

The Effect of Fibre Direction on the Mechanical Properties of Polyester Matrix-Based Palm Oil Fibre Composite

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ABSTRACT

The increasing use of composite materials, especially for the two-wheeled vehicle industry, requires an in-depth study of fibre direction. Where the fiber direction can determine the occurrence of initial damage to the composite material. This study aims to produce a composite board from oil palm fruit fibre reinforced with a polyester matrix. In this study, the composite board consists of 3 types, namely sample 1 (discontinuous direction 0°), sample 2 (discontinuous direction 90°), and sample 3 (random fibre direction). The highest bending and impact test results were in specimen 1 with a 0° fibre direction, namely 63.93 MPa and 0.519 Joules/mm², while the lowest bending and impact test results were in specimen 3 with a random fibre direction, namely 58.63 MPa and 0.382 Joules/mm². Specimens with horizontal fibre directions have higher strength values. When the fibres are arranged in a 90° direction and a random direction, the mechanical strength is lower, because the load is mostly borne by the material matrix, which is generally weaker than the fibres. Macro photography at 0° shows that the bonding mechanism of oil palm fruit fibres with the polyester resin matrix is quite good, with visible fibre pullout. This indicates that the bond between the fibre and the matrix weakens as the applied load increases. When the matrix fails, the fibres can still bear the load, so the fracture process does not occur simultaneously. If the composite fibres become more brittle and the load is distributed to the fibres, which pulls them out, this will result in high toughness and bending strength.

Keywords: Fibre Direction, Oil Palm Fruit Fibre, Polyester Resin, Mechanical Strength

1. INTRODUCTION

Indonesia boasts extensive forests across the archipelago. Non-timber forest products derived from renewable plants have not received the government's full attention, despite their significant economic

contributions and employment creation. The advantages of natural fibres have enabled innovation and product development in recent years, such as the development of fibre-reinforced composites in the automotive, building construction,

geotextile, and agricultural industries (Wardhana, 2016, p. 7).

The utilisation of waste in the form of empty oil palm bunches (EFBs) is still limited to furniture and household crafts, and it has not yet been processed into natural fibre composites for automotive technology products. Empty oil palm bunch waste has significant potential for use as a natural fibre composite (Dody Yulianto, 2022).

Several efforts have been made to utilise natural fibres as construction materials. Reinforcement materials, such as natural fibres, are used in composites (Setiawan, 2021, p. 194). These natural fibres are expected to increase the composite material's strength. One area where research has begun to explore its uses is oil palm empty fruit bunch (OPEFB) fibre. This fibre is categorised as a natural fibre derived from plants whose fruit is harvested (Arifin, 2023, p. 44). Oil palm empty fruit bunch (OPEFB) fibre is a waste product from palm oil mills. Fibre classification indicates that this fibre is extracted from the fruit stalks of plants. OPEFB is a cellulose fibre that is readily available. Indonesia produced a total of 45.58 million tons of palm oil in 2022, according to data from the Directorate General of Plantations (DGT, 2023).

The effect of varying the mixture of palm fibre and coconut fibre with epoxy resin on mechanical strength during bending strength testing, where the greater the mixture of palm fibre and coconut fibre with epoxy resin, the greater the effect on the elastic strain of the fibre core (cellulose) and the optimal shear stress. (Dody Yulianto, 2025).

The sugar palm (*Arenga pinnata*) is widely cultivated throughout Indonesia as a natural source of black fibre (ijuk). However, ijuk fibre has not been fully utilised; much of it is burned or left unused. Similarly, coconut fibre has been the subject of numerous studies and experiments aimed at increasing its economic value and producing high-quality products. Agricultural waste, such as coconut fibre, offers various benefits, including waste reduction, transformation into valuable materials, and increased economic potential (Agus Syahputra, 2010).

Research exploring the use of palm frond fibre, aluminium powder, and polyester resin as brake lining materials offers a promising and environmentally friendly solution. The potential environmental benefits of this research are expected to foster hope and optimism about the future of brake pad materials. The composition is close to the SAE standard brake pad hardness level, particularly in sample 3, which contains 60% palm fronds, 10% aluminium powder, and 30% polyester resin. With this composition, the hardness value is 38.2 kg/mm². Sample 3 consisted of 60% oil palm fronds, 10% aluminium powder, and 30% polyester resin, resulting in a composition similar to that of brake pad wear, as defined by SAE standards. The wear value for this composition was 0.9342×10^{-7} mm²/kg. The wear test results showed that the higher the percentage of oil palm frond fibre and the lower the aluminium powder content, the higher the wear value and tensile test results. (Dody Yulianto, 2025)

Based on the description above, further research is needed to

determine the direction of oil palm fibres for creating polyester resin matrix composites.

2. MATERIALS AND METHODS

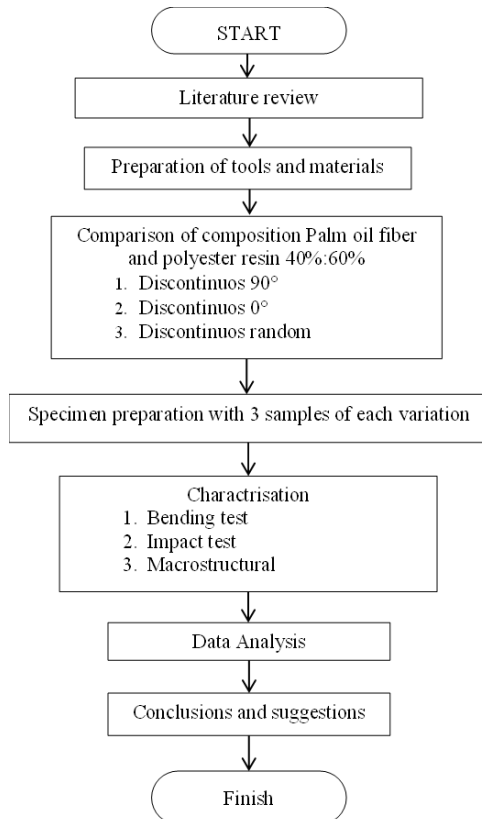


Figure 1. Research flow diagram

The following are the steps for making composite boards:

1. Prepare oil palm fibres that have been cleaned of dust and dirt.
2. Prepare oil palm fibres that have been cut to the same length.
3. The oil palm fibres that have been cut to the same length are then weighed according to the size of sample 1. This is also done for samples 2 and 3.
4. Next, weigh the polyester resin according to the size requirements for sample 1. This is also done for samples 2 and 3.
5. Then, mix the oil palm fibres, polyester resin, and catalyst evenly in a container according to the

composition variations specified for samples 1, 2, and 3.

6. Pour the mixture of oil palm fibres, polyester resin, and catalyst evenly into the mould container.
7. Allow the mixture to dry and harden for 24 hours.
8. Once the mixture is confirmed to be completely dry and hard, the results are analysed and subjected to bending and impact tests on the composite material specimens.

2.1 Compositing Process

1. Preparing the mould
2. Preparing materials such as oil palm fibre, polyester resin, and a catalyst.
3. Based on the mould used, Vc (mould volume) can be calculated as follows:

$$V_c = \text{Length} \times \text{Width} \times \text{Height} \text{ (cm}^3\text{)} \dots (1)$$

Where:

$$\text{Length} = 16 \text{ cm}$$

$$\text{Width} = 9 \text{ cm}$$

$$\text{Height} = 0.1 \text{ cm}$$

$$\begin{aligned} V_c &= \text{Length} \times \text{Width} \times \text{Height} \text{ (cm}^3\text{)} \\ &= 16 \text{ cm} \times 9 \text{ cm} \times 0.1 \text{ cm} \\ &= 14.4 \text{ cm}^3 \end{aligned}$$

Based on the density of the oil palm fruit fibre, polyester resin, and catalyst, the following calculation can be made:

$$\rho = m/V$$

Where:

$$\rho = \text{Density (kg/m}^3\text{) or (gr/cm}^3\text{)}$$

$$m = \text{Mass (kg) or (gram)}$$

$$V = \text{Volume (m}^3\text{ or cm}^3\text{)}$$

For the mass of oil palm fibre and polyester resin, the following is true:

$$\text{Mass of oil palm fibre} = V_{\text{mold}} \times \rho_{\text{fiber}}$$

$$\text{Polyester resin} = V_{\text{mold}} \times \rho_{\text{fiber}}$$

$$\text{Catalyst} = V_{\text{mold}} \times \text{Fibre mass}$$

For the mass of oil palm fibre and epoxy resin, the following is used:

$$\begin{aligned} \text{Palm fibre mass} &= V_{\text{mold}} \times \rho_{\text{fiber}} \dots (2) \\ &= 14.4 \text{ cm}^3 \times 0.1207 \\ &\text{g/cm}^3 \\ &= 1.738 \text{ grams} \end{aligned}$$

$$\begin{aligned}\text{Polyester resin} &= V_{\text{mold}} \times \rho_{\text{fiber}} \dots\dots(3) \\ &= 14.4 \text{ cm}^3 \times 1.17 \text{ g/cm}^3 \\ &= 16.84 \text{ grams}\end{aligned}$$

a. Sample 1

Sample 1 is a mixture with the desired volume composition (40% oil palm fruit fibre and 60% polyester resin), 90° discontinuities, and a unidirectional arrangement.

$$\begin{aligned}\text{Oil palm fiber} &= 40\% \times 1.738 \text{ grams} \\ &= 0.69 \text{ grams}\end{aligned}$$

$$\begin{aligned}\text{Polyester resin fiber} &= 60\% \times 16.84 \text{ grams} \\ &= 10.10 \text{ grams}\end{aligned}$$

b. Sample 2

Sample 2 is a mixture with the desired volume composition (40% oil palm fibre and 60% polyester resin), a 0° discontinuity, and an unidirectional arrangement.

$$\begin{aligned}\text{Oil palm fiber} &= 40\% \times 1.738 \text{ grams} \\ &= 0.69 \text{ grams}\end{aligned}$$

$$\begin{aligned}\text{Polyester resin fiber} &= 60\% \times 16.84 \text{ grams} \\ &= 10.10 \text{ grams}\end{aligned}$$

c. Sample 3

Sample 3 is a mixture with the desired volume composition (40% oil palm fibre and 60% polyester resin), arranged in random directions.

$$\begin{aligned}\text{Oil palm fiber} &= 40\% \times 1.738 \text{ grams} \\ &= 0.69 \text{ grams}\end{aligned}$$

$$\begin{aligned}\text{Polyester resin fiber} &= 60\% \times 16.84 \text{ grams} \\ &= 10.10 \text{ grams}\end{aligned}$$

2.3 Specimen Testing

1. Bending Test

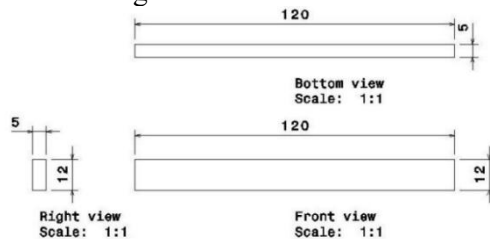


Figure 2. Bending test ASTM D790

2. Impact test

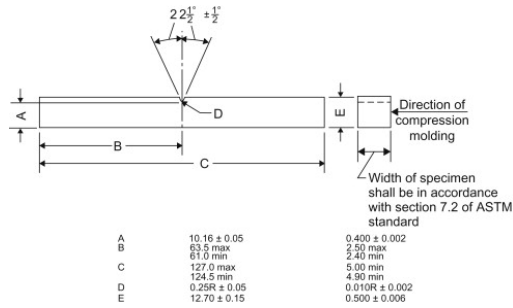


Figure 3. Impact test ASTM D6110

2.2 Material Mixing Process

The following are the steps in mixing the materials for making the composite specimens in this study:

1. Prepare oil palm fibres that have been cleaned of dust and dirt.
2. Prepare oil palm fibres that have been cut to the same length.
3. The oil palm fibres that have been cut to the same length are then weighed according to the size of sample 1. This is also done for samples 2 and 3.
4. Then, weigh the polyester resin according to the size requirements for sample 1. This is also done for samples 2 and 3.
5. Then, mix the oil palm fibres, polyester resin, and catalyst evenly in a container according to the composition variations for samples 1, 2, and 3.
6. Pour the mixture of oil palm fibres, polyester resin, and catalyst evenly into the mould.
7. Allow the mixture to dry and harden for 24 hours.
8. After the mixed material is confirmed to be completely dry and hard, the next step is to carry out analysis results and bending tests, as well as impact tests on the composite material specimens.

3. RESULT AND DISCUSSION

The results of the study of the influence of fibre direction on the mechanical properties of oil palm fruit fibre composites with a polyester polymer

matrix. This research was conducted at the Mechanical Engineering Laboratory of the Faculty of Engineering, Riau Islamic University, using discontinuous fibre directions of 0° , 90° and random as influences in the manufacture of composite boards. In the process of making composite boards, the fibre-to-matrix ratio is 40% oil palm fruit fibre and 60% polyester resin. The results of making composite board specimens are shown in Figure 4 below.

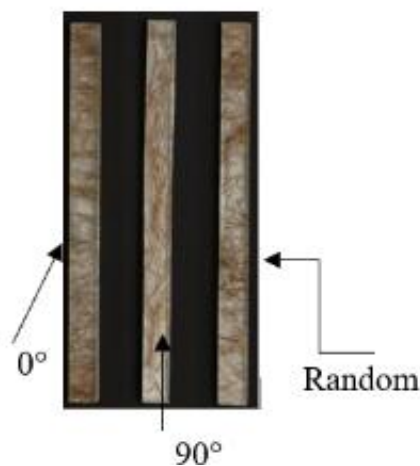


Figure 4. Results of composite boards in variations of discontinuous fibre direction 0° , 90° and random direction.

3.1 Bending Test Results

Bending tests were conducted in accordance with ASTM D 790 standards at the Mechanical Engineering Laboratory of the Islamic University of Riau. After testing each composite board specimen, damage was observed due to the discontinuous fibre direction (0°), discontinuous fibre direction (90°), and discontinuous fibre direction (random). The bending test results for each composite board are shown in Table 1.

Table 1. Bending test results on variations in discontinuous fibre direction at 0° , 90° and random.

Specimen	Area (mm ²)	Max. Force (N)	Bending Strength (MPa)	Average Bending Strength (MPa)
Discontinuos 0°	48,6	232,4	88,6	63,93
	48,6	154,7	59,0	
	48,6	116,0	44,2	
Discontinuos 90°	48,6	129,3	48,1	59,76
	48,6	131,8	49,0	
	48,6	219,1	82,2	
Discontinuos random	48,6	177,2	67,5	58,63
	48,6	157,1	59,9	
	48,6	127,4	48,5	

The bending test results in Table 1 are then entered into Figure 5 below.

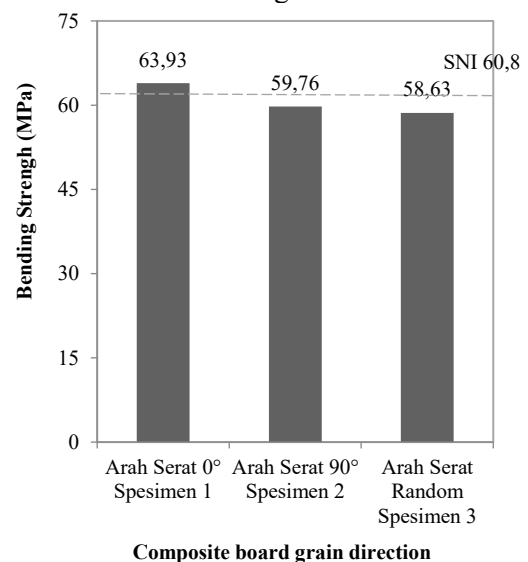


Figure 5. Bending test graph for variations in discontinuous fibre direction at 0° , 90° and random directions.

Figure 5 shows a bending test graph for a composite board with fibre directions of 0° , 90° , and random. The graph above shows that specimen 1, with a 0° fibre direction, has a bending value of 63.93 MPa. Specimen 2, with a 90° fibre direction, has a bending value of 59.76 MPa. Specimen 3, with a random fibre direction, has a bending value of 58.63 MPa.

58.63 MPa. This indicates an influence on the composite board, as fibre direction determines how the bending load is distributed and absorbed by the composite board made from palm oil fibre and polyester resin.

Graph 3 shows that the highest bending test value is for specimen 1 with a 0° fibre direction, at 63.93 MPa, while the lowest bending test result is for specimen 3 with a random fibre direction, at 58.63 MPa. Specimens with horizontal fibre directions have higher strength values (Rendy, 2021). When the fibres are arranged in a 90° direction and a random direction, the mechanical strength is lower, because the load is mostly borne by the material matrix, which is generally weaker than the fibres.

3.2 Impact Test Results

Impact testing was conducted using the Charpy method in accordance with ASTM D 6110, conducted at the Mechanical Engineering Laboratory of the Islamic University of Riau. After testing each composite board, it was observed that the fracture form of the composite board material was given different fibre directions, namely discontinuous fibre direction 0° , discontinuous fibre direction 90° , and discontinuous fibre direction random. The composite board has a volume fraction of 40% oil palm fruit fibre and 60% polyester resin. The impact test results were conducted as a quick, easy quality check to assess impact properties. Can be seen in Table 2.

Table 2. Impact test results (Charpy) on variations in discontinuous fibre direction 0° , 90° and random.

Sampel	Area (mm ²)	β°	Energy (Joule)	HI (Joule/mm ²)	Average HI (Joule/mm ²)
Discontinuos 0°	70,68	128	40,25	0,569	0,519
	75,23	129	38,01	0,505	
	78,21	129	38,01	0,485	
Discontinuos 90°	78,21	129	38,01	0,485	0,470
	76,72	131	33,68	0,438	
	73,34	130	35,92	0,489	
Discontinuos random	78,68	136	23,52	0,299	0,382
	78,31	133	29,67	0,385	
	77,46	130	35,92	0,463	

The results of the impact test above are then entered into Figure 6, as follows:

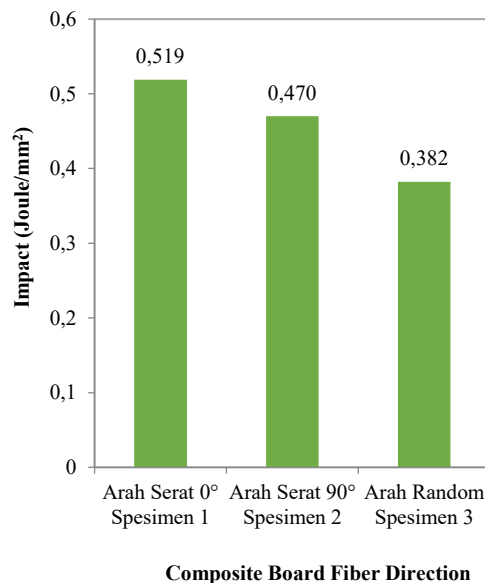


Figure 6 Graph of the results of the impact price test on variations in the direction of the discontinuous fibre direction 0° , 90° and random

Figure 6 shows a graph of impact value tests for discontinuous fibre orientations at 0° , 90° , and random. Specimen 1, with a 0° fibre orientation, showed an impact value of 0.519 Joules/mm², specimen 2, with a 90° fibre

orientation, 0.470 Joules/mm², and specimen 3, with a random fibre orientation, 0.382 Joules/mm².

Impact testing of these specimens yielded the highest impact value for the specimen with the 0° direction variation, at 0.519 Joules/mm². The impact values were lower for the specimens with the 90° and random directions, at 0.470 Joules/mm² and 0.382 Joules/mm², respectively. This is due to the straight, horizontal fibre orientation parallel to the 0° direction, indicating that the fibres effectively reinforce the matrix. A uniform fibre-resin mixture can increase the impact value. As Pamungkas et al. (2017) state, the smaller the direction angle, the higher the impact energy value and impact price. Furthermore, Lasikun et al. (2018) revealed that the relevant resistance of the ideal fibre-angle-oriented composite is at its maximum at 0°, but decreases at 90°.

3.3 Macrostructural

This visual observation was conducted on a composite board of oil palm fibre with a polyester resin matrix, with fibre directions: discontinuous 0°, discontinuous 90°, and random discontinuous. After that, the process of printing the test specimen material continued, where, in this process, the composite board will be formed using the layer method (hand lay-up). The results of visual observations (macro) can be seen in Figures 5, 6 and 7 as follows.



Figure 7 Results of visual observation (macro) on specimen 1 with discontinuous direction 0°.

Figure 7 shows a macro photo of the fracture cross-section of a 0° bending test specimen. The photo shows a fairly good bonding mechanism between the oil palm fruit fibres and the polyester resin matrix, with visible fibre pull-out. This indicates that the bond between the fibres and the matrix weakens as the applied load increases. When the matrix fails, the fibres can still bear the load, so the fracture process does not occur simultaneously. If the composite fibres become increasingly brittle and the load is distributed to the fibres, causing them to be pulled out, this will result in high toughness and bending strength.



Figure 8 Results of visual observation (macro) on specimen 1 with a discontinuous direction of 90°.

Figure 8 shows a macro photograph of a fractured cross-section of a 90° bending test specimen. The photograph demonstrates poor bonding between the oil palm fibres and the polyester resin matrix, as evidenced by numerous fibre breaks. This indicates that the load distribution is not reaching the fibres, leading to their breakage.

Furthermore, the fractured surface of the specimen is uneven and uneven, resulting in a dull, non-glossy appearance. The uneven fracture surface is due to poor bonding between the fibres and the matrix, which, in turn, does not transfer stress optimally. This is caused by voids between the filler and the matrix, which detach and break the fibres under the unidirectional force they are subjected to. Visual observation results (macro) of specimen 3



Figure 9 Results of visual observations (macro) on specimen 3 with a mixture of 60% bamboo fibre and 40% polyester resin

Figure 9 shows a macro photograph of a fracture cross-section of a random-angle bending test specimen. The photograph demonstrates poor bonding between the oil palm fibres and the polyester resin matrix, as evidenced by numerous fibre breaks. This indicates that the load distribution does not reach the fibres, leading to their breakage.

The fracture surface of the specimen is also uneven and uneven, resulting in a dull, non-glossy appearance. The uneven fracture surface is due to poor bonding between the fibres and the matrix, which, in turn, does not transfer stress optimally. This is caused by voids between the filler and the matrix, which detach and break the fibres under the unidirectional force they experience.

4. CONCLUSION

1. The highest bending test result was 63.93 MPa for specimen 1 with a 0° grain direction, while the lowest bending test result was 58.63 MPa for specimen 3 with a random grain direction. This is because the 0° grain direction is better able to withstand bending loads than the 90° direction. When the fibres are arranged at a 90° angle and a random direction, the mechanical strength is lower because the load is largely borne by the material matrix, which is generally weaker than the fibres.
2. The highest impact test result for the specimen with the 0° direction variation was 0.519 Joules/mm². The impact value was lower for the specimens with 90° and random directions, namely 0.470 and 0.382 Joules/mm², respectively. This is because the horizontal and straight fibre direction is parallel to the 0°

direction, meaning the fibres fully withstand impact loads. A uniform fibre-resin mixture can increase the impact value.

- The macro photography results at a 0° angle show that the bonding mechanism of oil palm fruit fibres with the polyester resin matrix is quite good; fibre pull-out can be seen. This indicates that the bond between the fibre and the matrix weakens when the applied load continues to increase. When the matrix fails, the fibre can still bear the load, preventing simultaneous fracture. If the composite fibre becomes increasingly brittle and the load is distributed to the fibre, which pulls it out, it will produce high toughness and bending strength.

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