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Research Article

The Effect of Fiber Length on the Strength of Composites as Boat Body Materials

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ABSTRACT

Purpose of the study: This study investigates the effect of coconut fiber length on the mechanical performance of polyester-based composite materials intended as an alternative body material for small boats, addressing the growing demand for sustainable and locally sourced marine materials.

Methodology: An experimental research design was employed using coconut fiber reinforcements with lengths of 10 mm, 30 mm, and 50 mm at a fixed fiber–resin ratio of 5%:95%. Composite specimens were fabricated using the hand lay-up method, reflecting practical production conditions commonly used in small-boat construction. Mechanical characterization was conducted using flexural strength testing in accordance with ASTM D790-02 and impact strength testing in accordance with ASTM E-23, using a Zwick Roell Z020 universal testing machine.

Main Findings: The results demonstrate a clear positive correlation between fiber length and mechanical strength, with longer fibers providing more effective stress transfer and energy absorption within the composite matrix. The composite reinforced with 50 mm of coconut fiber exhibited the highest performance, achieving a flexural strength of 63.4 MPa and an impact strength of 45.42 kJ/m², both of which meet the mechanical requirements for small-boat materials set by the Indonesian Classification Bureau.

Novelty/Originality of this study: Optimization of coconut fiber length for marine-grade polyester composites, offering empirical evidence that locally available natural fibers can meet regulatory standards for small vessel applications. This research advances eco-friendly composite technology and presents coconut fiber–reinforced polyester as a viable, sustainable alternative to conventional wood-based boat materials.

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1. INTRODUCTION

The increasing scarcity of wood as the primary material for boat construction has intensified the demand for alternative materials that are lightweight, mechanically strong, and resistant to harsh marine environments. In Indonesia, traditional wooden boat hulls are still widely used; however, wood presents several inherent limitations, including low resistance to prolonged water exposure, vulnerability to biological degradation, and high maintenance requirements [1]-[6]. These shortcomings not only shorten the service life of vessels but also raise operational and maintenance costs for coastal communities. Consequently, the development of alternative boat hull materials that are both durable and environmentally sustainable has become an urgent necessity in the marine sector.

Composite materials have emerged as a promising solution to address these challenges. Composites are formed by combining two or more materials with different physical and mechanical properties to produce a new material with enhanced performance characteristics [7]-[10]. In recent years, research attention has increasingly shifted toward natural fiber–reinforced composites due to growing environmental concerns and the need to reduce reliance on synthetic fibers. Among the various natural fibers abundantly available in Indonesia, coconut fiber (coir) has gained considerable interest because of its renewability, low cost, and favorable mechanical properties. Coconut fiber contains high levels of lignin and cellulose, which contribute to its elasticity, moisture resistance, and sufficient mechanical strength for reinforcement purposes [11]-[14]. These characteristics make coconut fiber particularly suitable for applications in humid and corrosive environments such as marine settings. Previous studies have demonstrated that coconut fiber–reinforced composites have been applied in construction panels, automotive interior components, and upholstery materials due to their lightweight and biodegradable nature. In marine applications, coconut fiber composites offer additional advantages, including corrosion resistance and relatively low production costs compared to metal-based or heavily processed wooden materials [15]-[17]. These attributes position coconut fiber composites as a potential alternative material for small boat hulls.

The mechanical performance of natural fiber composites is influenced by several key parameters, one of the most critical being fiber length. Fiber length plays an essential role in determining stress transfer efficiency between the fiber and the matrix, thereby affecting tensile, flexural, and impact strength. Previous studies have reported that optimal fiber length can enhance load distribution, improve energy absorption, and increase overall composite toughness [18]-[22]. Conversely, fibers that are too short may fail to provide effective reinforcement, while excessively long fibers can result in poor dispersion, fiber agglomeration, and weakened interfacial bonding.

In addition to fiber length, chemical treatment of fibers significantly influences composite performance. Alkali treatment using sodium hydroxide (NaOH) is widely employed to modify natural fibers by removing non-cellulosic components such as lignin, hemicellulose, and pectin that can inhibit fiber–matrix adhesion [23]-[26]. This treatment enhances interfacial bonding between coconut fibers and polymer matrices, leading to improved mechanical properties, including tensile strength, flexural strength, and impact resistance. Despite these advancements, the interaction between fiber length variation and polyester matrix reinforcement in marine-oriented composite applications remains insufficiently investigated. Although numerous studies have explored natural fiber–reinforced composites, most existing research focuses on general mechanical characterization or non-marine applications, such as building materials and automotive components. Research specifically examining the effect of coconut fiber length variation on both impact strength and bending strength of polyester-based composites intended for boat hull applications is still very limited. Furthermore, many previous studies emphasize variables such as fiber volume fraction, matrix type, or chemical treatment in isolation, without systematically analyzing fiber length as a dominant factor under controlled conditions.

In addition, most experimental studies have been conducted using industrial fabrication techniques or highly controlled laboratory conditions that may not reflect the realities of small-scale boat production. There is a notable lack of studies that integrate controlled fiber length variation, fixed fiber–resin composition, alkali-treated fibers, and practical fabrication techniques such as the hand lay-up method, while simultaneously linking the resulting mechanical performance to applicable marine material standards. This gap has resulted in limited empirical guidance regarding the optimal coconut fiber length configuration for polyester composites intended for marine structural components.

To address this research gap, the present study investigates the effect of coconut fiber length variation (10 mm, 30 mm, and 50 mm) on the impact strength and bending strength of a BQTN 157 polyester composite with a fixed composition of 5% fiber and 95% resin, fabricated using the hand lay-up method. By systematically evaluating the mechanical performance associated with different fiber lengths, this study aims to identify the most effective fiber configuration for enhancing composite strength and toughness in marine applications. The findings are expected to contribute to the development of environmentally friendly composite materials that meet the mechanical performance requirements for boat hull structures, support innovation in sustainable marine materials, and provide empirical data relevant to compliance with the standards of the Indonesian Classification Bureau, while reducing dependence on increasingly scarce wood resources.

2. RESEARCH METHOD

This study used an experimental approach in the laboratory with the aim of determining the effect of variations in coconut fiber length on the impact strength and bending strength of polyester resin-based composites. The independent variable in this study was the length of the coconut fiber, while the dependent variable was the impact strength and bending strength values obtained from the test results. This study was conducted in the Engineering Materials Laboratory, with a duration of approximately two months. This study used several main materials that play an important role in the process of making natural fiber-based composites. The first material used was coconut fiber that had been soaked in a sodium hydroxide (NaOH) solution for two hours. This alkalization process aims to remove dirt, lignin, and other impurities that can inhibit the adhesion between the fiber and the matrix. The matrix used in this study was BQTN 157 type polyester resin, which functions as a fiber binder to form a strong and homogeneous composite structure. In addition, an alkaline NaOH solution was also used as a chemical treatment agent for the fiber, as well as a catalyst as a hardener that accelerates the resin drying process. Without a catalyst, the resin would take a very long time to harden completely.

The tools used in this study consisted of specimen molds with ASTM D790-02 standards for flexural testing and ASTM E-23 for impact testing. These molds were used to form composite specimens with dimensions according to the test standards. A digital scale was used to measure the mass of the material with high accuracy, while scissors were used to cut the fibers according to the specified length variations. The resin and catalyst mixing process was carried out using a plastic cup as a container and a wooden stick as a stirring tool. Strength testing was carried out using an impact testing machine and a Zwick Roell Z020 type bending testing machine. In addition, a vernier caliper was used as a precision measuring tool to ensure that the specimen dimensions were in accordance with the established testing standards.

This study uses a laboratory experimental design with a controlled variable approach to determine the effect of variations in the length of coconut fiber on the mechanical strength of polyester resin-based composites. The variables used in this study consist of independent variables, dependent variables, and fixed variables. The independent variable in this study is the length of coconut fiber with three size variations, namely 10 mm, 30 mm, and 50 mm. The dependent variable is the result of mechanical testing which includes bending strength and impact strength. The fixed variables include the immersion time of the fiber in a 5% sodium hydroxide (NaOH) solution for two hours and the composition of the volume fraction of polyester resin and coconut fiber with a ratio of 95%:5%.

The research process begins with the processing of coconut fiber. The fiber is first cut into small pieces to separate the hard and cork parts. The fiber is then soaked in water until softened, then mechanically processed to separate the fiber from the binder layer. After that, the fiber is washed thoroughly and dried in the sun or using a drying machine until its moisture content decreases. The dried fiber is combed using a steel comb to separate it completely, then soaked in a 5% NaOH solution for two hours to remove lignin and impurities that can inhibit adhesion to the resin. After the soaking process is complete, the fiber is rinsed with clean water until the pH is neutral and dried again until it is ready to be used as a composite reinforcement material. The next stage is the manufacture of composite specimens using the hand lay-up method. The molds used follow the ASTM D790-02 standard for bending testing and ASTM E-23 for impact testing. Coconut fibers that have been cut to the length of each variation are arranged evenly in the mold. A mixture of BQTN 157 polyester resin and catalyst is made with a ratio of 99:1, then stirred until homogeneous. The resin mixture is poured slowly into the mold that already contains the fiber, then leveled so that the resin evenly covers all parts of the fiber. The specimens are allowed to harden at room temperature for 24 hours before being removed from the mold and cut to the standard test size.

Three specimens were made for each fiber length variation for each type of test, resulting in a total of nine specimens. This research process was conducted systematically so that the results obtained could represent the effect of fiber length on the mechanical strength of the composite. The stages of the research procedure can be illustrated in a flow diagram as in Figure 1, which contains the sequence of processes starting from fiber processing, material mixing, composite molding, to the drying and testing processes.

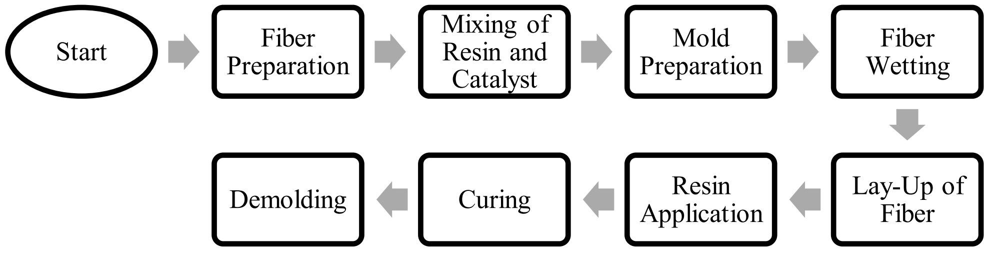

Figure 1. Shows the flow diagram of the composite manufacturing process using the hand lay-up method.

Tests were conducted to obtain data on the mechanical strength of the composite, including bending and impact tests. Both tests aimed to determine the extent to which coconut fiber length affects the strength and toughness of polyester resin-based composite materials. Bending tests were conducted using a Zwick Roell Z020 machine using the three-point bending method according to the ASTM D790-02 standard. Before the test began, the jig or fixture was ensured to be properly installed on the machine. Supporting software such as TestXpert was used to set parameters and record test results automatically. The specimen's dimensions, including length, width, and thickness, were first measured, then the data was entered into the software system. After that, the specimen was placed on two machine supports, and the load was applied slowly at a predetermined compression speed based on the standard. The machine pressed the specimen until fracture occurred or until the maximum load was reached. All parameters such as maximum force, deflection, load-resilience curve, bending strength , and flexural modulus were automatically recorded in the system.

Meanwhile, impact testing was conducted to measure the composite's resistance to shock loads using the Charpy impact test method based on the ASTM E23 standard. The specimen was placed in a horizontal position and struck with a pendulum at a certain speed. The energy absorbed when the specimen broke was read directly by the instrument and expressed in kilojoules per square meter (kJ/m^2). This absorbed energy value indicates the material's level of toughness against sudden impact forces. Test data were obtained in the form of tables and graphs, automatically recorded by the software system. Each fiber length variation was tested three times for each type of test to obtain a representative average value. The test results were then processed and compared to determine the effect of fiber length variations on the increase in bending strength and impact strength of the composite. The data acquisition process was carried out with the principles of accuracy and replication of results so that they can be used as a basis for analysis in the results and discussion sections.

3. RESULTS AND DISCUSSION

This section describes the results of mechanical strength testing of coconut fiber composites based on BQTN 157 polyester resin with fiber length variations of 10 mm, 30 mm, and 50 mm. Tests were conducted to determine the effect of fiber length on the bending and impact strength of the composite.

3.1. Bending Test Results

Bending test results indicate that fiber length significantly influences the flexural strength of the composite. The highest bending strength value was obtained for the composite with a fiber length of 50 mm, while the lowest value was found for the fiber length of 10 mm. The average test results are presented in Table 1.

Table 1. Results of bending tests of coconut fiber composites

Fiber Length (mm)	Bending Strength (MPa)
10	34.9
30	52.6
50	63.4

Table 1 shows that increasing fiber length is directly proportional to the increase in the composite's flexural strength. This is because, as the fiber length increases, the contact area between the fiber and the matrix also increases, resulting in a more effective transfer of shear forces from the matrix to the fiber. This mechanism enhances the composite's ability to withstand bending loads.

Flexural test results show that coconut fiber length significantly affects the composite's flexural strength. Flexural strength values increased as fiber length increased from 10 mm to 50 mm. The composite with a fiber length of 50 mm produced the highest flexural strength value of 63.4 MPa, while the composite with a fiber length of 10 mm showed the lowest value of 34.9 MPa. This increase indicates that longer fibers can transfer stress from the polyester matrix to the fibers more effectively. The longer fiber length increases the contact area at the fiber-matrix interface, enabling more efficient load transfer and stress distribution. As a result, the composite becomes more resistant to bending loads. This increase in flexural strength is closely related to the stress-transfer mechanism between the matrix and the fibers. Longer fibers have a larger aspect ratio, allowing them to transfer shear stress from the matrix to the fibers more effectively. Increasing fiber length also increases the fiber-matrix interface contact area, contributing to a more even stress distribution and reducing local stress concentrations in the matrix. This makes the composite more resistant to deformation and flexural failure.

This phenomenon aligns with research conducted by Khieng et al [27] and Ma et al [28], which states that the longer the fiber in a composite material, the greater the fiber's ability to withstand bending strain due to more optimal stress transfer from the matrix to the fiber. These results align with the shear-lag theory proposed by Kelly and Tyson, which states that the efficiency of fiber reinforcement in a composite increases with increasing fiber length until it reaches a critical length [29]. Natural fiber composites with longer fibers exhibited a significant increase in flexural strength, as the fibers could withstand greater strain before failure. In composites with short fibers, flexural failure occurred more quickly due to fiber pullout and matrix cracking [30]-[35]. In contrast, in long-fiber composites, failure was dominated by fiber fracture, which requires greater energy.

Furthermore, alkalization of the fiber increases adhesion between the fiber and resin, thereby reducing the likelihood of debonding during testing. Moreover, alkali treatment of coconut fibers significantly increased the flexural strength of the composites. Alkalization can remove lignin, hemicellulose, and surface impurities from the fibers, thereby improving surface roughness and mechanical adhesion between the fibers and the resin. This improved interfacial bond reduces the likelihood of debonding under flexural loading and allows for more effective load transfer from the matrix to the fibers.

3.2. Impact Test Results

Impact testing was conducted to determine the composite’s resistance to shock loads. The test results showed that the longer the fiber length, the greater the composite’s impact energy absorption. The test results are shown in Table 2.

Table 2. Results of impact testing of coconut fiber composites

Fiber Length (mm)	Bending Strength (MPa)
10	23.88
30	34.15
50	45.42

The impact test results showed a consistent trend with the flexural test, with impact strength increasing with increasing fiber length. The composite with 50 mm fibers had the highest impact strength of 45.42, while the 10 mm fibers achieved only 23.88. This indicates that longer fibers have a greater impact energy absorption capacity. This increase indicates that longer fibers have a greater impact energy absorption capacity. When subjected to shock loads, long fibers can deform, stretch, and absorb energy before fracturing, thereby maximizing impact energy absorption. Conversely, short fibers tend to fracture more quickly because of their limited ability to absorb and distribute shock forces. This increase in impact strength is due to the ability of longer fibers to absorb impact energy through tension and fiber deformation before fracturing. In other words, the longer the fiber, the more energy can be absorbed before structural failure occurs.

Under impact loading, the energy absorbed by the material is dissipated through mechanisms such as matrix deformation, fiber tension, fiber bridging, and fiber pull-out. Longer fibers can undergo greater deformation and tension before fracturing, allowing impact energy to be absorbed gradually. Conversely, short fibers have limited shock-force distribution, resulting in more rapid, brittle failure. This finding is consistent with research by Iliyasu et al [36], Rejikumar and Anand [37], and Ali [38], which states that increasing fiber length improves the composite's ability to absorb impact energy because the shock force can be distributed more evenly along the fiber. Furthermore, the improved interfacial bonding from alkali treatment also enhances impact toughness by preventing premature fiber detachment during shock loading.

3.3. Comparative Analysis

Overall bending and impact test results indicate that the 50 mm fiber-length composite has the highest mechanical performance compared to the other two variations. The relationship between fiber length and composite mechanical strength can be seen in Figure 2.

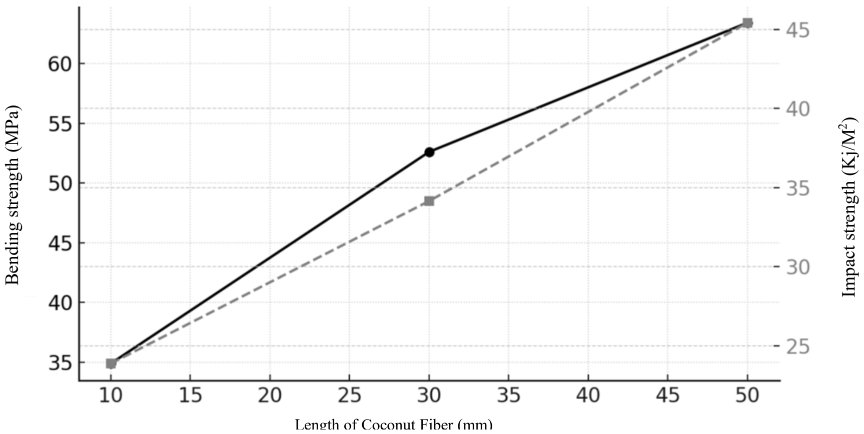

Figure 2. Relationship of Fiber Length to Bending & Impact Strength

From the graph in Figure 2, it can be seen that increasing fiber length has a positive effect on both mechanical strength parameters. Fibers with a length of 50 mm show an increase in bending strength of approximately 81% and impact strength of approximately 90% compared to specimens with a fiber length of 10 mm. Overall, these improvements in mechanical properties indicate that coconut fiber has significant potential as a natural reinforcing material for marine composites. Test results showed that the 50 mm fiber-length composite material met the minimum strength standards for boat materials based on the Indonesian Classification Bureau criteria, making it a suitable alternative to wood for small boat hull structures. This significant increase confirms that fiber length is the dominant parameter in increasing the strength and toughness of coconut fiber composites.

Overall, these improvements in mechanical properties demonstrate that coconut fiber has significant potential as a natural reinforcing material in composites, particularly for marine applications. Test results indicate that the 50 mm fiber composite meets the minimum strength standards for ship materials based on the Indonesian Classification Bureau criteria. Therefore, coconut fiber composites have the potential to serve as an alternative to wood for small ship hull structures, offering not only adequate mechanical strength but also greater environmental friendliness and sustainability [39]-[44].

The novelty of this research lies in the optimization of coconut fiber length (10 mm, 30 mm, and 50 mm) in the BQTN 157 polyester composite for small-boat hull applications, which was evaluated simultaneously through flexural and impact tests. This study provides experimental evidence that local coconut fiber of a specific length can meet BKI mechanical standards, even when used at a low fiber fraction (5%) and produced via the hand lay-up method. Thus, this study expands the use of coconut fiber from a standard alternative material to a sustainable, marine-grade composite material. The results of this study strengthen the stress transfer and shear-lag theory in short-fiber composites, which states that increasing fiber length to near the critical length can improve load transfer and energy absorption efficiency. These findings also add to the literature on the mechanical behavior of natural fiber composites in marine applications. Practically, this research provides a scientific basis for shipbuilders and small industries to use coconut fiber composites as an alternative to wood in small boat hull construction. The use of local coconut fiber not only reduces production costs but also supports sustainability principles and helps reduce the exploitation of natural wood.

This research has several limitations. First, the parameters studied were limited to variations in fiber length at a fixed fiber volume fraction, thus not accounting for interactions between fiber length and a broader range of fiber fractions. Second, the tests conducted included only flexure and impact tests, without considering other mechanical properties, such as tensile, fatigue, and seawater resistance. Third, microstructural observations, such as SEM analysis to determine the failure mechanism, were not performed.

4. CONCLUSION

Based on the research results, it can be concluded that the length of coconut fiber significantly influences the flexural and impact strength of polyester composites. Increasing the fiber length from 10 mm to 50 mm consistently improves the composite's ability to transfer loads and absorb energy. The composite with a fiber length of 50 mm demonstrated the highest mechanical performance, with a flexural strength of 63.4 MPa and an impact strength of 45.42 kJ/m², meeting the minimum requirements for small-boat hull materials set by the Indonesian Institute of Sciences. Therefore, 50 mm coconut fiber-reinforced polyester composites have the potential to serve as an environmentally friendly, economical, and mechanically feasible alternative to wood in small boat hull construction. This research makes a significant contribution to the development of sustainable composite materials based on local Indonesian resources.

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AUTHOR CONTRIBUTIONS

Conceptualization, methodology, software, investigation, validation, AP; formal analysis, writing original draft preparation, data curation, writing review and editing, Y and J.

CONFLICTS OF INTEREST

The author(s) declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

The authors declare that no artificial intelligence (AI) tools were used in the generation, analysis, or writing of this manuscript. All aspects of the research, including data collection, interpretation, and manuscript preparation, were carried out entirely by the authors without the assistance of AI-based technologies.

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