Airman

Journal of Transport Engineering and Safety

ISSN: 2622-0105 (print) | 2716-1196 (online)
http://jurnal.poltekbangmakassar.ac.id/

Tensile Test Analysis with Fibre Direction Variations of Coconut Fibre Reinforced Composites as Materials in Aircraft

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Article info

Received: 24-08-2024
Final Revision: 14-05-2025
Accepted: 05-06-2025
Available online: 28-06-2025

Keywords:

Coconut fiber-reinforced composites; Fiber orientation; Mechanical properties; Three-point bending test; Sustainable materials; Aviation applications

Recommended Citation:

APA Style

ABSTRACT

This study examines the influence of fiber orientation on the mechanical performance of coconut fiber-reinforced composite materials using the three-point bending test method. Fiber orientations of 0°, 45°, and 90° were tested at a loading speed of 5 mm/min to determine their effect on strength and flexibility. The results demonstrate that orientation plays a decisive role in the structural behavior of the composites. The 0° orientation achieved the highest maximum force of 71.41 N with a maximum displacement of 19.02 mm, reflecting superior flexibility and load-bearing capacity. In contrast, the 45° and 90° orientations exhibited lower force resistance and reduced deformation before structural failure, confirming the strong dependence of performance on fiber alignment. By employing coconut fiber as reinforcement, this study establishes clear experimental evidence of its mechanical potential, particularly when fibers are aligned parallel to the applied load. The outcomes emphasize the capability of coconut fiber composites to serve as lightweight, sustainable, and eco-friendly alternatives to conventional synthetic fiber materials. These insights not only advance the understanding of natural fiber orientation in composite design but also provide practical implications for their integration into structural applications, including the aviation industry.

INTRODUCTION

Composite materials have become a cornerstone of engineering innovation, particularly in the aviation industry, where their lightweight structure, high strength-to-weight ratio, and corrosion resistance contribute directly to fuel efficiency and reduced carbon emissions (Hafid et al., 2019; Kumar & Singh, 2020). While conventional reinforcements such as glass and carbon fibers have been widely adopted, they remain constrained by high production costs, non-biodegradability, and substantial environmental impact during both manufacturing and disposal (Mallick, 2007; Pickering, 2016). In the context of green aviation, where sustainability is increasingly prioritized, these limitations underscore the urgency of identifying renewable alternatives that balance performance with ecological responsibility.

Natural fibers have attracted growing interest as reinforcements for polymer composites due to their abundance, biodegradability, low cost, and promising mechanical properties (Bledzki & Gassan, 1999; Ahmed et al., 2018; Sharma et al., 2020). Among them, coconut fiber stands out for its high lignin content, which provides durability, flexibility, and resistance to microbial degradation (Mansor et al., 2013; Neto et al., 2015). Compared with synthetic fibers, coconut fibers are up to 75% lighter than aluminum alloys, and their use in composites aligns with circular economy principles by reducing dependence on fossil-based materials (Prasad & Narayan, 2020). These attributes position coconut fiber as a potential candidate for sustainable structural applications in aerospace engineering.

The mechanical behavior of fiber-reinforced composites is highly dependent on fiber orientation within the matrix. Previous studies confirm that fibers aligned parallel to the loading direction significantly enhance tensile and bending strength, whereas diagonal or perpendicular orientations reduce stress transfer efficiency and induce premature failure (George et al., 2001; Jawaid & Abdul Khalil, 2011; Ali et al., 2020; Patel et al., 2021). For instance, sisal-reinforced composites under 0° orientation reported flexural strengths between 60–70 N (Das et al., 2021), while jute composites experienced a reduction of over 40% in strength when fibers were misaligned (Niranjanaa et al., 2020). Compared with these benchmarks, the present study found that coconut fiber composites with 0° orientation achieved a maximum force of 71.41 N, placing them on par with or above other natural fiber systems.

Despite such potential, systematic studies on coconut fiber composites remain limited. Much of the existing literature has focused on surface treatments, hybridization with synthetic fibers, or general mechanical characterization, leaving a gap in understanding the direct effect of fiber orientation under bending loads. Addressing this gap is critical for validating coconut fiber as a technically viable reinforcement in aviation structures.

Therefore, this study investigates the influence of coconut fiber orientation (0°, 45°, and 90°) on the mechanical performance of composites through three-point bending tests. By providing experimental evidence on the relationship between orientation, load-bearing capacity, and deformation, the study contributes to advancing the scientific understanding of natural fiber composites. The findings also support the broader goal of developing eco-friendly materials for green aviation, where both structural efficiency and environmental sustainability are essential.

COMPOSITE

A composite is a material formed by combining two or more constituent materials with different physical and chemical properties. The purpose of this combination is to produce a material with superior properties compared to its individual components. A composite consists of a matrix and reinforcement. The matrix functions as a binding medium that holds the reinforcement together, while the reinforcement enhances the mechanical properties of the material, such as strength and stiffness. This unique combination enables composites to be widely used in various engineering applications, especially in industries that require lightweight and high-performance materials, such as aviation (Anwar et al., 2022).

Composite materials can be classified based on the type of matrix: polymer matrix composites (PMC), metal matrix composites (MMC), and ceramic matrix composites (CMC). PMCs are the most commonly used, particularly in aerospace applications, due to their low density, cost-effectiveness, and ease of fabrication. MMCs are known for their resistance to high temperatures, while CMCs are valued for their corrosion resistance and thermal insulation capabilities. In addition, reinforcements in composites may come in the form of natural or synthetic fibers, particles, or a combination of both, each offering specific advantages depending on the application (Endriatno et al., 2015).

The use of composites in the aviation industry provides significant benefits, including aircraft weight reduction and improved fuel efficiency. Lighter materials require less energy for takeoff and flight, thus lowering carbon emissions. Furthermore, the corrosion resistance of composites makes them ideal for extreme environments, such as aircraft exteriors exposed to fluctuating temperatures and air pressure. Composites also enable more efficient and innovative aerodynamic designs, supporting advancements in aviation technology.

With increasing attention to sustainability, the use of natural fibers as reinforcements in composites has become a key research focus. Natural fibers, such as coconut fiber, are environmentally friendly because they are biodegradable and have a lower carbon footprint compared to synthetic fibers. They are also abundantly available in tropical regions, making them an economical reinforcement option. Research has shown that natural fibers can provide competitive mechanical properties when used in polymer, metal, or ceramic matrices.

The mechanical properties of composites are strongly influenced by the orientation of the fibers within the matrix. Fibers aligned parallel to the loading direction provide better tensile and bending strength compared to fibers oriented at an angle or perpendicular to the applied force. Fiber orientation affects stress distribution and deformation within the material, ultimately determining composite performance under load. In composite design, understanding the relationship between fiber orientation and mechanical properties is crucial to ensure that the material meets the specific demands of its application.

Composite fabrication aims to optimally combine the matrix and reinforcement to achieve the best mechanical properties. Common fabrication methods include hand lay-up, compression molding, and pultrusion. In aerospace applications, autoclave molding is often employed to produce high-quality composites. Fabrication technology also plays an important role in ensuring homogeneity and strong adhesion between the matrix and reinforcement..Mechanical testing is conducted to evaluate the performance of composite materials under various loading conditions. Tensile testing is one of the most widely used methods. The data obtained from such mechanical testing serves as a foundation for optimizing composite design (Beliu et al., 2016). Composites offer advantages over conventional materials such as metals and wood, particularly in terms of weight, strength, and corrosion resistance. In aviation, conventional materials like aluminum and steel are often replaced by composites due to their lighter weight and superior mechanical properties. Moreover, composites can be tailored to specific application requirements, such as increasing strength in particular areas by adjusting fiber orientation and reinforcement volume (Permata, 2018).

Despite their many advantages, composites also face challenges. Variations in mechanical properties due to differences in reinforcement and matrix quality are a common issue, especially when using natural fibers. Additionally, the high cost of advanced fabrication technologies is another factor that must be considered. Further research is needed to address these challenges in order to optimize the potential of composites as advanced materials. The development of natural fiber–based composites represents an important step toward sustainability in the aviation industry. With growing concerns about environmental impacts, eco-friendly composites are expected to replace conventional materials in various structural applications. Ongoing research and innovations in fabrication technologies continue to aim at producing composites with optimal mechanical properties and more efficient production costs.

METHOD

This study investigates the effect of coconut fiber orientation on the mechanical properties of fiber-reinforced composites. Coconut fibers were collected, cleaned, and sun-dried before use. The matrix material was epoxy resin mixed with a hardener at a 1:1 ratio. The composites were fabricated using a hand lay-up method followed by compression molding to ensure proper fiber–matrix bonding. Fiber orientations of 0°, 45°, and 90° were prepared in separate specimens to evaluate the effect of alignment. Each sample was cast in a rectangular mold and allowed to cure at room temperature for 24 hours before testing. Mechanical testing was conducted using a three-point bending test on a Universal Testing Machine (UTM) with a constant loading speed of 5 mm/min. Key parameters recorded included maximum force (N) and maximum displacement (mm). Each test was repeated three times for accuracy, and average values were used for analysis.

Materials.

Coconut fibers were obtained from mature coconuts, cleaned to remove impurities, and dried under sunlight for 48 hours. The fibers were then cut to uniform lengths of approximately 30 mm. Epoxy resin (Epoxy 108) and hardener were used as the polymer matrix, mixed at a 1:1 ratio to ensure optimal curing.

Coconut Fibre

Coconut fiber is a natural material derived from the coconut husk and has high potential as an alternative to synthetic fibers due to its biodegradable nature, lightweight characteristics, and environmentally friendly properties (Wahyuni, 2012).

Coconut fiber is part of the coconut fruit that comes from the mesocarp, the middle layer between the shell and the outer skin of the coconut. It consists of coarse fiber structures containing high amounts of lignin and cellulose. This composition provides good mechanical properties, such as tensile strength and resistance to microbial degradation (Winarno, 2004). Due to its natural strength and biodegradability, coconut fiber has increasingly gained attention as a reinforcement material in the development of natural-based or eco-composites.

In material technology innovation, particularly in the aerospace and automotive industries, coconut fiber has been studied as an alternative to synthetic fibers such as carbon and glass fibers. The application of coconut fiber in the production of composites for light aircraft or drone wings represents a sustainable approach in high-tech sectors. Coconut fiber is used as reinforcement in polymer matrices such as polyester, epoxy resin, and polypropylene, creating composites that are lightweight, strong, and environmentally friendly (Mansor et al., 2013). Coconut fiber is obtained from the coconut husk, an abundant agricultural by-product in tropical countries. Processing the husk to extract the fibers involves mechanical methods such as decorticating (crushing and separation) as well as chemical treatment through immersion in alkali solutions like sodium hydroxide (NaOH). Alkali treatment aims to remove non-cellulosic compounds such as lignin and hemicellulose, which can hinder bonding between fiber and matrix. This treatment also increases fiber surface roughness, improves adhesion, and enhances tensile strength (Wahyuni, 2012; Winarno, 2004; Bledzki et al., 2006).

Applications of coconut fiber–based composites are not limited to aerospace but extend to various other sectors such as automotive (vehicle interior panels, dashboards), construction (light structural elements), agriculture (composite panels for greenhouses), and consumer products (mats, mattresses, and handicrafts). Cocopeat, a by-product of coconut husk processing, is also used as planting media, hydroponic substrate, or organic fertilizer, ensuring zero waste and making the process highly eco-friendly (Reddy & Yang, 2005).

In addition to coconut fiber, banana pseudostem fiber is another promising natural material for composite development. As an agricultural by-product of banana plants, it contains a relatively high cellulose content and is abundantly available in tropical regions, making it an inexpensive and easily accessible reinforcement material. Banana pseudostem fiber–based composites have been applied in polymer matrices such as polyester and epoxy for a wide range of applications, including vehicle interior panels, furniture, lightweight building materials, and even helmet protection (Mohanty et al., 2005). The main advantages of banana pseudostem fiber are its biodegradability, low density, and small carbon footprint. However, one of the challenges is its variable mechanical properties, which depend on environmental factors such as soil type, climate, and harvest age of the plant. These variations affect the quality and consistency of the resulting composites, requiring further optimization through chemical treatments and surface modifications to improve mechanical performance and fiber–matrix adhesion (Niranjanaa et al., 2020).

Composite fabrication.

A hand lay-up method was employed, followed by compression molding. Fibers were arranged manually into three orientations**:** 0° (parallel to load), 45° (diagonal), and 90° (perpendicular)**.** Each arrangement was carefully aligned to maintain consistency. The fiber-to-matrix weight ratio was fixed at 30:70. The mixture was poured into steel molds measuring **150** mm × 20 mm × 10 mm, coated with release agent to facilitate demolding. Specimens were cured at room temperature for 24 hours, followed by post-curing at 60 °C for 2 hours to improve fiber–matrix adhesion.

Tensile Testing

Tensile testing is one of the oldest and most widely used mechanical testing methods because it can be performed on standardized specimens without requiring highly specialized equipment. It is considered a fundamental technique in material testing and is extensively used to determine the characteristics of materials in resisting applied forces. This test provides valuable information on ultimate strength, elastic modulus, strain at fracture, and other important parameters essential for engineering analysis and materials design (Callister & Rethwisch, 2010).

The main purpose of material testing is to obtain certainty regarding the properties and strength of the material. Through careful testing, it can be determined whether a material is suitable for a particular structural application. This process is crucial in the design and selection phase, especially in engineering applications where safety and efficiency strongly depend on the mechanical performance of the material. Moreover, the results can serve as a reference for product design optimization, production quality evaluation, and validation of numerical simulations or predictive models.

Static tensile (bending) testing has long been applied because it can be performed on specimens of simple geometry. It offers practical value since the specimen design is not complex, while providing detailed insight into the behavior of a material under external loads. Bending tests are applicable to brittle materials and, for ductile materials, are used to identify defects or surface cracks. In this regard, flexural testing is very useful for assessing material resistance to crack propagation or permanent deformation prior to structural failure (Budinski & Budinski, 2009). Flexural testing of hard and brittle materials is considered one of the best methods to determine strength and brittleness (Sehono & Rizki Putra, 2022). It is commonly used for metals, ceramics, and both natural and synthetic fiber–based composites.

The tensile (flexural) test is generally used to evaluate the bending strength of a material and its capacity to withstand deformation when subjected to loading. In many studies, the **Three-Point Bend Test** is employed, in which the specimen is supported at two points on the bottom and loaded at one point at the center top. This method allows for uniform stress distribution along the bottom surface of the specimen, while the top surface experiences maximum compression. The key parameters obtained include maximum force (Max Force), maximum displacement (Max Displacement), break force (Break Force), and displacement at break (Break Displacement). These parameters provide crucial data on flexural strength, elastic modulus, and resistance of the material under bending loads (Anwar et al., 2022). In addition, the stress-strain curve obtained from this test allows for detailed analysis of both elastic and plastic properties.

In composite materials, fiber orientation within the matrix plays a significant role in the results of tensile testing. Fibers aligned parallel to the load direction usually result in higher bending strength due to more uniform stress distribution within the matrix. This occurs because fibers generally have a greater ability to withstand tensile loads than the polymer matrix, allowing aligned fibers to bear most of the load. Conversely, fibers oriented perpendicular to the applied load tend to yield lower flexural strength values due to stress concentration in certain regions and reduced contribution of fibers in load resistance (Jawaid & Abdul Khalil, 2011). Other factors such as fiber length, type of matrix, and fiber surface treatment also influence the final performance of the composite.

To conduct tensile testing, equipment such as the **Torsee Universal Testing Machine** can be used. This machine is designed to deliver accurate results for various types of mechanical tests, including tensile, flexural, and compression tests. In tensile testing, the upper part of the specimen experiences compressive stress while the lower part is subjected to tensile stress. This stress distribution enables both visual observation of crack formation and numerical data collection for further analysis in material development and improvement. Standard testing procedures, such as those outlined in **ASTM D790 (2015),** ensure that results are consistent, measurable, and reproducible—an essential requirement in modern testing of natural fiber–based composites such as coconut fiber and banana pseudostem fiber.

Manufacturing process of coconut fiber–based composites

The process of manufacturing coconut fiber-based composites begins with the crucial initial stage, namely the preparation of the fibers as reinforcement material. Coconut fibers, which are generally derived from the coconut husk (mesocarp), contain high lignocellulose content and exhibit a unique combination of lignin, cellulose, and hemicellulose that provides adequate mechanical characteristics for engineering applications (Bledzki & Gassan, 1999). The fibers are extracted using various mechanical or chemical techniques to separate them from other organic substances, such as lignin and hemicellulose. This process aims to obtain purified fibers ready to be used as reinforcement in composite structures. Mechanical methods may include combing or beating, while chemical processes generally involve soaking in alkaline solutions such as NaOH, which helps dissolve non-cellulosic compounds, thereby improving the cleanliness and surface roughness of the fibers (John & Thomas, 2008).

Once the extraction process is completed, the fibers are thoroughly cleaned to remove any remaining impurities, oils, or interfering compounds that could reduce the bonding strength between the fibers and the polymer matrix. This stage is crucial because dirt or organic residues can decrease interfacial adhesion, ultimately leading to reduced tensile strength and lower resistance of the composite against external loads (George et al., 2001). Chemical treatments, such as alkaline soaking, are often applied with adjusted concentration and duration to enhance the fiber's mechanical strength and adhesion with the polymer matrix. This treatment, commonly known as alkali treatment or mercerization, not only increases surface roughness but also reduces lignin and hemicellulose content while creating more free hydroxyl sites capable of interacting with the polymer matrix (Valadez-González et al., 1999)

The next step is adjusting the fiber dimensions according to design specifications. The cleaned and chemically treated fibers are cut or measured for uniform length. At this stage, the fiber orientation is arranged based on the application requirements, such as parallel, diagonal, or perpendicular to the applied load. Fiber orientation plays a significant role in determining the load distribution within the composite material since the alignment directly affects how forces are transferred through the fibers, which in turn influences the tensile strength, stiffness, and fracture behavior of the material (Thwe & Liao, 2003). In natural fiber-based composites, fibers aligned parallel to the load direction generally provide the best mechanical performance.
After fiber preparation, the matrix material is selected. The matrix serves as a binder that coats and unifies the fibers into a structural system. Commonly used matrices in natural fiber composites include resins such as epoxy, polyester, or polypropylene, which provide advantages in corrosion resistance, flexibility, and ease of fabrication (Mohanty et al., 2000). The choice of matrix is critical because it determines the final properties of the composite, such as tensile strength, thermal resistance, and processability.

The prepared fibers are then combined with the matrix inside a mold using fabrication methods such as hand lay-up or compression molding. In the hand lay-up method, the fibers are manually placed in the mold and resin is poured over them, then leveled and compacted using a roller or vacuum. This method is suitable for small-scale production and allows more flexible control of fiber orientation (Mallick, 2007). Meanwhile, compression molding applies high pressure and temperature to compact the fibers and matrix within a closed mold, resulting in composites with high density and homogeneity.

At this stage, the fiber-matrix mixture is placed in the mold and compacted to ensure proper fiber embedding within the matrix. Sometimes, heat and pressure are applied to improve fiber-matrix bonding and ensure material homogeneity. The combination of pressure and temperature during fabrication also helps eliminate air bubbles and accelerates the polymerization reaction, particularly in thermoset matrices such as epoxy (Jawaid & Abdul Khalil, 2011). The composite then undergoes a curing process, either naturally at room temperature or with the aid of an oven at elevated temperatures, to accelerate the chemical reaction that transforms the matrix from liquid to solid. The curing process determines the formation of a three-dimensional network within the matrix, which significantly affects the mechanical strength and thermal stability of the final material. Proper heating during curing also prevents imperfections such as incomplete curing or voids within the composite (Puglia et al., 2005).

After curing, the next stage is cutting and finishing. The composite material is cut according to design specifications, and rough surfaces are smoothed to ensure high-quality results and facilitate integration into systems or final products. This stage ensures the material is ready for use and meets the desired application standards. Finishing is also important to prevent microstructural damage at the edges, which could serve as initiation points for failure. Finally, the composite material is tested to evaluate its mechanical properties. Tests such as tensile, flexural, and impact are performed to ensure the material possesses the required strength and durability for technical applications in industries such as aerospace, automotive, or lightweight construction. This process ensures that the developed composite not only meets mechanical requirements but also supports environmental sustainability through the use of natural fibers. These tests are typically conducted following ASTM or ISO standards, and the results serve as references for technical validation and further industrial-scale development (Kabir et al., 2012).

Tensile test results

The tensile test was carried out using the 3-Point Bend Test method to evaluate the mechanical properties of the composite material with fiber orientations of 0°, 45°, and 90°. The testing speed was 5 mm/min with plate-shaped specimens. The main parameters measured included maximum flexural strength (Max Force), maximum displacement (Max Displacement), breaking force (Break Force), and displacement at break (Break Displacement). The following are the results and analysis of the test.

Table 1. Testing Analysis Result

Name Parameters Unit	Max Force Calc. at Entire Area N	Max Disp. Calc. at Entire Area mm	Break_Force Sensitivity 10 N	Break_Disp. Sensitivity 10 mm
P 00	71.4135	19.0219	37.3101	19.1414
P 45	19.8968	6.61780	-.-	-.-
P 90	11.2470	8.77450	-.-	-.-

The specimen with fibers aligned at **0° orientation** exhibited the highest mechanical performance among all configurations. The maximum force recorded was **71.41 N**, accompanied by a maximum displacement of **19.02 mm**. In addition, the breaking force reached **37.31 N**, with a displacement at break of **19.14 mm**. These values reflect an efficient stress distribution, as the fibers were oriented parallel to the applied load, allowing them to bear most of the stress and enhance both strength and flexibility.

In contrast, the specimen with a **45° orientation** showed a considerable reduction in performance. The maximum force was limited to **19.89 N**, and the maximum displacement reached only **6.62 mm**. The diagonal alignment of fibers disrupted uniform stress transfer within the matrix, leading to premature failure and lower overall strength compared to the parallel orientation.

The weakest performance was observed in the **90° orientation**, where fibers were positioned perpendicular to the applied force. This configuration resulted in a maximum force of only **11.25 N**, while the maximum displacement was **8.77 mm**. The perpendicular alignment created localized stress concentrations, which prevented effective load transfer and significantly reduced the structural integrity of the composite material.

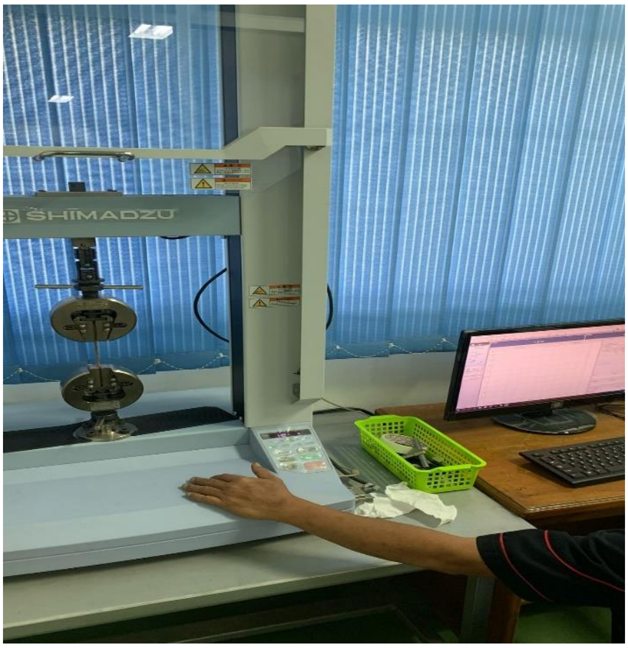

Figure 1. Fracture Results before Testing

Figure 2 shows the initial condition of the specimen before the tensile test was conducted. Typically, in this figure, the specimen is in an intact state without any visible damage. This condition is important for comparison with the test results, allowing the analysis of changes or damage that occurred in the material after the applied load.

Airman: Jurnal Teknik dan Keselamatan Transportasi
Volume 8 Issue 1 June 2025 | page 12-23
DOI: http//doi.org/10.46509/ajtk.v8i1.649

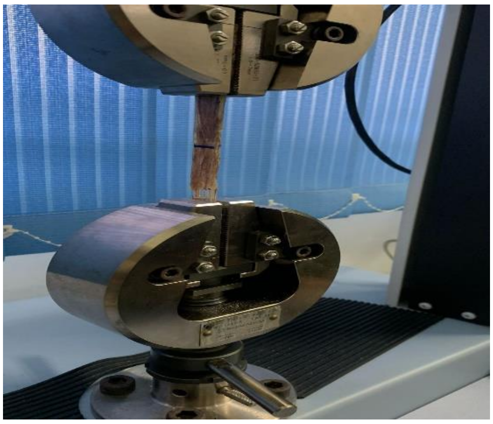

Figure 2. Tensile Test Process

Figure 3 illustrates the tensile testing process using the 3-Point Bend Test method. In this test, the specimen is placed on two supports, with the load applied at the midpoint of the specimen. This process is used to measure the material's response to the applied flexural force, including its strength and elasticity.

Figure 3. Fracture Results after Testing

Figure 4 shows the condition of the specimen after the tensile test, where visible damage or fracture occurred in the material.After the load was applied at a certain point, the specimen experienced deformation that led to fracture or cracking. In this figure, the damage can be compared with the measurement results in the table, which present the breaking force and displacement at break.

Fiber orientation graph

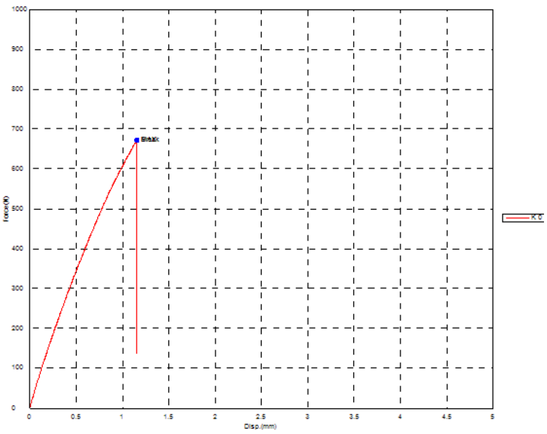

Figure 4. Orentation Graph 0° (P00)

In the **0° fiber orientation**, the fibers are aligned with the direction of the applied flexural load, allowing for an even distribution of force across the entire specimen. As a result, the material demonstrated optimal mechanical performance with a **maximum force of 71.4135 N,** which is the highest value compared to other fiber orientations. This indicates excellent flexural strength of the material. Furthermore, the material's ability to withstand deformation is evident from the **maximum displacement of 19.0219 mm,** showing maximum flexibility. Additional parameters such as a **breaking force of 37.3101 N** and a **break displacement of 19.1414 mm** were also recorded for this orientation. These results indicate that the material was able to endure significant deformation before fracturing, confirming that the parallel fiber orientation is the most effective configuration for supporting structural applications under flexural loads. This outcome highlights the crucial role of fiber orientation in determining the mechanical properties of composites for various technical applications.

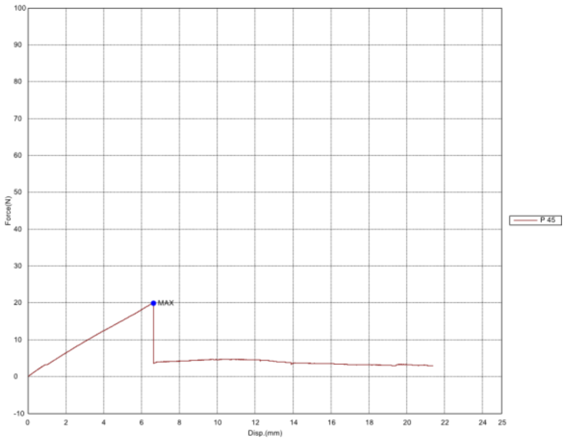

Figure 4. Orientation Graph 45^0 (P45)

In the **45° fiber orientation**, the fibers are positioned diagonally to the direction of the applied flexural load. This arrangement results in a less uniform force distribution within the composite material compared to the 0° orientation. Consequently, the material exhibited lower mechanical performance. The **maximum force recorded was 19.8968 N**, showing a significant decrease compared to the 0° orientation. In addition, the **maximum displacement reached only 6.6178 mm,** indicating that the material was stiffer and had limited deformation capacity. The absence of data for **breaking force** and **break displacement** suggests that the material failed earlier before reaching its breaking point, likely due to its stiffness, which restricted flexibility.

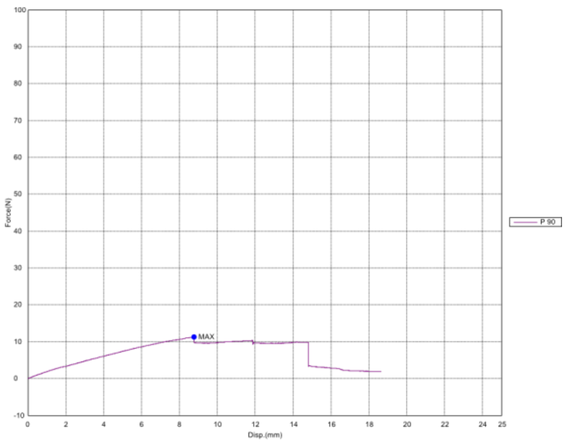

Figure 5. Orientation Graph 90^0 (P90)

In the **90° fiber orientation**, the fibers are positioned perpendicular to the direction of the applied flexural load, preventing the material from effectively distributing the force along the fibers. This condition leads to stress concentration at specific points, which accelerates material failure. In this orientation, the **maximum force reached only 12.2870 N**, representing the lowest performance compared to the other orientations. The **maximum displacement was recorded at 5.7745 mm,** indicating a slightly higher deformation capacity than the 45° orientation, but still significantly lower than the 0° orientation. Similar to the 45° orientation, no data for **breaking force** and **break displacement** were recorded, likely because the material fractured earlier due to the limited ability of the perpendicular fibers to withstand the applied load.

Overall, the **45° and 90° fiber orientations** clearly demonstrate that fiber misalignment with the direction of force drastically reduces the mechanical performance of the material, both in terms of strength and flexibility. This emphasizes the importance of proper fiber orientation design in determining the mechanical properties of composites, especially for applications requiring high flexural strength and flexibility, such as in the aviation industry. The **parallel fiber orientation (0°)** evidently provides far superior results compared to the other two orientations.

CONCLUSION

The results of this study demonstrate that fiber orientation plays a decisive role in determining the mechanical performance of coconut fiber–based composites. Among the tested configurations, the **0° orientation** achieved the highest flexural strength (**73.41 N**) and maximum displacement (**19.02 mm**), indicating superior strength and flexibility due to efficient stress transfer along the fiber direction. In comparison, the **45° orientation** produced a significantly lower flexural strength of **29.90 N** with limited displacement (**6.62 mm**). In contrast, the **90° orientation** exhibited the weakest performance, recording only **13.25 N** of flexural strength and a displacement of **8.77 mm**. These results indicate that misaligned fibers, whether diagonal or perpendicular to the applied load, result in stress concentration and reduced structural integrity. Overall, the study confirms that aligning fibers parallel to the load direction (0°) provides the most favorable distribution of force, thereby maximizing both strength and deformation resistance. This orientation can therefore be recommended for **structural applications in which high flexural performance is required**, particularly in industries such as aviation, automotive, and lightweight construction. Moreover, the findings provide a valuable foundation for the continued development of **sustainable, natural fiber–reinforced composites**, supporting global efforts to replace synthetic fibers with biodegradable and eco-friendly alternatives. Future research should extend this work by exploring hybrid natural fiber systems, optimizing fiber treatment methods, and evaluating long-term durability under dynamic loading to better align with the rigorous performance demands of aerospace and other high-technology applications.

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