of 0.256707 due to its lack of production rate and mechanical performance.

Sensitivity analysis investigates how changes in the weight of the priority vector for each criterion impact the results. The analytical result is considered robust if these changes have little effect despite variations in the underlying assumptions. Kenaf fibre emerges as the top choice in one of the four criteria identified in the sensitivity analysis: tensile strength. Additionally, kenaf ranked in the top 2 for three other criteria, including Young's modulus, density, and availability. Hence, the choice of kenaf as a viable option using the AHP proves reliable, as consistent outcomes were achieved with changes in the priority vector weightage for each criterion. The sensitivity analysis confirms that kenaf fibre is the most suitable fibre for the hybrid thermoplastic composites used in the fruit picker pole. Following these results, kenaf fibres were employed together with glass fibre mesh in ABS composites to evaluate the effect on bending performance of various fibre orientation sequences.

3.2 Flexural Properties

To understand the application of kenaf fibre in hybridising with glass fibre mesh in ABS composites, a flexural test was conducted to examine the bending behaviour. In this case, the flexural strength of the composite laminates was determined to assess the material's ability to withstand flexural stress without failure. Figure 11 shows the flexural strength of kenaf/glass fibre mesh composites with varying stacking sequences. The results revealed that kenaf orientation significantly affected the flexural strength of the composite laminates. From Figure 11, composite laminates with UD exhibit the highest flexural strength of 65.76 MPa. In contrast, composite laminates with QI-2 exhibited the lowest flexural strength of 52.05 MPa. It was found that changing the fibre orientations of two kenaf layers from 0° to 90° in composite laminates with CP reduced the flexural strength by 11.16 %. In addition, it is visible that composite laminates have a very similar flexural strength when multidirectional kenaf fibre layers are incorporated into them. The flexural strength of the composite laminates with QI-1 was only 5.37 % lower than that of the composite laminates with CP. This indicates that the fibre orientations of 90°, +45° and -45° did not significantly contribute to the flexural strength of the composite laminates. Moreover, altering the fibre orientation of the bottom fibre layers was found to have a minimal impact on the flexural strength of the composite laminates. Overall, 0°/0°/0°/0° was identified as the fibre stacking sequence that could provide composite laminates with optimum flexural strength. This is most probably due to the better load-transferring efficiency and load-sustaining capability of this fibre stacking sequence. It means that the fibre layers at 0° can effectively carry a significant portion of the load, thereby improving the flexural strength of the composite laminates. The unidirectional 0°/0°/0°/0° sequence is considered a baseline or datum, representing the ideal condition for maximum load transfer along the fibre direction. However, to understand the effect of bending and load transfer under real-world applications, it's crucial to evaluate multiple orientations. Different fibre arrangements can absorb impact differently, transfer stresses more effectively, and improve toughness or impact resistance, especially in complex loading conditions like bending. Testing multiple orientations allows researchers to identify configurations that optimise flexural strength, modulus, and impact energy dissipation. For instance, research shows that anisotropic orientations tend to enhance impact and flexural properties as fibres are aligned in a specific direction to resist bending, while isotropic arrangements provide more uniform, though generally lower, performance across various loading directions. This makes the analysis more comprehensive, aiding in the design of composites tailored to specific load conditions, such as those experienced by fruit picker poles, where bending occurs in multiple directions. Unlike the fibre layers at 0°, fibre orientations at +45° and -45° may have an inferior effect on the flexural strength of the composite laminates due to inadequate stress transfer within the composite laminates. As mentioned by Caminero et al. [33], the off-axis effect, such as off-axis matrix cracking, may result in the deterioration of the mechanical strength and stiffness of the composites. Quasi-isotropic laminates are designed to obtain similar mechanical properties in multiple directions within the plane of the laminate. It can be observed that the flexural strength of the composite laminates with CP, QI-1, and QI-2 was apparently lower than that of UD.

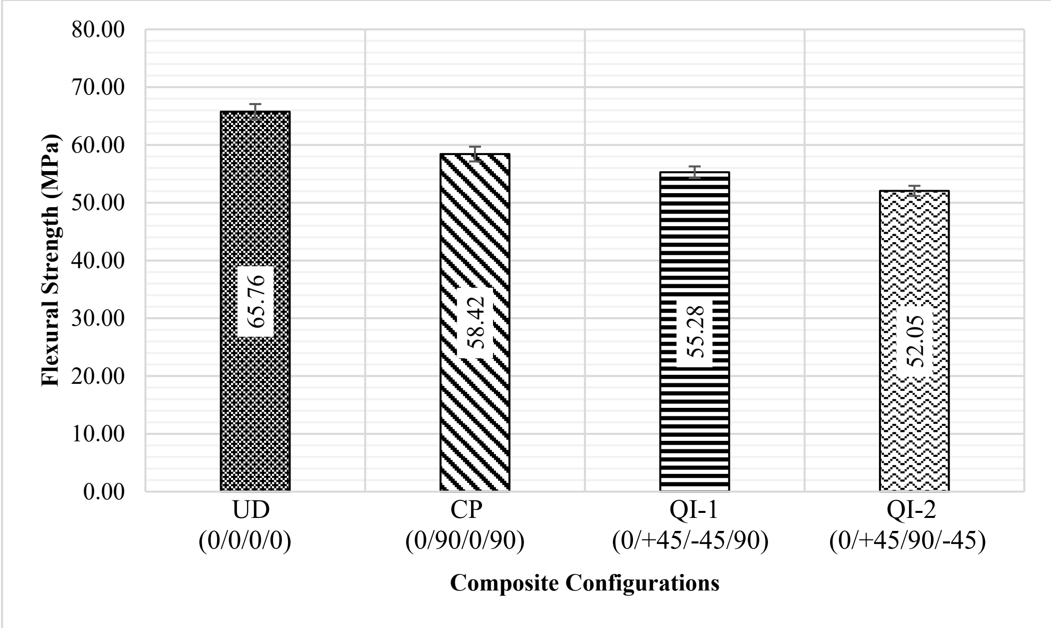


Figure 11: Flexural strength (MPa) of kenaf/glass fibre mesh-reinforced ABS composites with varying stacking sequences.

Flexural modulus, also known as bending modulus or modulus of elasticity in bending, measures the material stiffness in response to a bending or flexural load. It represents the ratio of stress to strain in the elastic (linear) region of the stress-strain curve of the materials obtained from the flexural test. Materials with a higher flexural modulus are generally stiffer and have greater resistance against deformation under a given load without undergoing plastic deformation. However, a higher flexural modulus does not necessarily mean higher flexural strength. Flexural strength is more directly related to the material's ability to resist fracture, which may not always correlate with stiffness.

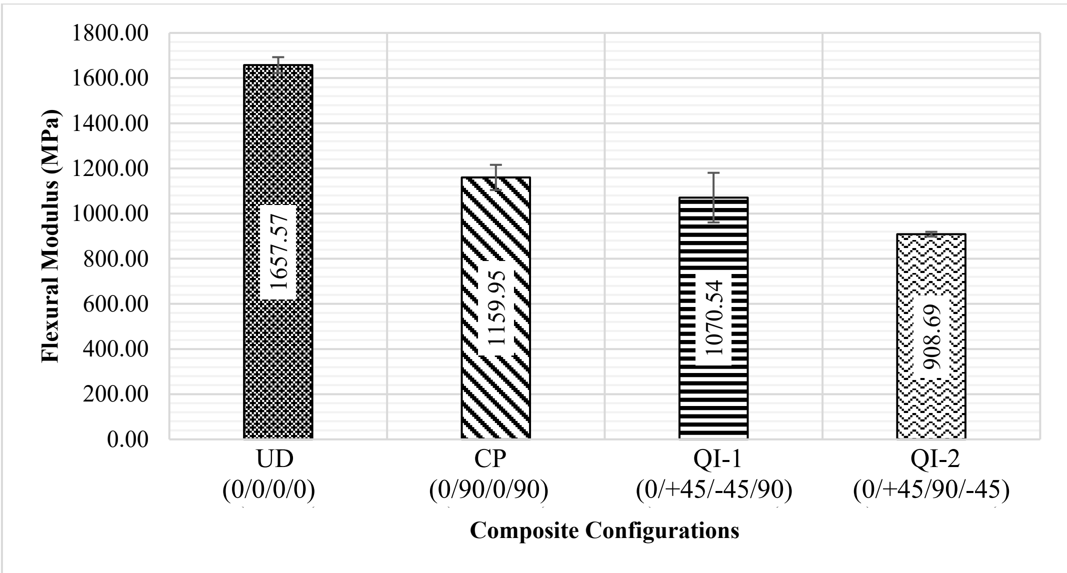


Figure 12: Flexural modulus (Mpa) of kenaf/glass fibre mesh-reinforced ABS composites with varying fibre stacking sequences.

Figure 12 illustrates the flexural modulus of composite laminates featuring various fibre stacking arrangements. The pattern observed closely mirrors that of the flexural strength across the different stacking sequences. According to the data, the composite laminates designated as UD demonstrated the highest flexural modulus at 1657.57 MPa, while the lowest value of 908.69 MPa was recorded for laminates with QI-2. Altering the fibre orientation of two layers from 0° to 90° resulted in a 30.02% reduction in the flexural modulus. When examining the laminates with CP, 3, and 4, their flexural moduli were comparable despite differing stacking patterns. Specifically, the flexural modulus for QI-1 was only 7.71% less than that of CP. These results suggest that fibre orientations of 90°, +45°, and -45° have minimal impact on the flexural modulus of the laminates. Besides flexural strength, a stacking sequence of 0°/0°/0°/0° also appears to provide the greatest resistance to bending deformation in the composites. As mentioned in the previous section, arranging the kenaf fibre in a unidirectional manner can provide composite laminates with better load transfer efficiency when subjected to flexural loads. Additionally, the kenaf fibre at 0° can sustain a significant amount of the flexural load and resist higher levels of deformation, thus enhancing the flexural properties of the composite laminates. Composite laminates with QI-1 and QI-2 showed particularly lower flexural modulus, mainly due to the kenaf fibre at an off-axis angle. The off-axis effects can degrade the stiffness of the composite laminates [34–36]. In other words, the off-axis effect resulting from the fibre orientation may deteriorate the material properties [33]. These results indicate that the stacking sequence may affect the flexural modulus of kenaf/glass fibre mesh-reinforced ABS composites. In engineering applications where structural integrity is paramount, such as automotive components or load-bearing structures, composites with higher flexural moduli, such as the composite laminates with UD, would be preferred [37,38]. These materials can withstand greater loads and minimise deformation under stress, contributing to the longevity and safety of the final product. Additionally, flexural loading involves a combination of tension, compression, and shear stresses. Even though the quasi-isotropic nature of the composite laminates could offer balanced properties in all loading directions, it often comes with lower mechanical properties than anisotropic composite materials. Moreover, the balanced nature of quasi-isotropic laminates may lead to a more complex stress distribution within the material, which in turn affects the overall stiffness or modulus.

3.3 Fracture behaviours

Figure 13 shows the fracture behaviours of composite laminates with varying stacking sequences. The findings demonstrated that the stacking sequence played a critical role in determining flexural strength, stiffness, and failure modes. The fibre arrangement, such as unidirectional, cross-ply, or angle-ply configurations, can lead to variations in stiffness, strength, and deformation behaviour. Flexural load typically induces failures such as compressive, tensile, or shear failures, which are associated with delamination, matrix cracking, and fibre breakage.

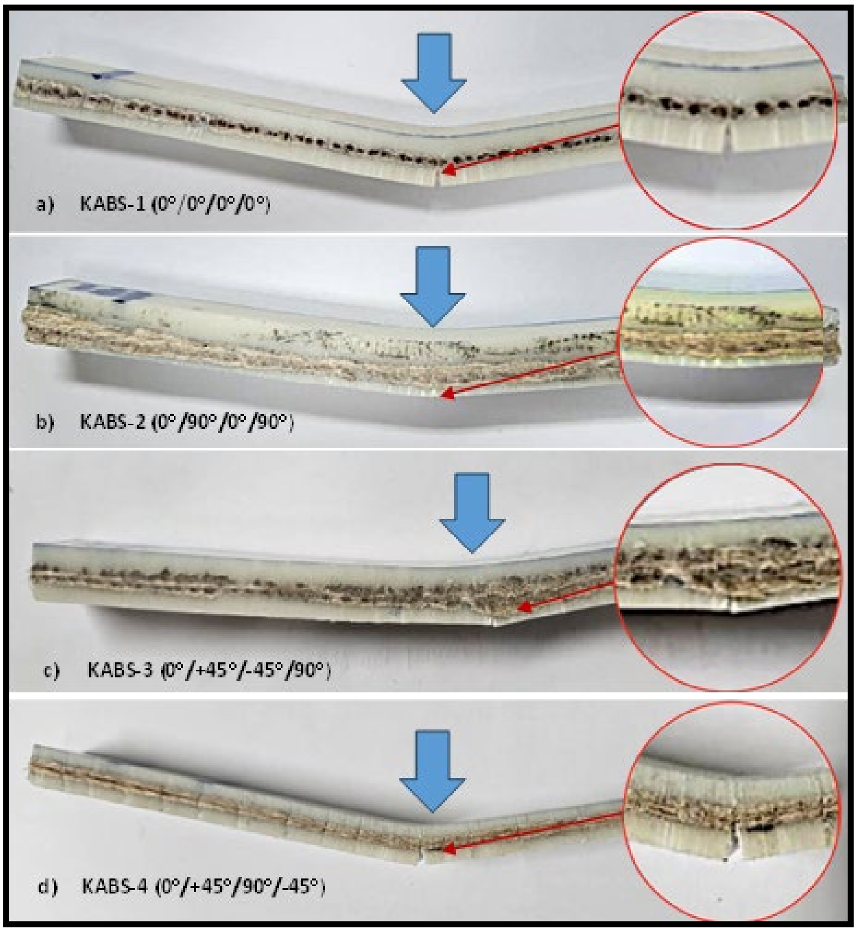


Figure 13: Fracture Behaviour of composite after flexural testing, showing matrix cracking at the bottom layers across all configurations. More severe failure observed in QI-2

From Figure 13, it is evident that the fracture behaviours of all the composite laminates show similarity. A crack was observed at the bottom layer of the composite laminates, irrespective of the fibre stacking sequences. In contrast, no cracks were observed on the top layers of the composite laminates. The fracture behaviours of the composite laminates indicate that all the composite laminates failed under the tensile stress of the bottom layer. However, as visible in Figure 13(d), composite laminates with QI-2 displayed more severe damage than other composite laminates. Matrix cracking and fibre breakage were observed in composite laminates with QI-2. The fracture behaviours of composite laminates with QI-2 agreed with the results shown in Figures 11 and 12, in which the flexural strength and modulus of composite laminates with QI-2 were the lowest. As for the composite laminates with UD, the fibre remained intact after matrix cracking was noticed in the bottom layer. Due to the high effectiveness of the fibre stacking sequence, this fracture behaviour enables composite laminates to exhibit higher flexural properties.

4.0 CONCLUSION

This work explores fibre selection using the AHP and assesses how fibre orientation sequence affects the flexural properties of ABS composites. Kenaf fibre was identified as the most suitable option, aligning with key design requirements for the fruit picker pole.

Sensitivity analysis confirmed kenaf's preference by achieving the highest priority score in one of the four evaluated criteria, reinforcing the reliability of the AHP method. The AHP technique is a valuable tool for multi-criteria decision-making, providing a structured approach to selection and problem-solving across various fields. It also facilitates effective natural fibre selection for diverse technical applications. After material selection, flexural testing was performed on hybrid kenaf/glass fibre mesh-reinforced ABS composites to evaluate bending behaviour for pole suitability. Results showed the fibre stacking sequence significantly influences flexural properties. Laminates with a 0°/0°/0°/0° stacking sequence demonstrated the highest flexural strength and modulus (65.76 MPa and 1657.57 MPa, respectively), while those with a 0°/+45°/90°/-45° sequence had the lowest. Aligning fibres at 0° notably enhanced flexural properties, with strength and modulus reductions of 11.16% and 30.02%, respectively, when changing to the latter sequence. Laminates with off-axis and 90° orientations exhibited similar flexural properties, suggesting a lesser influence on bending behaviour. The flexural strength and stiffness of laminates with QI-1 were only marginally lower than those with CP by 5.37% and 7.71%, respectively. This research highlights the importance of fibre stacking sequence in designing kenaf/glass fibre mesh-reinforced ABS composites, enabling the development of environmentally friendly, high-performance fruit picker poles.

Future studies could examine a wider range of natural fibres, such as jute, hemp, or flax to evaluate their compatibility and performance in hybrid composites. Adjusting hybrid ratios between natural and synthetic fibres may help find optimal blends that balance strength, flexibility, cost, and sustainability. Exploring different fibre stacking sequences could also improve specific mechanical properties, such as impact resistance and fatigue life, for various applications. Long-term durability tests are crucial for understanding how these composites withstand moisture, UV exposure, and temperature fluctuations over time. Environmental impact assessments, including life cycle analysis, would clarify the ecological benefits of these materials compared to conventional ones. Research on manufacturing scalability is also necessary to enhance production efficiency, quality control, and cost-effectiveness for commercial use. These directions will enhance the development of eco-friendly composites by tailoring fibre selection, orientation, and formulation. This approach supports the creation of sustainable, high-performance materials designed to meet functional needs and environmental goals across various applications, including fruit picker poles.

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