Vol 14 (2), 2025, 53-61 DOI: 10.23960/jpkv2.1426
Jurnal Pendidikan dan Pembelajaran Kimia
e-ISSN: 2714-9595 | p-ISSN 2302-1772
http://jurnal.fkip.unila.ac.id/index.php/JPK/index

Manufacture and Characterization of Physical Properties of Composites Based on Coconut Fiber Composition (*Cocofiber*)

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Received: Jun 2nd, 2025 Accepted: Jul 7th, 2025 Online Published: Aug 25th, 2025

Abstract:Manufacture and Characterization of Physical Properties of Composites Based on Coconut Fiber Composition (*Cocofiber*). This study aims to analyze the quality of coconut fiber reinforced composites through evaluation of physical properties including density, porosity, and water content. The composites were made using coconut fiber modified by immersion in 5% NaOH, epoxy resin as a matrix, and MEKPO catalyst using the hand lay-up method. Five variations of resin:fiber volume composition were used, namely 95:5%, 85:15%, 75:25%, 65:35%, and 55:45%. The results showed that the composite with 5% fiber content produced optimal performance with the highest density (0.94 g/cm³), the lowest porosity (22%), and the lowest water content (0.57%). Increasing fiber content tended to decrease density but increase porosity and water content, indicating that low fiber compositions resulted in better fiber-matrix bonding and potentially superior mechanical properties.

Keywords:composite, coconut fiber, density, porosity, water content

Abstrak:Pembuatan dan Karakterisasi Sifat Fisik Komposit Berdasarkan Komposisi Serat Sabut Kelapa (Cocofiber). *Penelitian ini bertujuan untuk menganalisis kualitas komposit berpenguat serat sabut kelapa melalui evaluasi sifat fisik meliputi densitas, porositas, dan kadar air. Komposit dibuat menggunakan serat sabut kelapa yang dimodifikasi dengan perendaman NaOH 5%, resin epoksi sebagai matriks, dan katalis MEKPO dengan metode hand lay-up. Lima variasi komposisi volume resin:serat digunakan yaitu 95:5%, 85:15%, 75:25%, 65:35%, dan 55:45%. Hasil penelitian menunjukkan bahwa komposit dengan kandungan serat 5% menghasilkan performa optimal dengan densitas tertinggi (0,94 g/cm³), porositas terendah (22%), dan kadar air terendah (0,57%). Peningkatan kandungan serat cenderung menurunkan densitas namun meningkatkan porositas dan kadar air, mengindikasikan bahwa komposisi rendah serat menghasilkan ikatan serat-matriks yang lebih baik dan berpotensi menghasilkan sifat mekanik yang superior.*

Kata kunci: *komposit, serat sabut kelapa, densitas, porositas, kadar air*

▪ INTRODUCTION

The development of materials technology is a key driver of industrial progress. Traditional materials such as metals have long been the basis for manufacturing mechanical components (Ophelia et al., 2024). As industrial requirements become increasingly complex, particularly in terms of strength, stiffness, and efficiency, the need for more advanced materials is increasing. Composite materials, with structures consisting of two or more different components, have emerged as a promising alternative to meet these requirements (Susilawati et al., 2021). Combining various types of fibers as reinforcement with a polymer, metal, or ceramic matrix provides composite materials with superior properties in many respects. For example, carbon fibers offer high strength and stiffness, glass fibers offer good strength with low production costs, and aramid fibers offer a good combination of strength and ductility (Widodo, 2022).

The use of natural fibers in composite materials is a wise and sustainable decision. Natural fibers such as banana leaf fiber, sugar cane fiber, coconut fiber, and palm fiber have a variety of benefits, making them ideal for this application. One of their main advantages is their ability to biodegrade, making them an environmentally friendly choice compared to synthetic fibers (Nurfajriani et al., 2023).

Coconut plants are widely found throughout Indonesia. Based on the agricultural data center and information system, coconut production in Indonesia is estimated at 2.86 million tons in 2022. This production is expected to increase over the next five years, with an estimated production of 2.87 million tons in 2026. The average increase in coconut production over the next five years (2022-2026) is estimated at 0.14% per year. Therefore, with the availability of abundant coconut production that has not been optimally utilized, coconut fiber can be used as a filler or composite reinforcement fiber (Ya'qub et al., 2023).

Physical property evaluation is a fundamental step in composite material development, aiming to ensure the quality and performance of natural fiber composite materials in accordance with the desired application. The physical characterization of natural fiber composites encompasses several key interrelated parameters that influence the overall mechanical properties of the material (Syifa et al., 2021).

Density test is a basic parameter that indicates the mass density of the material per unit volume. The composite density follows the rule of mixture, where the composite density is determined by the volume fraction and density of each constituent phase. However, the presence of voids and porosity can significantly affect the actual density value (Nurfatih et al., 2023). Porosity test measures the level of voids or pores in the composite structure. High porosity indicates manufacturing defects such as air bubbles or imperfect bonding between the fiber and the matrix (Nuryati et al., 2020). Water content test in natural fiber composites is a complex phenomenon influenced by fiber content, porosity, and the hydrophilic properties of natural fibers. The water absorption process usually follows Fickian diffusion behavior, where the absorption rate depends on the availability of hydroxyl groups and diffusion pathways in the composite structure (Hisyam and Widyanti, 2021).

These three physical parameters are interrelated and provide a comprehensive picture of the quality of the resulting composite. Materials with high density, low porosity, and controlled moisture content generally exhibit superior mechanical properties and good resistance to environmental factors (Ramadani and Latief, 2024).

The hand lay-up method is one of the most commonly used manufacturing techniques for fiber-reinforced composites, especially in research and small-scale production. This method involves manually placing fibers in a mold and applying resin by hand, followed by consolidation to remove air bubbles and achieve proper fiber wetting. While this method is cost-effective and versatile, it can result in a higher void content compared to more sophisticated manufacturing techniques (Ramachandran et al., 2022).

In a previous study by Muriman et al., 2023, a composite was made based on variations in smoking time (3 hours, 4 hours, and 5 hours), coconut fiber as the basic material (filler). From the results of the smoking process, the water content in the fiber decreased by an average of 7% per hour. At a smoking time of 3 hours, the water content value was 11.2%, while at 5 hours of smoking time, the water content in the fiber was at 9.7%. The elasticity value of the composite material was 379.1 N/mm2 for the fiber material that was smoked for 3 hours, this value increased to 532.1 N/mm2 at a smoking time of 4 hours. There was an increase in the elasticity value of the composite material by 40.3% between the condition of the fiber that was smoked for 3 hours and the fiber that was smoked for 4 hours. (Muriman, 2023)

Based on the background description above, this study aims to make a composite derived from coconut fiber soaked in 5% NaOH alkali solution and to determine the quality of the composite through physical tests (density, porosity, and water content).

▪ METHOD

Composite Manufacturing

Composite specimens were made from coconut fiber that had been alkalized with 5% NaoH for 2 hours with the aim of reducing the lignin, cellulose, hemicellulose, and pectin components (Saputra et al., 2022) then the fiber is washed with 3% H_2O_2 which aims to bleach the fiber and help remove impurities (Zulkifli et al., 2020). And the addition of epoxy resin as a matrix with a small amount of MEKPO (methyl ethyl ketone peroxide) catalyst.The composite was made using the hand lay up method with a random fiber pattern, the comparison of matrix and fiber composition can be seen in Table 1.

Table 1. Comparison of Fiber and Matrix Composition

(%) Matrix	(%) Fiber	Sample Code
95	5	Sample A
85	15	Sample B
75	25	Sample C
65	35	Sample D
55	45	Sample E

Next, the fiber and matrix that have been measured are then mixed into a glass, added a catalyst and stirred slowly with a stirring rod until evenly mixed, then mold the mixture using a standard ASTM D683 composite mold that has been smeared with wax, smooth the surface of the mixture and close the mold then press with a molding machine for 10 minutes at a temperature of 100◦C. Lift the specimen and remove it from the mold, tidy it up according to the shape of the mold and the specimen is ready for physical testing.

Density Testing

The actual density test of the specimen begins by weighing the sample and recording the weight of the sample. Then the length, width and height of the sample are measured and recorded, and the volume of the sample is calculated (Nurfatih et all., 2023). Calculate the actual density of the sample using the equation:

$$\rho=\frac{m}{V}$$

Where ρ is the density (g/cm^3), m is the mass (g), V is the volume (cm^3) which includes (length (cm) x width (cm) x height (cm)).

Porosity Testing

The porosity test was carried out using actual density data and theoretical density, namely 1.2 g/cm^3 (Nuryati et all., 2020). The calculation to determine the porosity value of the composite sample using the equation:

$$\text{Porosity (\%)} = [1 - (\frac{density\ aktual}{density\ teoritis})] \text{ x } 1$$

Water Content Testing

Water content is the water content in a material which can be expressed based on wet weight and dry weight, the density equation used according to (Hisyam and Widyawati 2021).

$$KA = \frac{Ma - Mk}{Mk} \text{x } 100\%$$

Where KA is Water Content (100%), Ma is Initial Mass (grams) and Mk is Oven Dry Mass (grams).

▪ RESULT AND DISCUSSION

Composite Specimen Making Results

This research on the manufacture and characterization of the physical properties of coconut fiber-based composites has strong relevance to school learning, particularly in basic chemistry subjects. For example, research (Nurfajriani et al., 2023) that used various types of natural fibers such as areca nut husks, sugar cane fibers, corn husks, and coffee husks provides a broader context for the use of organic waste in composite technology. The consistency of the approach in evaluating the mechanical and physical properties of the material indicates that the research method used has become a standard in the development of natural fiber-based composite materials. The variety of materials used in this research teaches students about the diversification of Indonesia's natural resources and the potential for developing sustainable materials from agricultural waste.

The alkalization process of coconut fiber using 5% NaOH provides a concrete example of chemical change, where a reaction occurs between alkali and the lignin, cellulose, hemicellulose, and pectin components in the fiber. This differs from the physical changes that occur during the mechanical mixing of fiber and matrix. Students can understand that chemical changes produce new substances with different properties, while physical changes only change the form without changing the chemical composition (Melyna and Sopian, 2024). The curing reaction between epoxy resin and MEKPO catalyst is also a concrete example of a polymerization process that converts monomers into polymers with better mechanical properties (Mirmanto, 2022).

In specimen printing, epoxy resin and MEKPO (methyl ethyl peroxide) catalyst are mixed. When these materials are mixed, a curing reaction occurs between the epoxy resin and the MEKPO catalyst ($C_8H_{18}O_6$) causing the resin to dry. The function of the MEKPO catalyst is to increase the drying rate of epoxy resin.

The results of making composite specimens made from coconut fiber and epoxy resin using ASTM D683 Standard dimensions. Composites were made in five variations in each test with a ratio of resin and fiber of 95: 5, 85: 15, 75: 25, 65: 35, and 55: 45. The following are the results of making composite specimens from coconut fiber.

Figure 1. Coconut Fiber Composite Specimen (Personal source)

Density Test Results

Density testing is performed to determine the density of a composite material, which can provide information about the fiber and matrix distribution and help estimate the composite's mechanical properties. Density testing also serves to ensure consistent quality of the resulting composite product. The results of the density testing can be seen in Figure 2.

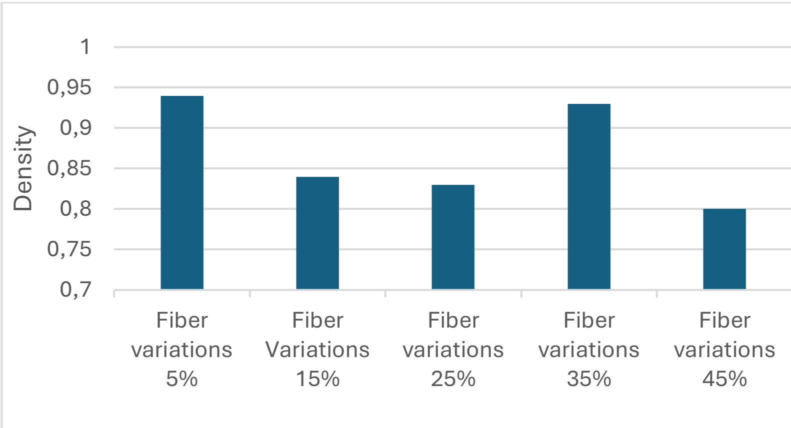

Figure 2. Graph of g/cm^3 density test results

Based on Figure 2, the density test results show an interesting relationship between fiber content and material density values. 5% fiber content produces the highest density of around 0.94 g/cm^3, while the addition of 15% and 25% fiber content decreases the density to 0.84 g/cm^3 and 0.83 g/cm^3. Interestingly, at 35% fiber content, the density increases to 0.93 g/cm^3, but then decreases again at 45% fiber content to reach the lowest value of 0.80 g/cm^3. In general, it can be concluded that increasing fiber content tends to decrease material density, although this relationship is not completely linear as indicated by the anomaly at 35% fiber content, but this study provides an in-depth understanding of the concept of density and its relationship to material composition. The results show that composites with 5% fiber content produce the highest density (0.94 g/cm^3), which can be explained through the basic formula $\rho = m/V$. This phenomenon teaches students that the physical properties of a material depend not only on the type of constituent material but also on the proportion and distribution of components within the composite (Tohir and Safira, 2021). Generally, natural fiber composites have a density of 1.0-1.5 g/cm^3. When compared to the density value according to SNI, natural fiber composites can be categorized as lightweight bricks, because the average density value is <2.0 g/cm^3 (SNI 03-0348-1989).

Porosity Test Results

Porosity testing is carried out to measure the number of cavities or pores contained in the composite. This is important because porosity can indicate defects in the manufacturing process and affect the quality of the bond between the fiber and the matrix. A high level of porosity will generally reduce the mechanical properties of the composite, and vice versa, a low level of porosity will improve the mechanical properties of the composite. So this test is an important parameter in evaluating the quality of the composite. The results of the porosity test can be seen in Figure 3.

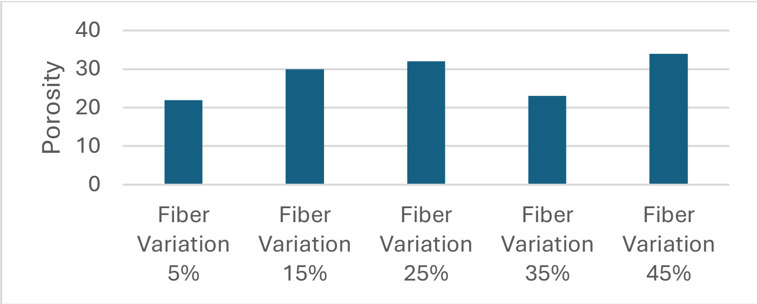

Figure 3. Porosity test results graph

Based on Figure 3, the results of the porosity test, at 5% fiber content shows a porosity value of 22%, then increases at 15% and 25% content with porosity values of 30% and 31% but there is a decrease in the 35% fiber content of 23% porosity and interestingly the porosity value increases drastically again at 45% fiber content of 34%. In accordance with the theory The concept of porosity related to the presence of air cavities in the material also provides an understanding of the microscopic structure that affects the macroscopic properties of the material. Students can understand that low porosity (22% in 5% fiber composites) produces better mechanical properties due to a denser and more homogeneous structure.

Water Content Test Results

Moisture content testing plays a crucial role because coconut fiber is hydrophilic, meaning it readily absorbs water. This test aims to determine the fiber's water absorption capacity and estimate the dimensional stability of the composite. Moisture content testing can also evaluate the material's environmental resistance and ensure optimal fiber drying. The results of the moisture content test can be seen in Figure 4.

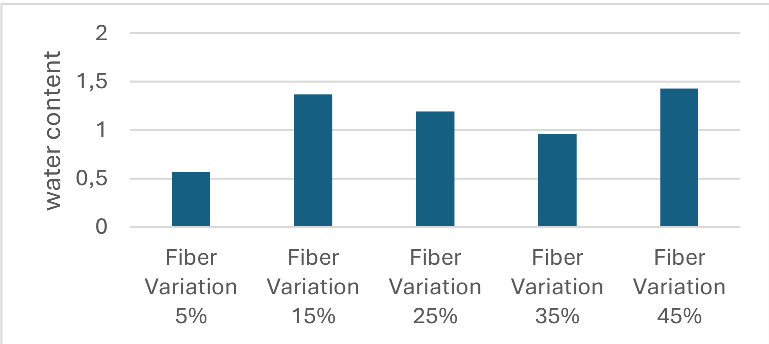

Figure 4. Water content test results graph

Based on the water content test results in Figure 4, variations in coconut fiber significantly affected the water content of the composite. The lowest water content occurred at 5% fiber variation (0.57%) and increased to a peak at 15% variation (1.37%). This increase is due to the hygroscopic nature of coconut fiber, which contains cellulose and hemicellulose with hydroxyl groups that readily bind water molecules.

At 25% and 35% fiber variations, the water content decreased to 1.19% and 0.96%, respectively, due to increased fiber packing density, which reduced void space and limited water diffusion pathways. However, at 45% variation, the water content increased again to 1.43% due to increased porosity and uneven fiber distribution. The results of this study provide insight into the structure of plant cell walls and their chemical components. Coconut fiber containing cellulose, hemicellulose, lignin, and pectin is a clear representation of the components of plant secondary cell walls. The hydrophilic nature of the fiber, which causes water absorption, can be explained by the presence of hydroxyl groups (-OH) in cellulose and hemicellulose molecules. The composite with a 5% variation showed the lowest water content with a value of 0.57%, thus providing an understanding of how chemical modification can change the natural properties of biological materials. This teaches students about the concept of biomaterials and how molecular structure affects the macroscopic properties of materials.

This research contributes to the development of students' innovative mindsets through an understanding of how environmental problems can be solved through a science and technology approach. Optimizing the fiber-matrix composition to achieve the best properties at a 95:5 ratio teaches students the importance of optimization in research and development. Students learn about design of experiments and data analysis to find optimal conditions in a process. The ability to interpret graphs and analyze data trends demonstrated in this research is an essential skill for students in the digital era and data-driven decision-making (Sinaga et al., 2023). Overall, this research on coconut fiber composites provides an excellent bridge between theoretical concepts learned in school and practical applications in materials technology. The integration of chemistry, physics, and biology concepts in one research topic demonstrates the importance of a multidisciplinary approach in solving complex problems (Fadiawati et al., 2022). The results of this research can be invaluable teaching materials for developing students' scientific literacy and preparing them to face future technological challenges that require sustainable and environmentally friendly solutions.

▪ CONCLUSION

Based on the analyzed physical characteristics, the composite with 5% fiber content showed the best performance with the highest density (0.94 g/cm³), the lowest porosity (22%), and the lowest water content (0.57%). This indicates that the composite with this composition has the best fiber-matrix bond quality and is expected to produce optimal mechanical properties. The manufacturing process of coconut fiber composites with epoxy resin can be an alternative environmentally friendly material for lightweight structural applications.

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