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The effect of variation in mixtures of *ijuk* fibres and coconut coir fibres with epoxy matrix on the mechanical strength of composites

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ABSTRACT

Fibre-based composites continue to be investigated and developed as alternative materials to replace metals, primarily due to their advantageous properties of high strength and lower weight compared to metals. This study aims to fabricate fibre composites using ijuk fibres and coconut coir fibres as a matrix with epoxy resin. In this research, mixtures of ijuk fibres, coconut coir fibres, and epoxy resin were prepared in proportions of 20%:30%:50%, 25%:25%:50%, and 30%:20%:50%. The highest bending strength test results were obtained in specimen 3, which consisted of a mixture of 30% palm fibre, 20% coconut fibre, and 50% epoxy resin. This specimen had a tensile strength value of 18.93 MPa and an impact value of 0.387 Joules/mm². This result can be attributed to the increasing proportion of ijuk fibres and the decreasing proportion of coconut coir fibres within the epoxy resin matrix, which influences the elastic strain of the fibre core (cellulose). The higher cellulose content of ijuk fibres enhances bending strength and impact resistance. This is supported by the impact (Charpy) test results, where specimen 3 (30%: 20%: 50%) exhibited the highest bending and impact strength. Conversely, increasing the proportion of coconut coir fibres reduced the impact strength. The fracture morphology revealed that specimen 1 exhibited a brittle fracture, whereas specimens 2 and 3 exhibited a fibrous brittle fracture.

Keywords: Arenga fibre, coconut coir fibre, epoxy resin, bending strength,

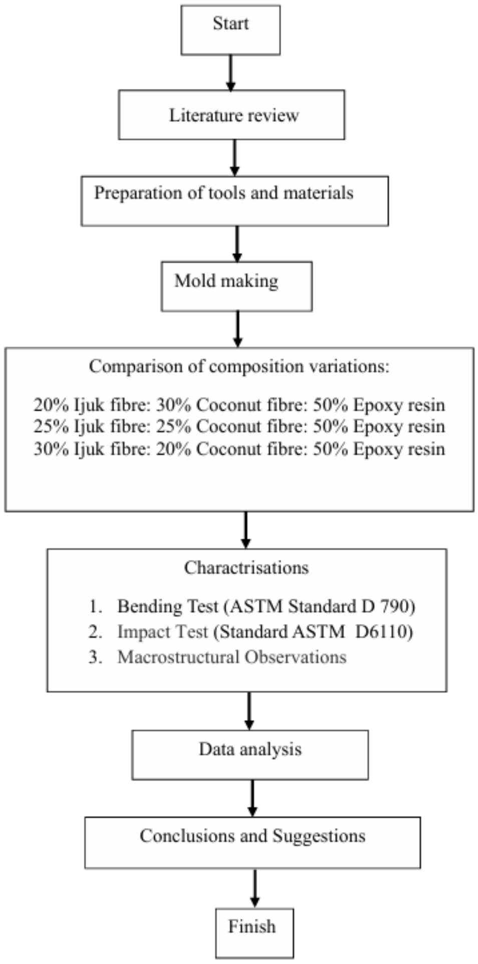
INTRODUCTION

Fibrous composites have been continuously investigated and developed as alternative materials to replace metals, primarily due to their superior strength-to-weight ratio. Composites are generally lighter than metals while maintaining considerable strength. The principal component of composites is fibre, which largely determines the overall characteristics of the material, including its strength and other mechanical properties.

The aren palm (Arenga pinnata) is widely cultivated across Indonesia as a natural source of black fibre (ijuk). However, ijuk fibre has not yet been fully utilised; a significant amount is still burned or left unused. Similarly, coconut coir fibre has been the subject of numerous studies and experiments aimed at enhancing its economic value and producing high-quality products. Agricultural waste, such as coconut coir, offers multiple benefits, including waste reduction, the transformation of waste into valuable materials, and an improvement in its economic potential (Agus Syahputra, 2010).

Previous studies on hybrid composites incorporating ijuk and coconut coir fibres have shown that the fibre ratio significantly influences the mechanical performance of the resulting composite. Among the tested variations, the composite with 20% ijuk fibre and 20% coconut coir fibre exhibited the highest tensile strength and modulus of elasticity, with a tensile strength of 35.86 MPa, representing a 96.92% increase (Nurfajri, 2019). A balanced ratio of ijuk and coconut coir fibres provides more optimal tensile strength compared to unequal ratios. This is attributed to the uneven distribution of reinforcement in composites with imbalanced fibre proportions, which reduces the overall tensile performance.

In the present study, composites will be fabricated using ijuk and coconut coir fibres as reinforcement with epoxy resin as the matrix. Considering the issues discussed above, this research seeks to explore the potential of combining ijuk and coconut coir fibres with epoxy matrix to produce composite materials with practical benefits for human applications.



Gambar 1. Research Flow Diagram

MATERIALS AND METHODS

The materials used and the tests conducted in this study are as follows:

1. The reinforcing materials for the composite are ijuk fibre (Arenga fibre) and coconut coir fibre.
2. The matrix used is epoxy resin.
3. The specimens were fabricated using the hand lay-up method (open mould technique).
4. The fibres were cut into lengths of 2 cm.
5. The fibres were treated with an alkali solution consisting of 200 g of alkali (NaOH) and 800 g of hot water, and then soaked for 2 hours.
6. The variations in the mixture ratios of ijuk fibre, coconut coir fibre, and epoxy resin were prepared as follows: 20%: 30%: 50%, 25%: 25%: 50%, and 30%: 20%: 50%.
7. The composites were subjected to bending tests (ASTM D 790), impact tests (ASTM D6110), and visual (macro) observations.

Bending Test

The fabricated composite specimens were tested using the bending test method in accordance with ASTM D790 standards. The procedure for conducting the bending test on the composite specimens was carried out as follows:

1. Prepare the fabricated specimens that are ready for testing.
2. Turn on the bending machine and ensure that the machine operates under proper safety conditions.
3. Lower the machine clamp so that the specimen can be positioned within the fixture.
4. Place the specimen into the bending machine fixture, then adjust the right and left sides of the clamp according to the predetermined specifications.
5. Slowly lower the clamp until its edge comes into contact with the specimen, ensuring that the specimen remains securely positioned during testing.
6. Install the dial indicator and set the pointer to the zero mark.
7. Apply the predetermined load specifications.
8. Rotate the machine handle until the machine needle begins to move and the dial indicator responds accordingly, then record the results of the bending test.
9. Repeat the procedure for the subsequent specimens until all tests are completed.
10. Process the collected data, followed by calculations, and present the results in the form of tables and graphs.

Impact Test

The impact test was conducted in accordance with ASTM D6110 standards. The testing procedure was performed as follows:

1. Ensure that the pointer is set at zero when the pendulum is in a free state.
2. Place the specimen on the support and ensure that the pendulum strikes precisely at the centre of the notch.
3. Slowly raise the pendulum until the pointer indicates the initial angle, at which point the pendulum locks automatically.
4. Press the release button so that the pendulum swings downward and fractures the specimen.
5. Repeat the procedure for the remaining specimens until all tests are completed.
6. After completing all specimen tests, record the observations and compile the experimental data.

RESULT AND DISCUSSION

The results of the specimen preparation are presented in the form of a fibre composite specimen, as shown in Figure 2 below.

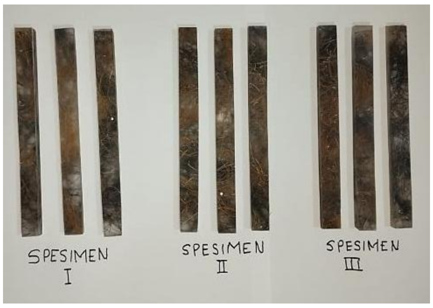


Figure 2. Results of making a composite

The Bending Test Results

The bending test results for each composite specimen are shown in Table 1 below.

Table 1. Bending test results on variations of mixtures of palm fibre, coconut fibre and epoxy resin.

Table 1. Bending test results on variations of mixtures of palm fibre, coconut fibre and epoxy resin.

Specimen	***Area* (mm²)**	***Max. Force* (N)**	***Bending Strength* (MPa)**	**Average *Bending Strength* (MPa)**	***Elongation* (%)**
Palm fiber 20% : coconut fiber 30% : Epoxy 50%	64,713	1021,9	15,79	16,45	1,45
	61,104	1081,1	17,69		1,45
	60,138	954,5	15,87		1,45
Palm fiber 25% : coconut fiber 25% : Epoxy 50%	65,000	1150,4	17,69	17,41	1,45
	71,194	1209,7	16,99		1,45
	69,600	1221,1	17,54		1,45
Palm fiber 30% : coconut fiber 20% : Epoxy 50%	65,620	1244,5	18,96	18,93	1,45
	62,338	1198,3	19,22		1,45
	62,642	1165,8	18,61		1,45

The table above shows that the average bending strength of Specimen 1, with a composition of 20% ijuk fibre, 30% coconut coir fibre, and 50% epoxy resin, was 16.45 MPa. Specimen 2, comprising 25% ijuk fibre, 25% coconut coir fibre, and 50% epoxy resin, achieved a bending strength of 17.41 MPa. In contrast, Specimen 3, with 30% ijuk fibre, 20% coconut coir fibre, and 50% epoxy resin, reached a bending strength of 18.93 MPa. The results of the bending strength tests were subsequently illustrated in Figure 3, as follows:

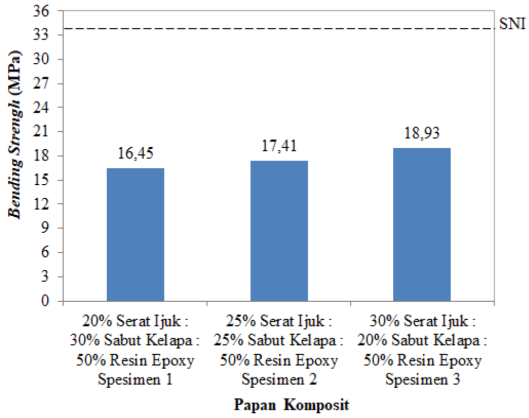


Figure 3. Bending test graph on variations of mixtures of palm fibre, coconut fibre and epoxy resin

Figure 3 presents the bending test results for composites with varying mixtures of ijuk fibre, coconut coir fibre, and epoxy resin. The graph shows that Specimen 1, with a composition of 20% ijuk fibre, 30% coconut coir fibre, and 50% epoxy resin, exhibited a bending strength of 16.45 MPa. An increase in bending strength was observed in Specimen 2 (25% ijuk fibre, 25% coconut coir fibre, and 50% epoxy resin) with a value of 17.41 MPa. A further increase occurred in Specimen 3, which contained 30% ijuk fibre, 20% coconut coir fibre, and 50% epoxy resin, resulting in a compressive strength of 18.93 MPa.

Based on Figure 3, it can be seen that the highest bending strength was obtained in Specimen 3, which consisted of 30% ijuk fibre, 20% coconut coir fibre, and 50% epoxy resin, yielding a value of 18.93 MPa. Conversely, the lowest bending strength was recorded in Specimen 1, which consisted of 20% ijuk fibre, 30% coconut coir fibre, and 50% epoxy resin, at 16.45 MPa. This indicates that the variation in the mixture ratio of ijuk and coconut coir fibres with epoxy resin significantly influences the mechanical performance under bending tests. Specifically, increasing the proportion of ijuk fibre while decreasing the proportion of coconut coir fibre enhances the elastic strain behaviour of the fibre core (cellulose) and optimises shear stress distribution.

This phenomenon demonstrates that natural fibre mixtures are capable of resisting unidirectional forces, resulting in a bending strength of 18.93 MPa, the highest among all tested materials. However, the bending strength of the composite specimens remains below the Indonesian National Standard (SNI) requirement for vehicle body materials, which is 49.60 MPa. This discrepancy is attributed to the relatively low cellulose content in ijuk and coconut coir fibres, which limits their reinforcing effect and prevents them from reaching the SNI standard. As reported by Li (2011), a higher cellulose content increases the reinforcing effect, as the greater number of cellulose particles also enlarges the surface area, thereby improving adhesion at the fibre–matrix interface. (Halasz, 2012)

Impact Test Results (Charpy)

The impact test was conducted as a rapid and straightforward method to evaluate the impact properties of the composites. The results are presented in Table 2.

Table 2. Impact test result (*Charpy*)

Speciment	Area (mm^2)	$\alpha°$	$\beta°$	Energy (Joule)	HI (Joule/mm^2)	Avarage HI (Joule/mm^2)
Palm fiber 20% : coconut fiber 30% : Epoxy 50%	82,215	150	136	23,57	0,286	0,335
	82,324	150	133	29,67	0,360	
	82,498	150	133	29,67	0,359	
Palm fiber 25% : coconut fiber 25% : Epoxy 50%	84,150	150	134	27,58	0,327	0,360
	83,984	150	131	33,68	0,401	
	84,182	150	133	29,67	0,352	
Palm fiber 30% : coconut fiber 20% : Epoxy 50%	83,537	150	131	33,68	0,403	0,387
	83,331	150	132	31,59	0,379	
	83,281	150	132	31,59	0,379	

According to the table above, the average impact strength of Specimen 1, which has a composition of 20% ijuk fibre, 30% coconut coir fibre, and 50% epoxy resin, is 0.335 J/mm². Specimen 2, with 25% ijuk fibre, 25% coconut coir fibre, and 50% epoxy resin, exhibited an impact strength of 0.360 J/mm². In contrast, Specimen 3, composed of 30% ijuk fibre, 20% coconut coir fibre, and 50% epoxy resin, achieved the highest value of 0.387 J/mm². The results of the impact tests are subsequently illustrated in Figure 4, as follows:

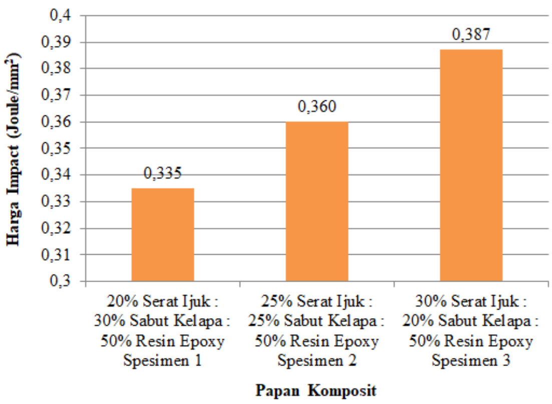


Figure 4. Graph of impact price test results

Figure 4.3 illustrates the impact strength test results for composites with varying proportions of ijuk fibre, coconut coir fibre, and epoxy resin. Specimen 1, comprising 20% ijuk fibre, 30% coconut coir fibre, and 50% epoxy resin, exhibited an impact strength of 0.335 J/mm². As the proportion of ijuk fibre increased while maintaining a constant epoxy content, the impact strength continued to rise, as observed in Specimen 2 and Specimen 3, with values of 0.360 J/mm² and 0.387 J/mm², respectively. This trend is attributed to the effect of fibre composition variation, which influences one of the key mechanical properties, namely impact strength. A higher cellulose content in the fibres contributes to an increase in impact resistance.

Based on Figure 4, the highest impact strength was recorded in Specimen 3 at 0.387 J/mm², while the lowest was observed in Specimen 1 at 0.335 J/mm². This difference is primarily due to the higher cellulose content in ijuk fibre (52%, Yumnawati, 2021), which enhances the impact strength of the composite, compared to the lower cellulose content in coconut coir fibre (32–43%, Sari, 2013). The results of the Charpy impact test clearly indicate that composites with higher ijuk fibre content exhibit greater impact strength, whereas increasing the proportion of coconut coir fibre reduces the impact strength. This phenomenon is further supported by macroscopic visual observations, which show that Specimen 3 exhibited a fibrous, brittle fracture pattern.

Visual Observation Results (Macro)

Visual observations (macro) were conducted to observe the fracture mechanism of each composite board specimen. The results of the visual observations (macro) are shown in Figures 5, 6, and 7 below.

Figure 5. Results of visual observation (macro) specimen 1

The results of macroscopic visual observation revealed the presence of a fibre break mechanism. This indicates that the applied load was not fully distributed to the fibres, leading to fibre fracture. Consequently, the composite became more brittle in absorbing the load, as illustrated in Figure 5.

Figure 6. Results of visual observation (macro) on specimen 2

The results of macroscopic visual observation on Specimen 2, composed of 25% ijuk fibre, 25% coconut coir fibre, and 50% epoxy resin, revealed the presence of a fibre pull-out mechanism. This indicates that the applied load was effectively transferred to the fibres, causing them to be pulled out. As a result, the composite exhibited greater toughness in absorbing the load, as shown in Figure 6.

Figure 7. Results of visual observation (macro) on specimen 3

The results of macroscopic visual observation revealed a fibre pull-out mechanism, which occurred due to the weakening of the bond between the fibres and the matrix under increasing applied loads. When the matrix failed, the fibres were still able to bear the load, thereby preventing the fracture process from occurring. This indicates that the composite exhibited a more fibrous brittle fracture, with the load being effectively transferred to the fibres, causing them to be pulled out. As a result, the composite demonstrated greater toughness in absorbing the load.

In Specimen 3, consisting of 30% ijuk fibre, 20% coconut coir fibre, and 50% epoxy resin, fibre pull-out was observed due to the inability of the matrix to withstand the applied load. This led to fibre detachment, followed by fracture under the unidirectional forces acting on the specimen.

CONCLUSION

1. The highest bending strength was obtained in Specimen 3, at 18.93 MPa, while the lowest value was observed in Specimen 1, at 16.45 MPa. This variation is attributed to the influence of the mixture ratio of ijuk fibre and coconut coir fibre with epoxy resin on the mechanical properties during bending tests. Increasing the proportion of ijuk fibre and reducing the proportion of coconut coir fibre within the epoxy matrix affects the elastic strain of the fibre core (cellulose) and optimises shear stress. This phenomenon is evident from the bending strength test results, where natural fibre composites were able to withstand unidirectional forces, resulting in a maximum bending strength value of 18.93 MPa.
2. The highest impact strength was achieved by Specimen 3, at 0.387 J/mm², while the lowest was found in Specimen 1, at 0.335 J/mm². This result is influenced by the higher cellulose content of ijuk fibre, which enhances impact strength. The Charpy impact test results clearly show that specimens with higher proportions of ijuk fibre exhibited greater impact resistance, whereas increasing the proportion of coconut coir fibre led to a decrease in impact strength.
3. The results of macroscopic visual observation revealed a fibre pull-out mechanism in Specimen 3, which occurred due to the weakening of the fibre–matrix interfacial bond under increasing applied loads. This indicates that

Specimen 1 exhibited a brittle fracture, while Specimens 2 and 3 showed fibrous brittle fracture patterns.

4. The bending test results are still below the SNI vehicle body standards. For future research, it is hoped that natural fibres can be selected that are more suitable for vehicle body needs.

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