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Experimental study of variations in fiber types and volume fractions of unsaturated polymer resin (UPR) composites on the mechanical and physical properties of the material

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Abstract

Biocomposites are a specific type of material derived from organic sources that exhibit enhanced biodegradability when they are discarded as waste. The utilization of biocomposites in various products can significantly contribute to waste reduction. This study focuses on the development of biocomposite materials using two different types of fibers, namely palm tree fiber and sea pandanus fiber, in combination with an Unsaturated Polymer Resin (UPR) matrix and varying volume fractions. The fabrication process involves creating four different types of specimens with distinct volume fractions: 5% fiber with 95% matrix, 10% fiber with 90% matrix, 15% fiber with 85% matrix, and 20% fiber with 80% matrix, utilizing the hand lay-up method. To evaluate the performance of the biocomposites, several physical and mechanical tests were conducted. The physical properties were assessed through density measurements, water absorption tests, and swelling tests. Interestingly, the physical property values were found to be relatively consistent across all fiber types. On the other hand, the mechanical properties, particularly the impact strength, exhibited variations among the different fiber composites. Notably, the palm fiber biocomposites demonstrated the highest impact strength, specifically at a fiber volume fraction of KSI3, yielding a value of 30,860 kJ/m2. Additionally, the tensile strength of the palm fiber biocomposite exhibited a deformation value of 25.73 MPa, indicating its ability to withstand stress. In summary, this research highlights the potential of biocomposites as environmentally friendly materials that can effectively reduce waste. The utilization of palm fiber in biocomposites shows promising results in terms of mechanical properties, particularly impact strength and tensile strength. These findings contribute to the advancement of sustainable materials and offer insights for further exploration and development in the field of biocomposites.

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Keyword

Biocomposite fiber, Volume fraction, Hand lay-up method, Unsaturated polyester resin

Introduction

Biocomposites are composed of organic materials and comprise two or more components with distinct chemical and physical properties. These composite materials are widely utilized in diverse industries, such as automotive manufacturing (e.g., car bumpers and dashboards), aerospace (e.g., aircraft bodies), and construction (e.g., particle board as a metal alternative). In addition to their strength, lightweight nature, and malleability, biocomposites are readily available and relatively inexpensive compared to polypropylene materials.

The characteristics of biocomposite materials are significantly impacted by the composition and arrangement of their constituent elements, as well as the interactions between these elements [1-3]. Additionally, various factors such as shape, size of particles or fibers, orientation of fibers, and distribution of reinforcement within the matrix can also influence the properties of composite materials [4-7]. Mechanical properties play a crucial role in determining the overall properties and attributes of a material. In structural applications, the mechanical properties are determined by the selection of the material blend [5-9]. In fiber-reinforced biocomposites, the primary function of fibers is to transmit stress between them, thereby providing resistance against adverse environmental conditions and safeguarding the fiber surface from mechanical and chemical impacts. Moreover, the contribution of fibers significantly affects the tensile strength of composite materials [5-9].

Fibers are broadly categorized into two types: synthetic fibers and natural fibers. Synthetic fibers, exemplified by fiberglass, are widely utilized in polymer composite production. These composites are favored for their ease of molding, excellent mechanical properties, lightweight nature, and resistance to corrosion, prompting ongoing development efforts within the industrial sector. One avenue of advancement involves the incorporation of natural fibers into composite materials. This technology integration has garnered increased attention, driven by the perceived environmental benefits of natural fibers compared to synthetic counterparts. Natural fibers are deemed more environmentally friendly due to their lower production costs and reduced generation of plant waste. Derived from plants within the immediate surroundings, these fibers are easily disposable after use, further enhancing their eco-friendliness.

Various types of fibers can serve as composite materials. At present, numerous composite materials are under investigation and advancement, wherein diverse natural fibers are being explored as alternatives to synthetic materials. The current focus of research lies in the development of biocomposite materials utilizing natural fibers. In this particular study, the researchers aim to create a comparable biocomposite material by altering both the natural fiber material and the volume fractions [5-8][11].

Method

This research is represented by following research flow diagram shown in Figure 1.

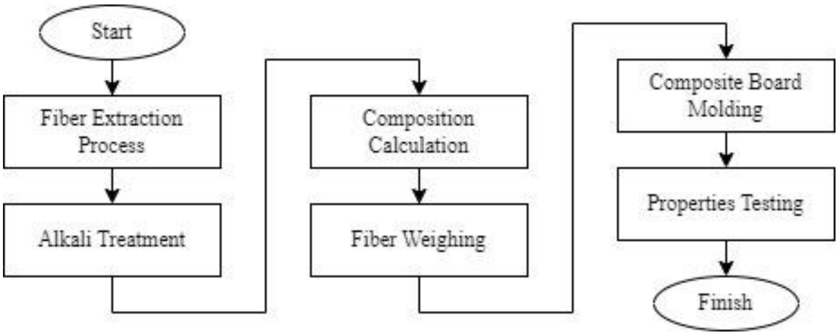


Figure 1. Research Flow Diagram

This study involved several stages, beginning with the extraction of fibers from fronds. Subsequently, the fibers underwent an alkaline treatment using a 5% NaOH solution. Composition calculations were conducted, followed by fiber weighing. Composite boards were then fabricated through the hand lay-up method, and subsequently, they were cut and shaped according to testing standards. The testing processes included tensile testing and assessments of physical properties.

1. Fiber Extraction Process: The first step involves extracting fibers from the fronds, separating the inner layer fibers from the outer layer. This process begins by brushing away the outer layer of the midrib using a wire brush, thereby isolating the fibers. Figure 2 illustrates the fibers extracted from the fronds.

Figure 2. Fronds and Fiber

2. Alkali Treatment: After separating the fiber from the midrib, it undergoes an alkali treatment by immersing it in a 5% NaOH alkaline solution for 60 minutes. This treatment aims to remove lignin content from the fibers. After soaking for 60 minutes, the fibers are rinsed with clean water and then dried under sunlight until they reach the desired texture. Figure 3 illustrates the appearance of the fiber post-alkali treatment [11-13].

3. Composition Calculation: The composition calculation is conducted based on the total volume of the mold utilized, measuring 20 x 20 x 0.5 cm. Various fiber volume fractions are considered in the calculation, as follows:
   a. Fraction Variation I (KS I).
   b. Fraction Variation II (KS II).
   c. Fraction Variation III (KS III).

Figure 3. Fiber Alkali Treatment

4. Fiber Weighing: Following the composition calculation, the fibers are weighed according to the calculated proportions. This step ensures accuracy in the measurement of fiber volume and helps prevent errors that could impact the mechanical properties of the composite board produced later on.
5. Composite Board Molding: Once the fibers are weighed according to the calculated composition, they are arranged in a glass mold. The hand lay-up method is then employed to apply resin (matrix) as a binder for the composite. After filling the mold with resin and reinforcement, it is left at room temperature for 24 hours to dry. Following this drying period, the mold is opened, and the composite board can be removed.
6. Physical Properties Testing: Specimens are created in accordance with the JIS A5908-2003 standard to facilitate testing of physical properties. Figure 4 depicts the process of specimen creation, ensuring adherence to the specified standard.

Figure 4. Test Specimen (a) Density (b) Water Absorption and Swelling

Explanation:

a. Density and water content test sample, measuring 10cm x 10cm.
b. Water absorption and swelling test sample measuring 5cm x 5cm.
c. Sample of bending strength (modulus of elasticity/MOE) and fracture strength (modulus of rapture/MOR) measuring 5cm x 20cm.
d. Sample of internal bond measuring 5cm x 5cm.

Mechanical properties testing; after a 24-hour waiting period, the dry composite board is to be separated or removed from the glass mold. Subsequently, the composite board should be cut into test standard sizes for material impact and tensile testing. The creation of the test specimen model follows the established guidelines for the size of the impact test specimen, specifically referring to the ISO 179-1 size standard. Furthermore, the shape of the tensile test specimen should be cut according to the reference standard provided by the ASTM D 638 – 1 standard.

Result and Discussion

Physical Properties Testing

Material physical properties are material behavior related to physical characteristics or material conditions that are not caused by loading which are more aiming to the material structure. Tests for physical properties in this study included testing for density, water absorption and swelling which refers to the JIS A5908 – 2003 standard. Each test will be explained as follows.

Density Testing

The quantity of mass per unit volume is known as density. The strength of a material increases with its density. Table 1 shows data from the composite board density test results.

Table 1. Density Test Results

Biocomposite Fiber	**Volume Fraction (%)**	**Volume (cm^3)**	**Mass (g)**	**Density (g/cm^3)**
Palm Tree Fiber	KSI 1	49	58.30	1.168
	KSI 2	49.33	57.43	1.176
	KSI 3	50.66	60.43	1.188
Sea Pandanus Fiber	KSP 1	52.95	59.375	1.121
	KSP 2	60.55	68.125	1.125
	KSP 3	68.50	77.175	1.126

According to the findings from the conducted density tests, it was determined that the density values of the two composite fibers were nearly identical. Overall, the research outcomes indicate that the density of the composite board produced increases with a higher volume of matrix utilized. This phenomenon occurs due to the augmented mass of fibers employed, resulting in an overall increase in the total mass of the composite board at a constant volume.

Water Absorption Testing

Water absorption is the ability of the composite board to absorb water during 24-hour immersion. There are two distinct types of water that infiltrate particle board: water that directly enters the board and water that permeates the fiber particles comprising it. According to the findings presented in Table 2, the KSI3 volume fraction of Palm Tree Fiber exhibits the highest water absorption rate at 1.41%. This particular composition demonstrates a relatively low water content, resulting in a dry composite space that can effectively absorb more water. On the other hand, Sea Pandanus Fiber tends to possess a greater capacity for water absorption compared to Palm Tree Fiber. As the fiber composition of Sea Pandanus Fiber increases, there is a corresponding increase in its water absorption value. This can be attributed to the nature of the filler in the composite, specifically sea pandanus fiber, which readily absorbs water. The greater the amount of fibers used in the composition, the higher the water absorption capacity of the specimen. The presence of a significant proportion of sea pandanus fiber in the composite leads to a greater water absorption by the composite board, consequently increasing the final mass of the specimen. In accordance with the JIS A509 – 2003 standard, a lower percentage of water absorption in the composite indicates a higher quality of the produced composite board. Based on the results obtained from the water absorption test, the resulting composite board meets the requirements of the JIS A509 – 2003 standard as the water absorption percentage falls below the maximum permissible value of 6%.

Table 2. Water Absorption Test Results

Biocomposite Fiber	**Mass (g)**				
	Volume Fraction (%)	**B_1**	**B_2**	**ΔB**	**Absorption (%)**
Palm Tree Fiber	KSI 1	14,8	14,975	0,175	1,18
	KSI 2	13,575	13,7	0,125	0,92
	KSI 3	15,875	16,1	0,225	1,41
Sea Pandanus Fiber	KSP 1	15,24	15,44	0,2	1,312
	KSP 2	16,84	17,26	0,42	2,49
	KSP 3	19,44	20,02	0,58	2,98

Swelling testing

Swelling is a physical property that will determine whether a particle board can be used for exterior or interior purposes. If the particle board swelling is high, it means that the dimensional stability of the product cannot be used for exterior use or for long periods of time, because its mechanical properties will immediately decrease drastically in a not too long period of time. Data from the swelling test results are displayed in Table 3.

The swelling value obtained after a 24-hour soaking period indicates that all volume fractions are within the lower limit of the specified maximum value, which is 12% according to the JIS A 5908-2003 standard. Therefore, the swelling of this particle board complies with the standard as it remains below 12%.

Table 3. Swelling Test Results

Biocomposite	**Thickness (mm)**

Fiber	Volume Fraction (%)	T_1 (mm)	T_2 (mm)	ΔT (mm)	Swelling (%)
Palm Tree Fiber	KSI 1	4.74	5.01	0.27	5.69
	KSI 2	4.81	4.93	0.12	2.49
	KSI 3	5.16	5.33	0.17	3.18
Sea Pandanus Fiber	KSP 1	5,2472	5,2757	0,028	0,533
	KSP 2	6,3016	6,3528	0,06	0,812
	KSP 3	7,171	7,25	0,079	1,10

Mechanical Properties Testing

Mechanical testing is used to find the mechanical properties of a material as it performs in a particular environment. Mechanical properties testing that is used in this research comprise two test which is impact test and tensile test.

Impact testing

Impact testing is carried out by referring to the ISO 179 standard. The condition of the specimen before (a) and after (b) impact testing is shown in Figure 5 and the data obtained from the impact testing results are summarized in Table 4, which shows the values of absorbed energy and impact toughness. average of test results on two fiber variations.

Figure 5 illustrates the configuration of the biocomposite subsequent to experiencing a shock load with varying absorption energy levels obtained by the fiber biocomposite. In addition to the type of fiber, the volume fraction is also a variable in this study, and it is observed that biocomposites containing palm fiber exhibit greater resilience in accommodating shock loads. The volume fraction of the fiber plays a significant role in determining the properties of the composite. As the fiber volume increases, the impact toughness also increases, as indicated by Rachman et al. Table 4 presents data indicating that the augmentation in impact toughness is directly proportional to the fiber volume. Consequently, a higher fiber volume results in a greater impact toughness exhibited by the composite. The ratio between the fiber and matrix determines the mechanical characteristics that are manifested in the final product, as highlighted by Amin and Raharjo [12].

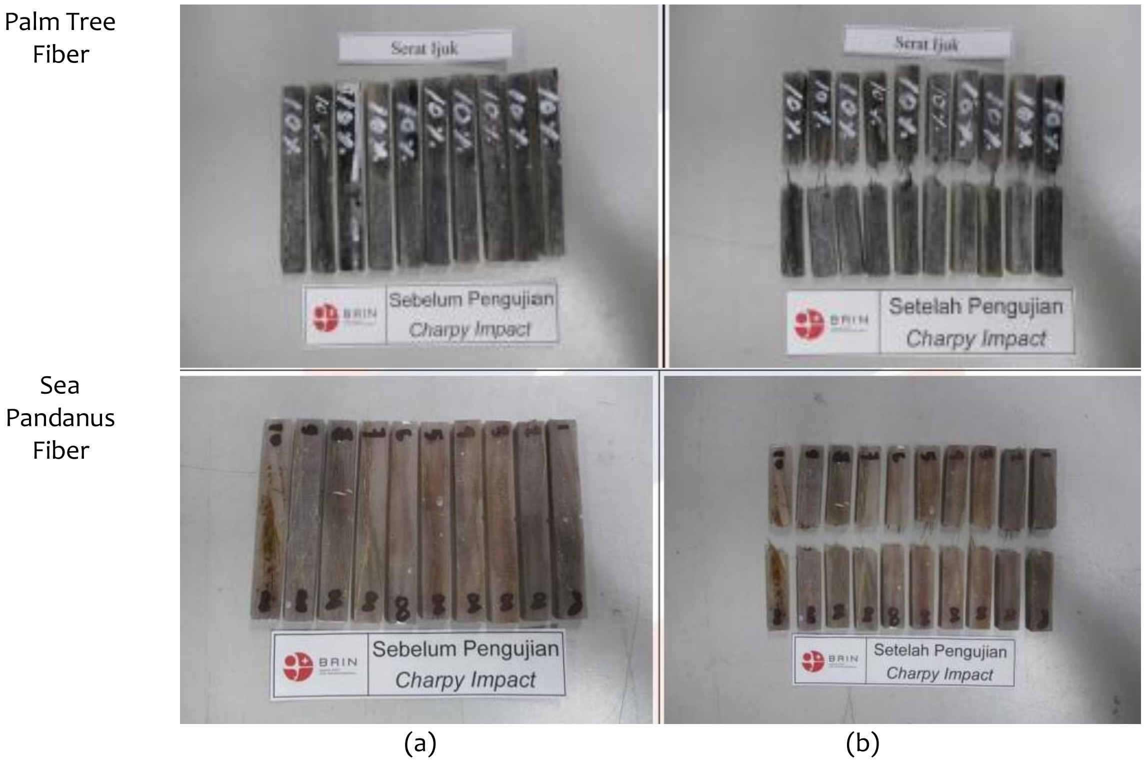


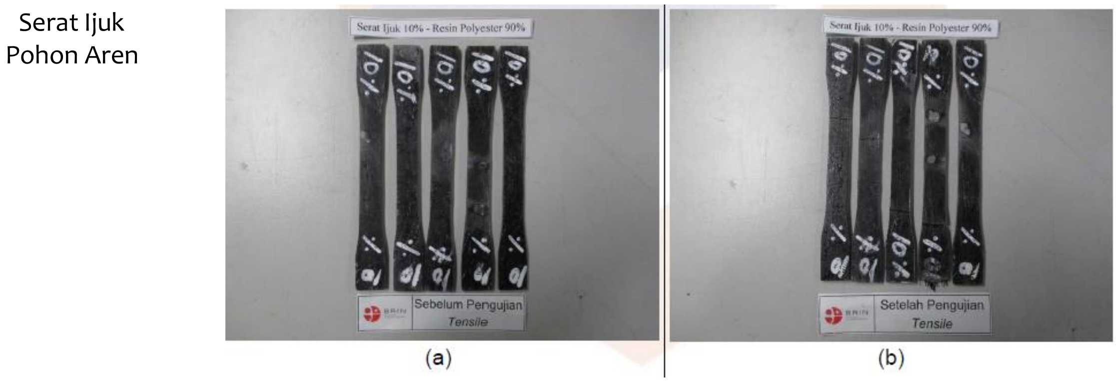
Figure 5. Before (a) and After (b) Impact Test

Table 4. Impact Testing Test Results

Biocomposite Fiber	**Absorbed Energy (Joule)**	***Impact Strength* (kJ/m²)**
KSI 1	0.431	10.465
KSI 2	0.522	14.802
KSI 3	1.481	30.860
KSP 1	0.074	1.814
KSP 2	0.148	3.460
KSP 3	0.221	5.094

Tensile testing

Tensile testing of biocomposite materials is carried out using ASTM D638 standards. The condition of the specimen before (a) and after (b) tensile testing is shown in Figure 6.



Serat Pandan Laut

Figure 6. Before (a) and After (b) Tensile Test

Table 5. Tensile Testing Test Results

Biocomposite Fiber	Tensile Strength (MPa)	Strain (%)	Elastic Modulus (GPa)
KSI 1	18.37	0.870	2.148
KSI 2	19.90	0.836	2.426
KSI 3	25.73	1.623	1.575
KSP 1	11.533	0.696	2.01
KSP 2	14.608	0.766	2.317
KSP 3	17	0.951	2.07

Table 5 presents the data indicating that the palm tree fiber with a volume fraction of 3 exhibited the highest tensile strength value of 25.73 MPa, surpassing the sea pandanus fiber. This suggests that the palm tree fiber possesses greater elasticity and can withstand external loads or forces for a longer duration, resulting in delayed deformation. Furthermore, the tensile strength value of the biocomposite material is influenced by the increase in fiber volume fraction, irrespective of the fiber type. The fibers, which serve as load-bearers, exhibit a strong bond with the matrix during the deformation of plastic biocomposites. The elongation percentage at tensile strain values remains below 1%, except for KSI3, where it exceeds 1%. Nevertheless, this value is still considered acceptable, and the biocomposites fall under the category of elastic materials.

Conclusion

Based on the type of unsaturated polyester resin matrix fiber and volume fraction, the density, swelling, and water absorption values were analyzed. The results indicated that the palm fiber biocomposite exhibited a higher value compared to the sea pandanus fiber biocomposite. However, the disparity between the values was not significant. The results of the impact and tensile strength tests indicated that the palm fiber biocomposite exhibited superior strength under shock loads, while also demonstrating satisfactory performance under tension, resulting in a deformation value of KSI 3

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