Design and Development of Coconut Fiber Sandwich Panel Ceilings

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Abstract: *This study aims to evaluate how varying the amount and length of coconut fiber affects the mechanical properties of sandwich ceiling panels, specifically their tensile and flexural strength. The panels are made of alternating layers of coconut fiber and plywood, bonded with polyester resin. Laboratory experiments were conducted at Manado State Polytechnic, focusing on tensile strength testing (ASTM D 638-02) and flexural strength testing (ASTM D 790-02). The coconut fiber volume fractions used were 30%, 40%, and 50%, with fiber lengths of 10-20 mm and 30-40 mm. Results showed a positive correlation between fiber volume fraction and length with improved tensile and flexural strength. The highest tensile strength (19.97 MPa) was achieved with a 50% fiber volume fraction and 30-40 mm fiber length, while the highest flexural strength (25.7 MPa) was obtained with a 50% fiber volume fraction and 10-20 mm fiber length.*

Keywords: Volume Fraction; Flexural Strength; Tensile Strength; Ceiling Sandwich; Coconut Fiber

1. INTRODUCTION

Coconut fiber is a sustainable organic substance with eco-friendly characteristics. Due to its lightweight, water-resistant, and fire-resistant characteristics, this material is commonly employed as a filler in the production of sandwich panels. Coconut fiber sandwich panel ceilings are a notable application of this material, which is gaining popularity in the building sector because of its exceptional strength and stability. To fully optimize the utilization of coconut fiber in sandwich panel ceilings, it is imperative to gain a comprehensive understanding of how the mechanical properties of the panel are affected by the volume percentage and length of the fibers. The mechanical properties of sandwich panels, such as tensile strength, flexural strength, and stiffness, can be significantly affected by the volume percentage and length of coconut fibers.

Some key concerns regarding this study area pertain to the inadequate understanding of how the volume fraction and fiber length affect the mechanical qualities of coconut fiber sandwich panel ceilings. The utilization of coconut fiber as a primary component for sandwich panels is a relatively recent development, thereby necessitating further investigation into the mechanical characteristics of coconut fiber sandwich panels. Furthermore, there are difficulties in determining the most suitable proportion of volume and length of fibers. To achieve ideal mechanical qualities in coconut fiber sandwich panels, it is crucial to carefully choose the appropriate volume percentage and fiber length. Choosing the appropriate volume fraction and fiber length can be a complex task due to various considerations, including the production technique, kind of fiber, and use of the sandwich panel.

Prior research has indicated that the mechanical characteristics of sandwich panels can be affected by the volume percentage and fiber length. However, there is currently a lack of study explicitly examining the impact of these two elements on the ceilings of coconut fiber sandwich panels. The study conducted by Sutriyono demonstrates that including coconut fiber into the polyurethane matrix for sandwich panels enhances both the compressive strength and stiffness of the panels [1]. According to this study, it was determined that the most effective amount of coconut fiber to enhance the mechanical characteristics of sandwich panels is approximately 20%. Shang and Zhang found that including coconut fiber into the epoxy matrix for sandwich panels can enhance the rigidity and durability of the panels [2]. According to this study, it was discovered that the most effective length of coconut fiber for enhancing the mechanical characteristics of sandwich panels is approximately 10 mm. In their study, Sari et al. shown that including coconut fiber into the polyurethane matrix for sandwich panels leads to enhanced tensile strength, stiffness, and compressive strength of the panels [3]. According to this study, it was discovered that the most effective amount of coconut fiber to enhance the mechanical characteristics of sandwich panels is approximately 25%. The study conducted by Fazli et al. demonstrated that the incorporation of coconut fiber into a polyester matrix for the production of sandwich panels can enhance both the tensile strength and stiffness of the panels [4]. According to this study, it was discovered that the most effective length of coconut fiber for enhancing the mechanical characteristics of sandwich panels is approximately 15 mm. The findings of this study demonstrate that including coconut fiber into sandwich panels can enhance their mechanical characteristics. To optimize the mechanical properties of the panel, it is crucial to carefully select the suitable volume percentage and length of coconut fiber. Nevertheless, additional investigation is required to enhance our comprehension of how the volume percentage and fiber length impact the mechanical characteristics of coconut fiber sandwich panel ceilings.

This research aims to investigate the impact of volume percentage and fiber length on the mechanical characteristics of coconut fiber sandwich panel ceilings. The study aims to achieve several specific objectives: to analyze the impact of varying the volume fraction of coconut fiber on the mechanical properties of coconut fiber sandwich panel ceilings; to analyze the impact of varying the length of the fiber on the mechanical properties of coconut fiber sandwich panel ceilings; to determine the ideal volume fraction and fiber length for producing coconut fiber sandwich panels with optimal mechanical properties; and to provide recommendations for selecting the appropriate volume fraction and fiber length when constructing coconut fiber sandwich panel ceilings.

This study aims to enhance the comprehension of the impact of volume fraction and fiber length on the mechanical qualities of coconut fiber sandwich panel ceilings by accomplishing these objectives. The aim of this research is to use the findings as a foundation for creating eco-friendly materials in the building sector. Additionally, it aims to offer suggestions on the ideal volume fraction and fiber length for producing coconut fiber sandwich panel ceilings.

2. MATERIALS AND METHODS

2.1. Ceiling

The term "ceiling" is derived from the Dutch word "plafond," which carries the same definition as "ceiling" in English and Indonesian. However, in Indonesia, it is commonly referred to as a "ceiling." The ceiling is an integral component of building construction, serving as the interface between the structural building frame and the roof frame. Therefore, it can be described as being positioned below the roof frame at the structural level.

2.2. Sandwich Structure

The sandwich structure has gained popularity as a versatile option for numerous engineering sectors, such as automotive, marine, aerospace, construction, and more. The sandwich structure typically comprises three layers, including a planar composite surface skin (referred to as the skin) and a central core material. This skin component often consists of a flat piece of metal, wood, or fiber composite material [5]. The various types of cores include honeycomb, corrugated, balsa wood, and cellular foams. Sandwich structures have a moderate vulnerability to low-speed impacts, but high-speed impacts do not provide a significant threat. In the case of low-speed collisions, the resulting damage is typically internal and not visually apparent. It possesses a lightweight construction yet exhibits exceptional rigidity and durability. Hence, sandwich composites are highly appropriate for withstanding bending loads, impacts, damping vibrations, and sound [6].

2.3. Composite materials

A composite is a heterogeneous blend of two or more distinct components that form a cohesive whole. Composite materials, which are commonly known, typically include of two components: fiber as a filler and a fiber-binding substance known as a matrix. Composites primarily consist of fibers as the main component, while the binding ingredient, commonly referred to as resin, is highly malleable. Coconut fiber is mostly utilized for evaluating the attributes of composite materials, including rigidity, durability, and other mechanical properties. Fibers are utilized as a filler material in order to endure the stresses exerted on composite materials. The matrix serves to safeguard and unite the fibers, enabling them to effectively withstand external forces. The matrix in issue exhibits greater ductility but lower stiffness strength. Meanwhile, the catalyst is employed to facilitate the drying process (curing) of the matrix material of a composite. Employing an excessive amount of catalysts or deviating from the prescribed dosage may accelerate the drying process even more, but it will also render the final composite material more prone to breakage [7].

2.4. Coconut Fiber

Coconut blankets or coconut shells contain valuable resources with excellent effectiveness, specifically coconut fiber (coco-fiber) and fiber powder (coco-peat), once the fiber components have been extracted. Coco-peat refers to coconut fiber that has been transformed into cork granules, which are sometimes referred to as coco-pith or coir pith. Coco-peat is a horticultural substrate derived from the fibrous material of coconuts [8].

2.5. Tensile Strength Testing

Tensile strength testing is a procedure in which a test object is subjected to a pulling force until it reaches its breaking point. The test specimen that is exposed to a tensile force will be positioned in a manner that is parallel to the axis and perpendicular to the cross-sectional surface. In addition, conducting testing for tensile strength is necessary to obtain essential design data and information regarding the strength of a material. These tests also serve as supporting evidence for material requirements if they are to be utilized. The tensile test allows for the gradual measurement of a material's ability to resist static forces, particularly those exerted on the ceiling. It is important to determine the tensile strength of the ceiling in order to assess its suitability for applications where the cross-sectional area impacts its tensile strength.

The general shape of the test sample of tensile strength is depicted as shown in Fig.1.

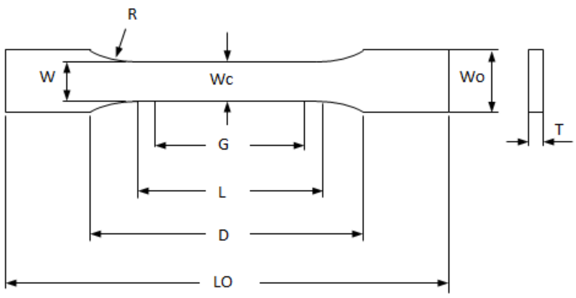

Fig. 1. Tensile test specimen

Note:
W = Width of narrow section
L = Length of narrow section
WO = Width overall, min
WO = Width overall, min
LO = Length overall, min
G = Gage length
G = Gage length
D = Distance between grips
R = Radius of fillet

2.6. Flexural Strength Testing

Flexural Strength Testing is employed to ascertain the flexural strength of a substance. One way to accomplish this is by conducting a test to measure the flexural strength of the composite material. The flexural strength test is conducted to assess the matrix's ability to withstand external forces. The data obtained from flexural strength testing is crucial for ceilings, as it accounts for both the flexibility and the vast cross-section of the ceiling. This flexural strength test follows the ASTM D 790 - 02 standard and is conducted under static test conditions. Flexural strength, also known as bending strength, refers to the maximum amount of stress that a material can withstand when subjected to external forces without undergoing significant deformation or failure. The magnitude of flexural strength is contingent upon the properties of the material and the applied load. During the flexural strength test, the upper portion of the specimen undergoes compressive force, while the lower portion encounters tensile stress. The general shape of the test sample of flexural strength is depicted as shown in Fig.2.

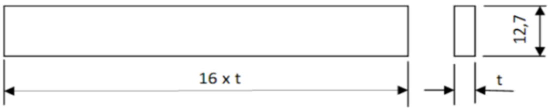

Fig. 2. Flexural strength test specimen

2.7. Research Methods

The research was conducted using an experimental laboratory setup, specifically utilizing the Zwick Roell Z100 Universal Testing Machine at the Materials Testing Laboratory, which is part of the Department of Mechanical Engineering at Manado State Polytechnic. The research conducted utilized coconut fiber with two size variations: 10 mm–20 mm and 30 mm–40 mm. Additionally, the fiber volume fraction varied at 30%, 40%, and 50% of the overall volume of the composite, which includes both the fiber and resin. The selection of the fiber percentage utilized in the study was driven by the necessity to investigate the impact of different fiber volume fractions on the mechanical characteristics of sandwich ceiling panels. Consequently, this study selected three different levels of coconut fiber volume percentage for evaluation. Furthermore, two variants in fiber length were also chosen for examination. The objective of this study is to establish the correlation between the volume fraction of fibers and the length of fibers in sandwich ceiling panels, and to identify the optimal combination of these two parameters that will enhance the mechanical strength of the panels. Subsequently, a verification process is conducted by creating test specimens of specified dimensions in order to assess the tensile strength (as depicted in Fig. 3) and flexural strength of the sandwich panel ceiling (as illustrated in Fig. 4). There are three test objects for each variation. The testing standards utilized in this research pertain to ASTM (American Standard Testing and Materials). By utilizing citations sourced from scholarly journals or relevant research studies. The coconut fiber is separated into two types based on fiber size: 10 mm–20 mm and 30 mm–40 mm. Additionally, there are variations in volume percentage, specifically 30%, 40%, and 50%. The evaluation of tensile strength on coconut fiber sandwich composites for ceilings is conducted according to the ASTM D 638-002 "Standard Test Method for Tensile Properties of Plastics" standard. The flexural strength testing of coconut fiber sandwich composites for ceilings follows the ASTM D 790-02 standards, which are the "Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials".

Fig. 3 Tensile strength test specimen

Fig. 4 Flexural strength test specimen

The composites produced in this study exhibit various compositions, including differences in the volume fraction percentage and fiber length, as indicated in Table 1. There are three different compositions of the composite based on variations in the volume fraction percentage used. These variants are as follows:

1. Composite variation 30% coconut fiber 70% matrix (98% polyester resin and 2% catalyst).
2. Composite variation 40% coconut fiber, 60% (98% polyester resin and 2% catalyst).
3. Composite variation 50% coconut fiber, 50% (98% polyester resin and 2% catalyst).

Table 1 Calculation of composite volume

Volume Fraction (%)	Fiber Volume (gr)	Matrix Volume (gr)	
		Polyester Resin	Catalyst
30	31.75	85.16	1.78
40	42.34	73.03	1.49
50	52.92	60.86	1.24

3. RESULTS AND DISCUSSION

3.1. Tensile Strength Test Results

The Zwick Roell Z100 UTM equipment is used to test the tensile strength of composite sandwich panel ceilings. The test results obtained from this machine directly align with the desired results and are accompanied by graphs that accurately represent the test outcomes. The results of the tensile strength test are presented in Table 2 and Fig. 5.

Table 2 Average results of tensile strength testing

Volume Fraction (%)	Fiber Length (mm)	Modulus of Elasticity (MPa)	Tensile strength (MPa)
30		1019.00	12,13
40	10 – 20	1063.33	18.80
50		1266.67	19.70
30		1120.00	18.03
40	30 – 40	1090.00	19.83
50		1266.67	19.97

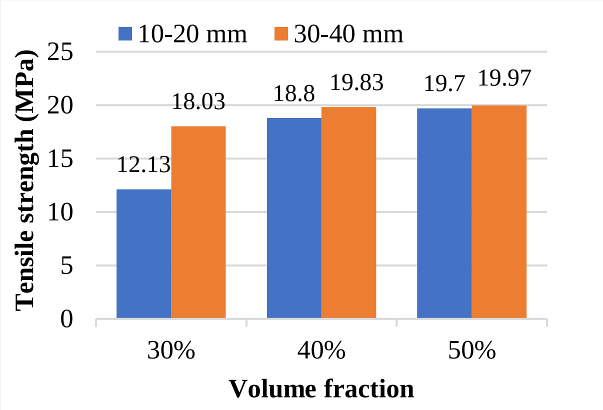

Fig. 5 Comparison diagram of tensile strength based on fiber length.

The conducted tests have yielded findings that are outlined in Table 2 and Fig.5. These results indicate that the composite with specimen variation 1 possesses a volume fraction of 50% and a fiber length ranging from 30 to 40 mm. The tensile strength test findings indicate that both changes in fiber length, specifically 10–20 mm and 30–40 mm, exhibited an improvement in tensile strength. Increasing the length of the fiber will result in a corresponding rise in its tensile strength. Based on the average results obtained for the two fiber length specimens, the greatest improvement in tensile strength was observed when the volume fraction ranged from 30% to 40%. Specifically, the 10-20 mm fiber length specimen had a significant increase in tensile strength of 6.67 MPa (55%). The average tensile strength varies depending on the fiber length and volume percent. The highest tensile strength, measuring 19.97 MPa, is seen in the variation with a 50% volume fraction and fiber length ranging from 30-40 mm. On the other hand, the lowest tensile strength is discovered in the variation with a 30% volume fraction and fiber length ranging from 10-20 mm. Based on the existing studies, it is advised to alter the volume fraction by 50% while using fiber lengths ranging from 30 to 40 mm and achieving a tensile strength of 19.97 MPa. Alternatively, it can indicate that a longer fiber length is required to enhance its tensile strength and minimize the need for costly resin in the market. In addition, fractures can exhibit various configurations in the geometry of the test object during the process of being pulled. This is due to the utilization of plywood in the core section, which necessitates an even distribution when separating the matrix, particularly in the plywood area that will be overlaid with coconut fiber. The lack of uniformity results in differences in the composite fracture morphology of each test sample.

3.2. Flexural Strength Test Results

In testing the flexural strength of composite sandwich ceiling panels, the tools used are the same as for tensile strength testing, namely using the Zwick Roell Z100 UTM tool. The results of the flexural strength test can be seen in Table 3 and Fig.6.

Table 3 Average results of flexural strength testing

Volume Fraction (%)	Fiber Length (mm)	Modulus of Elasticity (MPa)	Strength (MPa)
30		673.67	17.70
40	10 – 20	766.00	22.70
50		797.00	25.70
30		615.00	16.77
40	30 – 40	258.33	14.24
50		600.00	21.63

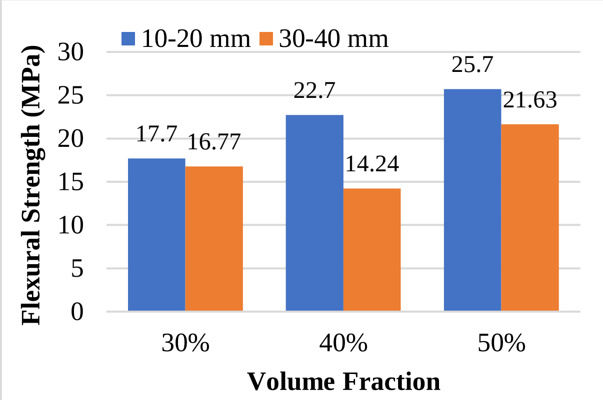

Fig. 6 Comparison diagram of flexural strength based on fiber length.

The results of the conducted flexural strength tests indicate that there is no significant increase in the specific flexural strength value when the fiber length varies between 10-20 mm for each volume fraction variation of 30%, 40%, and 50%. However, it is observed that the strength increases as the fiber volume fraction increases. The drag decreases. The analysis results revealed that the decline in flexural strength, observed at a volume fraction of 40%, was attributed to a decrease in the adhesive strength of the granular fiber elements [9], or alternatively, it could be attributed to a deficiency in binding capability [10]. In addition, the connection between the powder particles and the binder is solely based on mechanical bonding, resulting in a relatively weak binding between the particles. Based on the findings of research on flexural strength testing, it is advisable to alter the volume fraction by 50% while maintaining a fiber length of 10–20 mm and achieving a flexural strength of 25.7 MPa [11].

4. CONCLUSION

Based on the findings of the conducted experiments in this study, it can be inferred:

- The test results of this research demonstrate that differences in volume fraction (30%, 40%, 50%) and fiber length (10-20 mm, 30-40 mm) have a notable impact on the tensile strength of the coconut fiber composite. The greatest tensile strength is observed when the fluctuation is 50% with a fiber length ranging from 30 to 40 mm. Conversely, the lowest tensile strength occurs when the variation is

30% with a fiber length ranging from 10 to 20 mm. The tensile strength results for all fiber lengths ranging from 30 to 40 mm, with volume fractions of 30%, 40%, and 50%, were greater than those for fiber lengths ranging from 10 to 20 mm.

- The experimental results of this research demonstrate that differences in volume fraction (30%, 40%, 50%) and fiber length (10-20 mm, 30-40 mm) have a notable impact on the flexural strength of the coconut fiber composite. The flexural strength results for fiber lengths ranging from 10 to 20 mm, at volume fractions of 30%, 40%, and 50%, are greater than the flexural strength results for fiber lengths ranging from 30 to 40 mm.
- The ideal combination of volume fraction and fiber length for achieving optimal mechanical properties in coconut fiber sandwich panels is a volume fraction of 50% with a fiber length ranging from 30 to 40 mm, resulting in a tensile strength of 19.97 MPa. Additionally, a volume fraction of 50% with a fiber length ranging from 10 to 20 mm yields a flexural strength of 25.7 MPa.
- This research can offer suggestions on the ideal volume percentage and fiber length for constructing coconut fiber sandwich panel ceilings, resulting in panels with superior mechanical qualities. Implementing this method can enhance the efficiency and efficacy of coconut fiber sandwich panel manufacturing, decrease production expenses, and enhance the quality of the panels. In addition, the findings of this study can also aid in the advancement of eco-friendly materials within the construction sector.

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