International Journal Technology of Polymer and Plastics (IJTPLAS)
Volume 02, Issue 01, April 2026, pp. 11-20
DOI:

Development of Environmentally Friendly Safety Helmet Material Based 0n Coconut Fiber Composite and Epoxy Resin

Sri Hafizah Manik[1], Ahmad Nayan[2] , Muhammad[3], Syamsul Bahri[4], Nurul Islami[5]
[1] Department of Chemical Engineering, Faculty of Engineering, Universitas Malikussaleh, Lhokseumawe, Aceh, Indonesia
[2] Department of Mechanical Engineering, Faculty of Engineering, Universitas Malikussaleh, Lhokseumawe, Aceh, Indonesia
*E-mail addresses: pizah.2101900005@mhs.unimal.ac.id

ARTICLE INFO

Article history:
Received March 02 2026
Revised March 11, 2026
Accepted March 20, 2026
Available online April 30, 2026

Kata Kunci:
Komposit, Resin, serat serabut kelapa, uji tarik, uji impact.

Keywords:
Composite, Resin, coconut fiber, tensile test, impact test.

This is an open access article under the CC BY-SA license.

Copyright © 2022 by Author. Published by Universitas Pendidikan Ganesha.

ABSTRAK

Penelitian ini mempelajari Pengembangan Material Helm Safety Ramah Lingkungan Berbasis Komposit Serat Kelapa Dan Resin Epoxy. Diharapkan komposit yang diperkuat dengan serat sabut kelapa akan menunjukkan peningkatan sifat mekanik yang baik dan sebagai produk material alternatif. Penelitian ini terdiri dari empat tahap yaitu persiapan resin dan serat serabut kelapa, perendaman menggunakan NaOH 5% pada serat, pembuatan komposit menggunakan metode hand lay up, dan pengujian mekanik (tarik, impak, dan daya serap air) pada komposit. Orientasi serat pada penelitian ini adalah anyam dan acak dengan masing-masing variasi fraksi volume ialah 20:80. pengujian yang dilakukan yaitu uji tarik, uji impak, dan uji daya serap air. Uji tarik menggunakan standard ASTM D3039, *uji impak menggunakan standard ASTM D256-03. Hasil yang didapat pada penelitian ini ialah nilai kuat tarik tertinggi didapatkan pada orientasi anyam dengan variasi komposisi 20:80 dengan nilai kuat tarik 18,43 MPa, dan nilai kuat impak tertinggi didapatkan pada orientasi anyam variasi 20:80 dengan nilai tenaga impak 79,39 Joule. Orientasi sangat mempengaruhi nilai kekuatan pada material komposit dikarenakan serat berfungsi menahan beban pada komposit.*

ABSTRACT

This research studies the Development of Environmentally Friendly Safety Helmet Materials Based on Coconut Fiber Composites and Epoxy Resin. It is expected that composites reinforced with coconut fiber will show improved mechanical properties and as an alternative material product. This research consists of four stages, namely preparation of resin and coconut fiber, soaking using 5% NaOH on the fiber, making composites using the hand lay up method, and mechanical testing (tensile, impact, and water absorption) on the composite. The fiber orientation in this study is woven and random with each variation of the volume fraction being 20:80. The tests carried out are tensile tests, impact tests, and water absorption tests. Tensile tests use the ASTM D3039 standard, impact tests use the ASTM D256-03 standard. The results obtained in this study are the highest tensile strength value obtained in the weave orientation with a composition variation of 20:80 with a tensile strength value of 18.43 MPa, and the highest impact strength value obtained in the weave orientation variation of 20:80 with an impact strength value of 79.39 Joules. Orientation greatly affects the strength value of the composite material because the fiber functions to withstand the load on the composite.

1. INTRODUCTION

Workplace accidents can occur anytime and anywhere, unpredictably. This risk requires a robust workplace safety system, including the mandatory use of Personal Protective Equipment (PPE). One of the most important pieces of PPE is a safety helmet, designed to protect the head from injuries caused by high impacts, whether from falling objects, being struck by heavy equipment, or other workplace incidents.

The mechanical performance of interpenetrating phase composites (IPCs) with spinodal topology printed using multi-material PolyJet technology was investigated. In this study, the reinforcement phase has a spinodal shell structure, while the matrix consists of a softer polymer material. The results show that the spinodal shell composites have comparable compressive strength and stiffness to those with periodic structures such as Schwarz and octet lattices, but with better damage resistance and less catastrophic failure, especially at high reinforcement volume fractions. These characteristics make spinodal shell composites a promising candidate for energy absorption and impact protection applications (Zhang et al., 2021).

As material technology advances, emphasizing sustainability and environmental friendliness, natural fiber-based composite materials are increasingly being developed. Natural fibers, such as coconut fiber, offer advantages such as good strength, abundant availability, low cost, and biodegradability. Furthermore, coconut fiber has a microscopic structure that allows for effective interaction with resin to form a strong composite material.

Composites

A composite is a material formed from two or more different materials combined to produce properties superior to those of the individual materials. The primary purpose of a composite is to utilize the strength, durability, or special properties of each of the combined components to create a material that is stronger, lighter, more resistant to corrosion, or even better at thermal conductivity. Composites are commonly used because they possess desirable properties that cannot be achieved by other materials, from the constituent materials acting alone (Hamdi et al., 2022).

Alkalization Treatment (NaOH)

The physical and mechanical properties of fiber-reinforced composites depend on several parameters, one of which is the fiber treatment, namely alkali (NaOH) treatment. This is because coconut fiber contains lignin, which can disrupt the surface bond between the fiber and the matrix. Lignin is also hydrolyzed by acids, is only soluble in hot alkali, can be oxidized, and can be easily condensed by phenol (Zulkifli et al., 2020). Soaking the fibers in a NaOH solution aims to remove contaminants and non-cellulosic components such as lignin, hemicellulose, and oils that adhere to the fiber surface. This process helps improve adhesion between the fiber and the matrix in composite materials (Rai et al., 2025).

Coconut Fiber

The coconut tree, a member of the Palmae family, is a tropical plant native to the coast (its native habitat). However, through cultivation, humans have found it even further inland. This indicates that the coconut tree is highly tolerant of microclimates (soil, water, air, strong winds, sunlight), and especially soil nutrients (Handayani et al., 2023).

Coconut fiber composites are known to have increased tensile strength and modulus with increasing volume fraction. Coconut fiber, as a polypropylene reinforcement, has higher impact strength than jute and kenaf fibers, but lower tensile strength and modulus (Hidayah et al., 2023). Overall, randomly oriented coconut fiber composites show good potential for non-structural building applications requiring high flexural strength. However, for applications requiring high tensile strength, more regular fiber orientation or the use of other fiber combinations should be considered to improve the composite's mechanical performance (Simbar, 2022).

Figure 1. Coconut Fiber

Epoxy Resin

Epoxy resin is a type of polymer in which a mixture of two components ultimately forms a glass-like substance at room temperature, offering excellent electrical insulating properties and high water resistance. Epoxy belongs to the thermoset resin family, along with polyester, silicone, urethane, acrylic, and phenolic resins (Prasetya & Manggala, 2022). Epoxy resin is widely used in various industries, including chemical, electrical, mechanical, and civil engineering.

Figure 2. Shredded HDPE Plastic

Tensile Testing

A tensile test is the application of tensile force or stress to a material to determine or detect its strength (Salindeho, 2018). This test can determine the mechanical properties of the material, which are essential for engineering design. Tensile strength is the maximum stress that a test specimen can withstand before breaking or being damaged, the maximum load divided by the initial cross-sectional area of the test specimen. The tensile test is based on a damaged specimen under static testing conditions, and the results obtained are in the form of tensile strength. Tensile testing is carried out to determine the tensile strength of the composite material. Testing is carried out using a Universal Testing Machine. Tensile test specimens are formed according to the ASTM D 3039 standard, as shown in Figure 2.4 below:

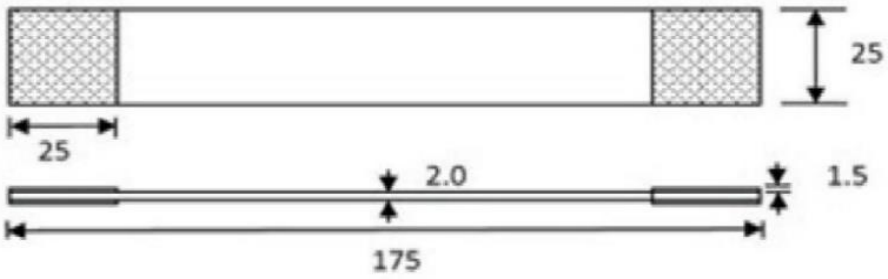

Figure 3. ASTM D 3039 Specimen

Tensile testing is used to assess the strength of composite materials by applying a uniaxial force load. The results obtained from tensile testing are crucial for engineering and product design because they provide data on the material's strength. From this tensile testing, we can determine several mechanical properties of the material, which are essential in engineering design. The linear relationship between stress and strain can be seen in the equation below:

Voltage formula:

$\sigma = F/A$ (1)

Strain formula:

$\varepsilon = \Delta L/Lo\ x\ 100\%$ (2)

Modulus of elasticity formula:

$E = \sigma/\varepsilon$ (3)

Impact Test

The toughness of a composite can be determined using an impact test. This test measures the toughness, or ability of a material to absorb energy before breaking (toughness). Impact testing is performed on standard test bar specimens. The material to be tested is initially formed into a test bar with a specific standard shape. The center of the test bar is the part that receives the stress.

Impact testing is a method used to determine the strength, hardness, and ductility of a material. Therefore, impact testing is widely used in the field of assessing the mechanical properties of a material (Wardani, 2017).

Impact testing uses the Charpy impact test method. The principle of the Charpy impact test aims to determine the level of resistance or ductility of a material, and the test is performed on a machine according to ASTM D 256-03. This can be seen in Figure 4 below:

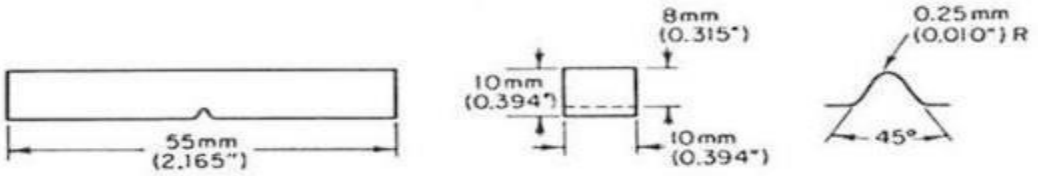

Figure 4. Impact Test Specimen

The breaking force is the pendulum lifted at an angle of less than 150°C, thus generating potential energy. To calculate the energy absorbed by the material, use the following potential energy equation:

Broken power formula:

$(W) = m.\ r\ (\cos\beta - \cos\alpha)$ (4)

Impact Price:

$W/A =$ (5)

Water Absorption Test

Water absorption is a critical factor in determining a film's biodegradability when used as packaging. Some films require high solubility, while others require low solubility, depending on the type of product being packaged (Rachmawati, 2009). Measuring water absorption is crucial to achieving the desired bioplastic quality. Mathematically, the percentage of water absorption (water uptake) can be calculated using the following equation:

$$\text{Absorbed water (\%)} = ((w - w0)/w0) \times 100\% \quad (6)$$

w = wet bioplastic weight
$w0$ = dry bioplastic weight

Volume fraction

Volume fraction is an important parameter in composite material design. Volume fraction indicates the ratio of the volume of a component to the total volume of the composite. The components whose volume fraction is usually calculated are fiber (Vf) and matrix (Vm). The volume fraction value significantly influences the mechanical and thermal properties of the composite, such as tensile strength, elastic modulus, and resistance to delamination (Daniel & Ishai, 2006).

Determining the volume of the composite mold :

$$Vc = (P\ x\ L\ x\ T) \quad (7)$$

Fiberless composite volume :

$$Vm = Vc\ x\ \rho m \quad (8)$$

Composite volume without matrix :

$$Vs = Vc\ x\ \rho s \quad (9)$$

Determine the volume of the composite :

$$Vk = (\%\ serat\ x\ Vs) + (\%\ matrik\ x\ Vm) \quad (10)$$

2. METHOD

This research will be conducted from June 2025 to September 2025 at the Mechanical Engineering Laboratory, Faculty of Engineering, Malikussaleh University. The processing carried out in this research includes processing coconut fiber as a filler and the composite manufacturing process.

Tools in Research

The tools used included a digital scale for weighing the ingredients, a spatula for scooping and mixing the ingredients, a measuring cup for measuring liquid volume, and a knife for cutting the samples. A brush was used to spread the ingredients evenly on the mold, while a safety helmet mold was used to shape the product. Additionally, an impact tester was used to test the material's durability, as well as molds measuring 0.3 x 10 x 18 cm and 1 x 3.5 x 6 cm for making test samples.

Material in Research

The materials used in this study included coconut fiber waste as a reinforcing agent, epoxy resin as a matrix, and hardener to accelerate the resin's curing process. Additionally, mirror glaze or wax was used as a mold coating to facilitate removal, and a 5% NaOH solution was used for pretreatment of the coconut fiber.

Composite Manufacturing

The fiber processing process begins with collecting coconut fiber from nearby plantations. The fiber is then cleaned, separated from the coconut husk, and thoroughly washed with water. The fiber is then dried in the sun and soaked in a 5% NaOH solution for 4 hours to remove dirt and improve adhesion. The fiber is then washed again with warm water to remove any remaining NaOH, dried, and cut into 3–4 cm lengths. The processed fiber is ready to be used as a reinforcing material in composite manufacturing.

This stage begins with cleaning the mold and coating it with a lubricant or mirror glaze to facilitate the composite's release. Next, a variety of random fibers are created according to the required size. Epoxy resin is mixed with a hardener at 1% of the resin volume and stirred thoroughly. The fiber is then placed in the mold in the desired orientation, and the resin is poured using a hand lay-up method with a brush to ensure even distribution. The drying process is carried out in the sun for 6–10 hours, or until the composite is completely dry. Once the desired thickness and dryness are achieved, the composite is removed from the mold using a cutter or knife. The finished specimen is then ready for testing.

Table 1. Research design

No	Fiber Direction	Volume Fraction (%) Resin: Coconut Fiber
1	Woven	20 : 80
2	Random	20 : 80

3. RESULT AND DISCUSSION

Result

After conducting the research, some data were obtained in the form of tables and graphs, then the test results will be analyzed, the results of the impact test on the composite material reinforced with coconut fiber with variations in the direction of woven and random fibers. This study conducted several tests including impact testing and free fall motion testing. The composite used is a composite made of epoxy resin and coconut fiber, the ratio of each woven fiber (resin: fiber, 20: 80), and random (resin: fiber, 20: 80).

Coconut Fiber Reinforced Helmet

We can see in Figure 5 the results of the Safety Helmet. The helmet has finished the drying process for 1-2 days, the composition of the materials in making the helmet can be seen in Table 1. Composition of Helmet Making Materials.

Figure 5. Safety Helmet Results

Table 2. Composition of Helmet Materials

No	Material	Information
1	Resin	240 gram
2	Hardener	30 gram
3	Fiber	60 gram

Impact Test

To facilitate analysis of the research data, the results will be presented in tabular form. The impact test results for specimens with varying woven and random fiber directions are shown in Tables 3 and 4.

Table 3. Impact test results on woven fiber direction composites

Volume Fraction (%) Resin: Coconut Fiber	Fiber Direction	Degree		Broken Power (joule)	Impact Price (joule/mm2)
		α	ß		
20 : 80	Woven	160	97	76,16	0,952
		160	106	61,85	0,773
		160	100	71,35	0,891
		160	95	79,39	0,992

Table 4. Impact test results on random fiber direction composites

Volume Fraction (%) Resin: Coconut Fiber	Fiber Direction	Degree		Broken Power (joule)	Impact Price (joule/mm2)
		α	ß		
20 : 80	Random	160	125	34,11	0,426
		160	125	34,11	0,426
		160	126	32,78	0,409
		160	127	31,48	0,393

Tensile Test

Tensile testing was conducted after the process of making coconut fiber reinforced composites with two types of orientations using epoxy resin in order to determine the effect of tensile strength of the two types of orientations with a predetermined volume fraction. The test was conducted on Tuesday, October 21, 2025 in the mechanical engineering laboratory of Malikussaleh University.

To facilitate analysis of the data from this study, the results will be presented in tabular form. The impact test results for specimens with varying woven and random fiber directions are shown in Table 5.

Table 5. Tensile test results

Volume Fraction (%) Resin: Coconut Fiber	Fiber Direction	Tensile Stress (MPa)	Strain (%)	Modulus Elasticity (MPa)
Resin : Fiber 20 :80	Woven	14,64	15,34	0,954
		15,29	15,59	0,981
		18,43	17,67	1,043
		12,81	17,88	0,716
Resin : Fiber 20 :80	Random	9,28	13,86	0,669
		9,02	10,08	0,895
		14,90	11,91	1,251
		10,59	9,50	1,114

Water Absorption Test

In this study, the eight samples will be tested and weighed first for their dry weight (W0) then soaked in water for 24 hours and weighed again. In this study, the results of the water absorption test can be seen in Table 6 below.

Table 6. Water Absorption Test Results

Volume Fraction (%) Resin: Coconut Fiber	Fiber Direction	Specimen Weight (Gram)		Water Absorption Capacity (%)
		Initial weight	Final Weight	
20 : 80	Woven	1,098	1,482	35
		1,122	1,481	32,01
		1,034	1,392	34,71
		1,021	1,385	35,72
20 : 80	Random	1,237	1,635	32,23
		1,118	1,5	34,2
		1,201	1,623	35,15
		1,173	1,578	34,53

Discussion

The toughness of a composite can be determined by using an impact test, namely by measuring the toughness or ability of a composite material to absorb energy before breaking (toughness).

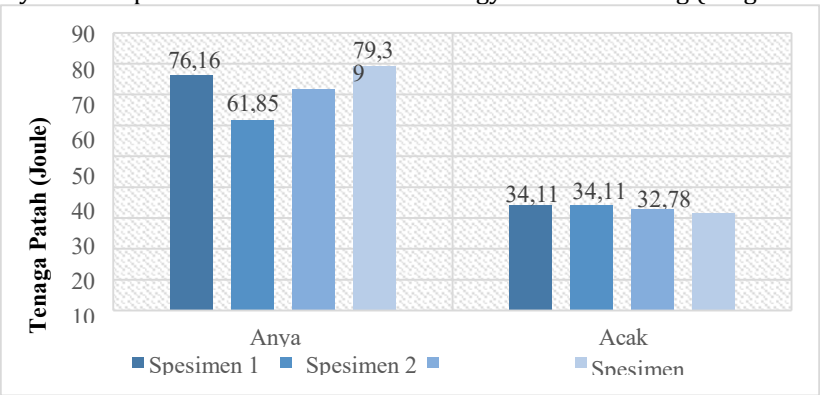

Figure 6. Impact Energy Comparison Bar Chart from Impact Test Results

Based on the impact strength test results, composite materials with woven fiber orientation showed a higher impact energy absorption capacity (61.85–79.39 Joules) compared to those with random orientation (31.48–34.11 Joules). Woven fiber orientation allows for a more even stress distribution along the fibers, thereby increasing shock load resistance. Conversely, random fibers cause uneven stress transfer and trigger faster cracking. In theory, impact toughness is influenced by fiber orientation, volume fraction, and fiber-matrix bonding. Fibers parallel to the load direction are able to withstand deformation better (Callister & Rethwisch, 2018; Hull & Clyne, 1996; Gibson, 2016). Thus, woven fiber orientation is more recommended for structural applications that require high impact toughness.

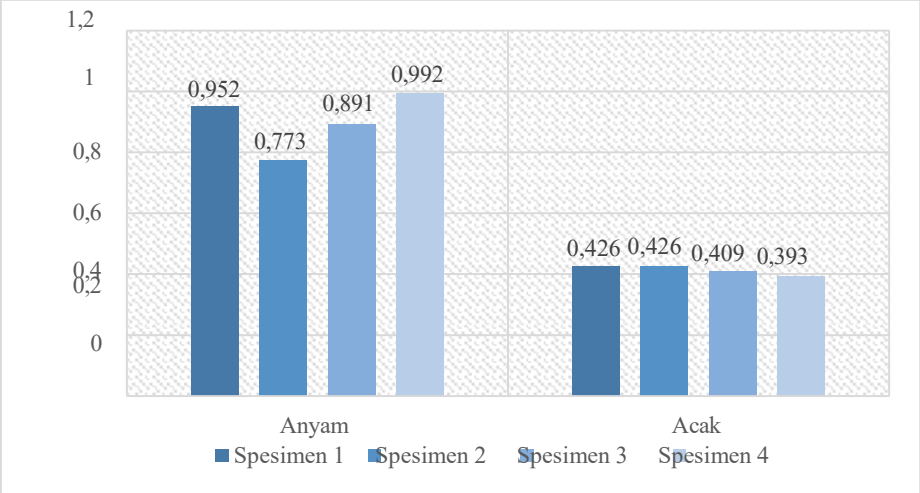

Figure 7. Bar Chart Comparison of Impact Prices from Impact Test Results

Based on the impact value test results, composite materials with woven fiber orientation have higher impact values (0.773–0.992 J/mm^2) compared to random fibers (0.393–0.426 J/mm^2). The woven fiber orientation allows the fibers to be arranged parallel to the stress direction, resulting in more efficient load distribution and energy absorption. Conversely, random orientation causes uneven stress flow, resulting in lower absorbed energy. In theory, impact strength is influenced by fiber orientation, volume fraction, and fiber-matrix bonding (Hull & Clyne, 1996; Callister & Rethwisch, 2018; Gibson, 2016). Woven fibers withstand tension and shock loads better because they are able to channel energy along the force direction. Thus, woven fiber-oriented composites are proven to be more resilient and efficient in absorbing energy per unit area than random fiber orientations.

The data listed in Table 5 can be visualized in the form of a bar chart. This is done to easily compare differences in tensile strength, strain, and modulus of elasticity parameters from the tensile test results of the 12 research samples tested.

Table 5. shows that the tensile strength values obtained ranged from 9.02 MPa to 18.43 MPa. A bar chart for the comparison of tensile strengths can be seen in Figure 8.

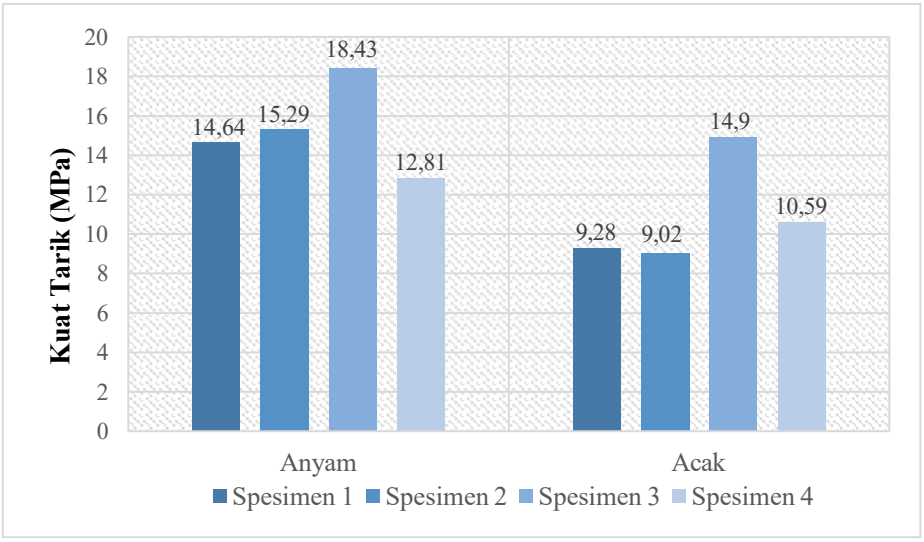

Figure 8. Comparison Line Diagram of Tensile Strength from Tensile Test Results

The tensile test results showed that fiber orientation significantly affected the tensile strength of coconut fiber-based composites with epoxy resin (80% fiber: 20% resin). Composites with woven fiber

orientation produced higher tensile strength (12.81–18.43 MPa) compared to random orientation (9.02–14.90 MPa). The regular fiber pattern in woven orientation allows for more even load distribution and stress transfer, while random orientation causes stress concentration that reduces tensile strength. According to Mallick (2007), good fiber orientation increases the strength and stiffness of the composite, especially under unidirectional loading. Although high fiber composition increases strength, its effectiveness still depends on the fiber orientation and the quality of the fiber-matrix bond. This finding is in line with Mohammed et al. (2015) who stated that fiber orientation has a greater influence on mechanical performance than fiber percentage alone.

Table 5. shows that the strain/elongation values obtained ranged from 9.5% to 17.88%. The bar chart for the strain/elongation comparison can be seen in Figure 9.

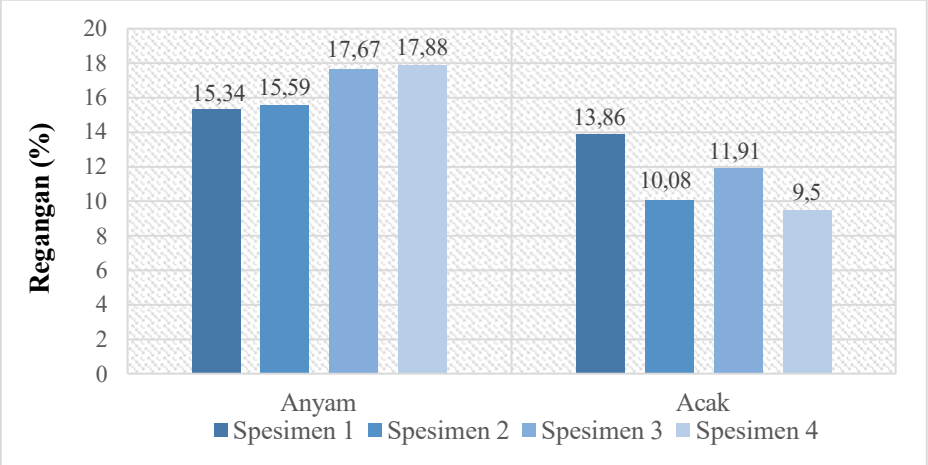

Figure 9. Strain Comparison Line Diagram from Tensile Test Results

The results of the strain test showed that fiber orientation significantly affected the elasticity of coconut fiber-based composites (80% fiber: 20% epoxy resin). Composites with woven fiber orientation had higher strain values (up to 17.88%) compared to random orientation (lowest 9.50%). The regular arrangement of fibers in the woven pattern allows for a more even stress distribution and delays cracking, making the material more elastic. Conversely, random orientation causes most of the load to be borne by the brittle matrix, making the material fracture more quickly. According to Callister & Rethwisch (2018) and Jawaid & Abdul Khalil (2011), parallel fiber orientation increases deformability and toughness because the fibers are able to absorb energy better during deformation. Thus, woven fiber-oriented composites have better strength and strain, making them more resilient for applications that require a combination of strength and flexibility.

Table 5 shows that the elastic modulus values obtained ranged from 0.669 MPa to 1.251 MPa. A bar chart for the comparison of elastic modulus can be seen in Figure 10.

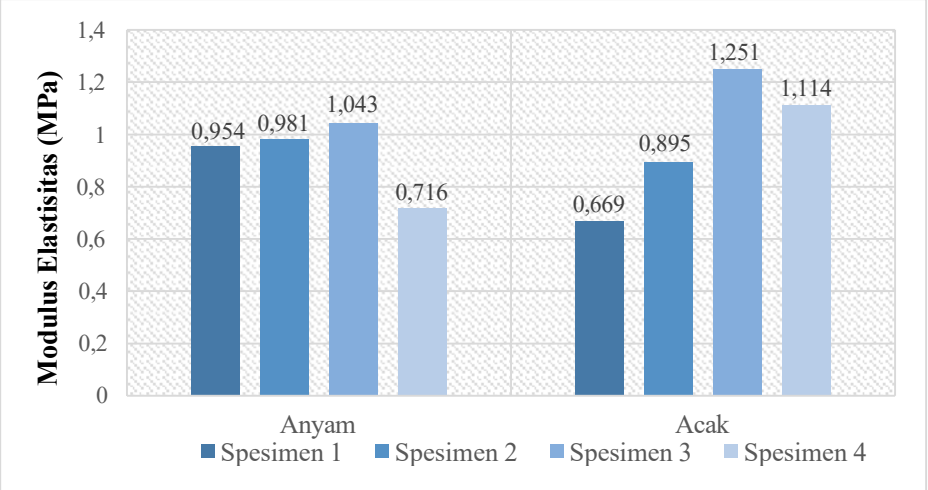

Figure 10. Comparison Line Diagram of Elastic Modulus of Tensile Test Results

Based on the results of the elastic modulus test, fiber orientation was shown to affect the stiffness of the composite. The highest value was obtained in random fiber orientation (up to 1.251 MPa), while the

woven orientation showed a lower value (the lowest was 0.716 MPa). This indicates that random fibers provide resistance to deformation from various directions, making the material stiffer. According to Mallick (2007), random orientation increases the isotropy of stiffness because the spread fiber distribution helps to withstand the load uniformly. However, high stiffness does not always mean better mechanical performance, because stiff composites tend to be brittle if their tensile and strain strengths are low. Thus, although random orientation provides a higher elastic modulus, woven orientation remains superior overall in terms of material strength and toughness.

The data listed in Table 6 can be visualized in the form of a bar chart. This is done to compare the differences in water absorption parameters from the results of the water absorption test of 8 research samples tested by immersion in water for 24 hours, which can be observed in Figure 11.

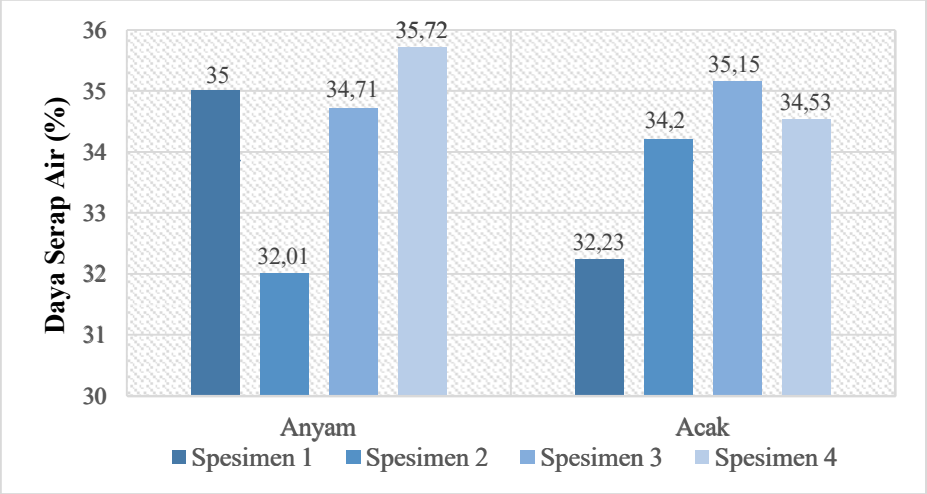

Figure 11. Bar Chart Comparison of Water Absorption Capacity from Water Absorption Test Results for (24 Hours)

The results of the water absorption test showed that fiber orientation affected the ability of coconut fiber-based composites (80% fiber: 20% epoxy resin) to absorb water. Composites with woven orientation had slightly higher absorption (32.01–35.72%) than random orientation (32.23–35.15%). This occurred because the woven fiber pattern formed micro-cavities that facilitated water absorption into the material, while the random structure was denser and inhibited water diffusion. In theory, water absorption was influenced by the hydrophilic properties of the fiber, the strength of the fiber-matrix bond, and the density of the structure (Callister & Rethwisch, 2018). The cellulose and hemicellulose content in coconut fiber resulted in high hydrophilic properties (Mwaikambo & Ansell, 2002), while the hydrophobic epoxy resin protected the fibers from water. However, because the resin fraction was only 20%, some of the fibers were not completely covered, so water could still enter the composite.

4. CONCLUSION

Based on the analysis and testing results, it can be concluded that fiber orientation has a significant effect on the mechanical and physical properties of coconut fiber composites with epoxy resin (80:20). Composites with woven fiber orientation showed the best performance in impact tests with the highest fracture strength value of 62.68 Joules and an impact value of 0.7835 J/mm^2, because the fiber arrangement is able to distribute impact energy effectively. In addition, woven orientation also produces higher tensile and strain strengths than random orientation, indicating better deformation resistance. Conversely, random orientation has a higher modulus of elasticity which indicates material stiffness, but is less resilient to tensile forces. In the water absorption test, woven orientation showed slightly higher absorption due to the presence of micro cavities between fibers that facilitate water penetration. Overall, woven fiber orientation is considered superior in increasing the strength and toughness of the composite.

5. REFERENCES

Zhang, Y., Hsieh, M.-T., & Valdevit, L. (2021). Mechanical Performance Of 3d Printed Interpenetrating Phase Composites With Spinodal Topologies. Composite Structures, 263, 113693.

Hamdi, F., Lapian, F. E. P., Tumpu, M., Mabui, D. S. S., Raidyarto, A., Sila, A. A., & Rangan, P. R. (2022). Teknologi Beton. Tohar Media.

Handayani, R. S., Khaidir, K., Usnawiyah, U., & Alfitra, A. Y. (2023). Eksplorasi Dan Karakterisasi Budidaya Tanaman Kelapa Di Kecamatan Dewantara Kabupaten Aceh Utara. Journal Of Biodiesel Research And Innovation (Journal Of Brain), 1(1), 35–40.

Simbar, R. D. (2022). Pengaruh Variasi Serat Sabut Kelapa Terhadap Kuat Tarik Dan Kuat Lentur Pada Pengujian Sandwich Panel Plafon. Politeknik Negeri Manado.

Prasetya, W., & Manggala, A. M. (2022). Analisis Kelayakan Elektrikal Material Resin Epoxy Silane Sebagai Material Isolator Tumpu Dengan Desain Dua Sirip Terpisah. Electron Jurnal Ilmiah Teknik Elektro, 3(2), 79–88.

Wardhani, R., & Yulianto, D. (2023). Pemanfaatan Serat Rami (Boehmeria Nivea) Sebagai Penguat Dengan Metode Acak Pada Bio Komposit. Enotek: Jurnal Energi Dan Inovasi Teknologi, 3(01), 26–31.

Daniel, I. M., & Ishai, O. (2006). Composite Materials: Engineering and Science. Springer.

Callister, W. D., & Rethwisch, D. G. (2018). Materials Science and Engineering: An Introduction. John Wiley & Sons.

Hull, D., & Clyne, T. W. (1996). An Introduction to Composite Materials. Cambridge University Press.