

## Investigation on Fiber Orientation to the Flexural Strength of Banana Fiber Reinforced Polyepoxydes Composite under Bending Loads

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### Abstrak

Komposit dengan perkuatan serat batang pisang diselidiki kekuatannya terhadap pembebanan lentur dalam artikel ini. Serat diekstraksi dari kulit batang pisang, kemudian diolah dengan NaCl dan dikeringkan. Matriks yang digunakan adalah resin epoksi, yang beratnya diusahakan sebesar 20% dari berat total komposit. Sejumlah sampel komposit dibuat dengan orientasi serat dalam tiga jenis: serat berorientasi 0°, serat berorientasi acak, dan serat dibuat tali bertenun. Kemudian sampel diuji kekuatannya terhadap pembebanan lentur. Hasil pengujian menunjukkan bahwa kekuatan komposit tidak mengalami peningkatan dan beberapa sampel tidak sesuai harapan dibandingkan dengan kekuatan resinnya.

**Kata kunci:** komposit, serat kulit batang pisang, epoksi resin, kekuatan lentur

### Abstract

*Composites with banana stem fiber reinforcement are investigated for their strength against bending loading in this paper. Fiber is extracted from banana peel, then treated with NaCl and dried. The matrix used is epoxy resin, the weight of which is kept at 20% of the total weight of the composite. A number of composite samples were made with three types of fiber orientation: 0° oriented fibers, randomly oriented fibers, and woven rope fibers. Then the samples were tested for strength against bending loading. The test results showed that the strength of the composite did not increase and some samples did not meet expectations compared to the strength of the resin.*

**Keywords:** composite, banana stem fiber, epoxy resin, flexural strength

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Diterima : 2 Februari 2024

Diperbaiki : 7 Maret 2024

Disetujui : 10 Maret 2024

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### Introduction

In the past, Thailand, Indonesia, Vietnam, the Philippines and Malaysia were listed as the world's largest natural rubber producing countries. Along with the fall in world natural rubber prices in the last decade, Malaysia has taken very significant actions with its natural rubber production. Many of the large rubber plantations were converted into oil palm plantations, while the smaller plantations were converted into Musang King durian plantations. Durian Musang King can usually start to be harvested after the age of 8 years from planting the seeds. To overcome this time gap, cultivators usually plant banana trees because they bear fruit only

three months after planting. Banana trees will never disappear, before they bear fruit they already have several saplings in their tubers. Thus there will be massive amounts of banana tree waste in the near future. It would be nice if this banana tree waste could be utilized for human needs.

The use of natural fibers as composite reinforcement instead of glass fibers has attracted the interest of scientists over the last decade. The disadvantages of glass fiber, such as non-biodegradability, non-recyclability, health risks if inhaled, and high energy consumption, have prompted research on natural fibers as a substitute for glass fiber. As a result, efforts have been made to manufacture natural fiber polymer composites through various processing techniques -such as extrusion, injection molding, woven and nonwoven composites- for applications such as construction materials and automotive components. In addition to natural fibers' biodegradability, low energy consumption, low cost, and renewable properties, few natural fibers are on par with glass fibers. In contrast, natural fiber composites have superior specific characteristics and are lighter than similar synthetic fiber composites (Anuar et al, 2017).

In the near future, the promise of composites will be realized thanks to recent advances in fiber technology. Identification of the uses of banana fiber is one of the most significant advances. Scientists from all over the world are starting to take an interest in banana fiber extracted from the trunk of a tree of the Musaceae species. It has been found that cellulose is the main component of plant fiber, followed by lignin, hemicellulose and pectin. Cellulose provides reinforcement for all the other components. The higher the fiber aspect ratio, the greater the tensile strength of the reinforcement. This diversity of qualities allows plant fibers to exhibit composite-like characteristics (Zampaloni et al, 2007).

The source of banana fiber is the bark of the tree. The waste is abundant in tropical countries. Whereas polymer composites reinforced by banana peel fibers have good fire retardant properties that can meet the demands of many applications. The use of banana fiber in composites is still limited due to extraction and preparation problems, as well as the lack of mechanical properties compared to synthetic fibers. Therefore, continuous research is needed to improve the extraction and preparation process and evaluate its potential as an alternative composite material in various industrial and commercial applications such as automotive parts, construction materials and packaging (Vishnuvarthanan et al, 2019). In term of mechanical properties, the tensile strength of banana stem fiber reinforced polyepoxyde composites under axial loading has been investigated by several researchers (Hung et al, 2023)

The purpose of this study was to examine the effect of banana fiber orientation on its mechanical strength due to bending loading. For this purpose, several composite samples were prepared with banana stem fiber reinforcement with various orientations. Then the samples were tested in a universal testing machine. The results obtained are then analyzed to then be concluded.

## **Methodology**

Briefly, this research was conducted in three stages: (1) the specimen preparation stage, (2) the specimen testing stage in the universal testing machine, and (3) the analysis stage and concluding the test results. Both specimen fabrication and testing are all carried out according to ASTM standards. We will test four samples as listed in Table 1. The first sample, sample A, is a sample made of poly-epoxide resin solely. This sample was made to determine the flexural strength of the poly-epoxide used as a resin. The second sample, sample B, is a composite made of resin with unidirectional fiber reinforcement in the longitudinal direction. Sample C as the third sample is a composite with random fiber directions as its reinforcement. The last sample, sample D, is a composite with woven fibers. From the selected sample, we hope that sample D has better flexural strength than samples B and C, and samples with fiber reinforcement will have better flexural strength than the resin used.

In the specimen preparation as the first stage, natural continuous banana fiber must be abstracted from the layers of the tree bark first. Then the fiber orientation must be prepared including if it needs to be woven first. Next, the mold needs to be made. After that, it is necessary to make a preliminary estimate of the ratio of fiber weight to total weight. Finally, the designed specimen was made.

Table 1. Specimen specification

Sample	Matrix	Fiber	Fiber orientation
A	Poly-epoxide	-	-
B	Poly-epoxide	Banana fiber	0° long continuous
C	Poly-epoxide	Banana fiber	Random long continuous
D	Poly-epoxide	Banana fiber	woven
E	Poly-epoxide	e-glass	Random long continuous

**Abstracting the natural continuous banana fiber.** The extraction process -as shown in Figure 1- is done manually which is also known as stripping. It is a laborious process as it is done using knives where pseudo-stem is de-sheathed first and followed by flattening. Further 50 – 80-mm-widestrips, known as tuxy, are formed with the help of knife. This separation process is called tuxing. It is followed by degumming, i.e. the removal of gum and other residual components by using knife. The fiber is then washed and being ongoing treatment by immersing in NaCl (also known as table salt) and dried for further applications.

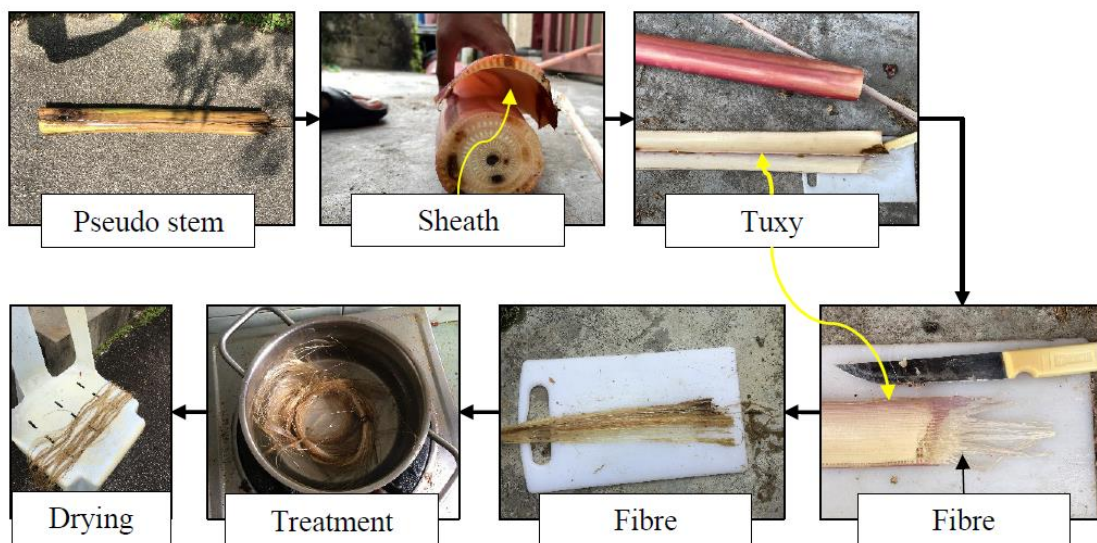


Figure 1. Overview of pseudo stem fiber extraction

**Woven making process.** To make sample D we need to weave the fiber first. We use plain weave with 0°/90° fiber orientation. To make woven manually from the raw fiber previously obtained, we have to go through several stages as described in Figure 2. The raw fiber will first go through a manual tying process to form long banana fiber threads. The process is done manually by hand with the correct technique. The threads are then woven using a manual weave kit.

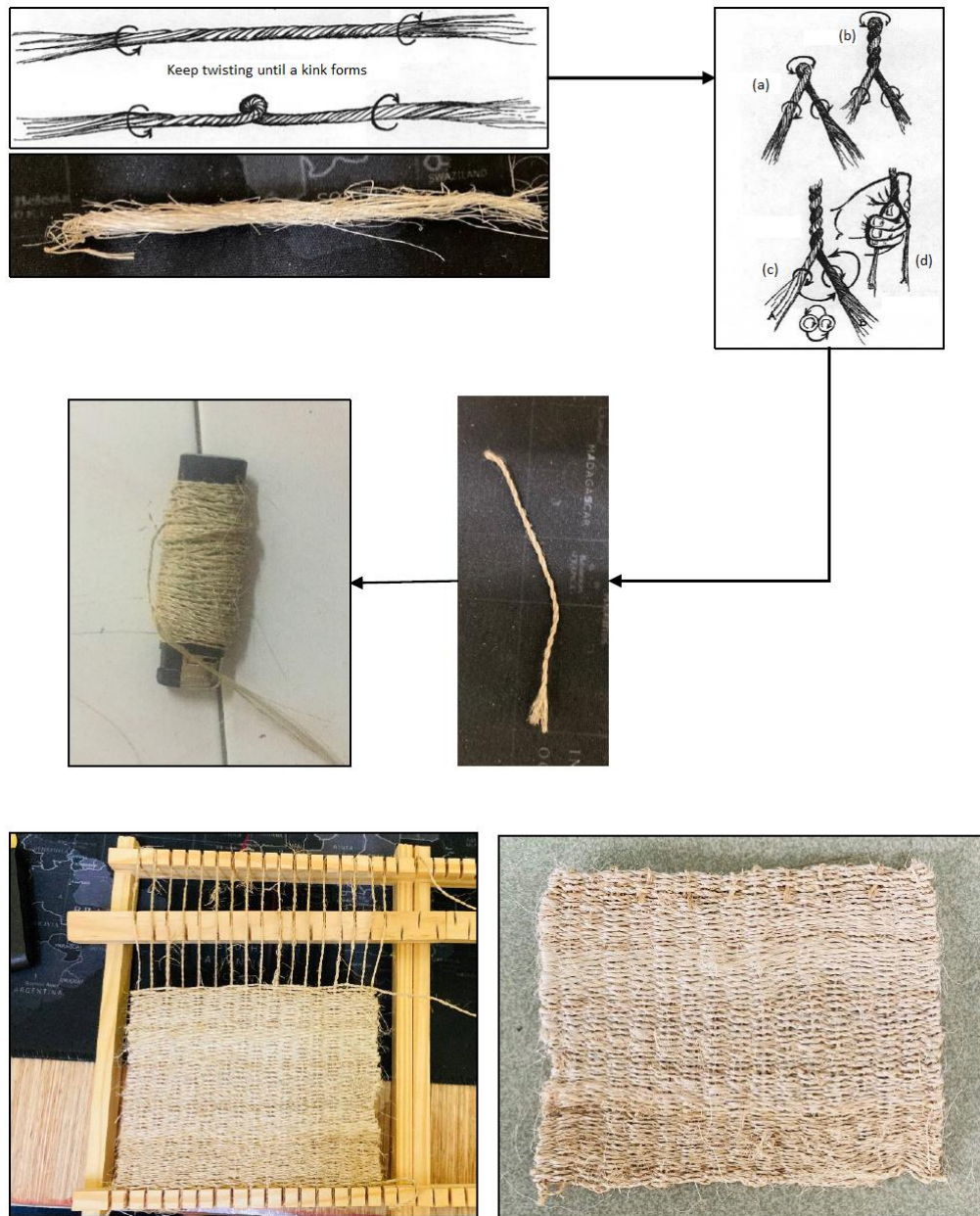


Figure 2. Overview of woven making process

**Mould preparation.** For the mould, 2 pieces of flat glass plate is used. Acrylic of 3-mm thickness was cut to a rectangular size of 12 cm x 10 cm to produce a mould of 120 mm x 100 mm x 3 mm. The acrylic then bind to the glass. Another glass then being use as compacter in the process of specimen making by using plastic clamp.

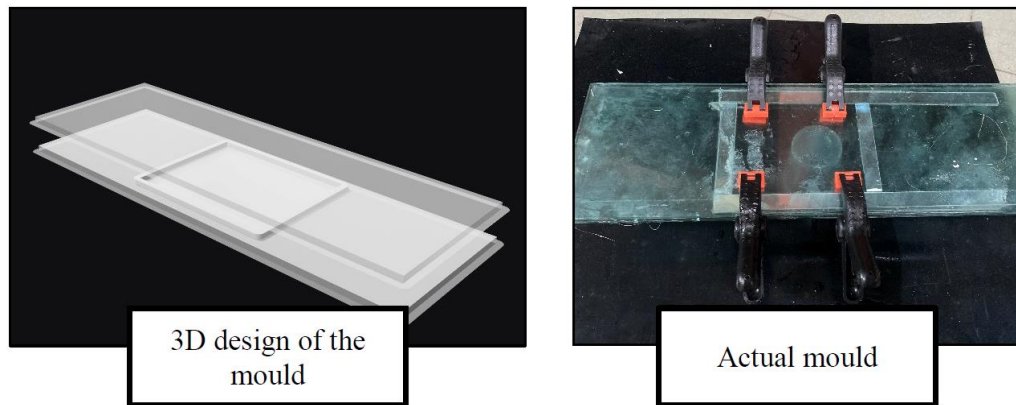


Figure 3. Overview of composite mould

**Fiber to weight ratio pre calculation.** To determine the required fiber weight, we first make specimen A by injecting 100% resin into the mould. The results of the specimens formed were weighed, and it turned out that a weight of 43 grams was obtained. With the aim of making a composite with a fiber weight ratio of 20% to the overall weight for specimens B, C and D, 8.6 grams of banana fiber is required.

**Fabrication of the composite specimen.** Every specimen will undergo same process as described in Figure 4. The difference for each specimen is on the fiber usage and orientation. The resulted composites have dimension about 120 mm × 100 mm × 3 mm. These composite plates are then cut into 120 mm × 15 mm × 3 mm specimens as required in ASTM D790 standard for bending tests.

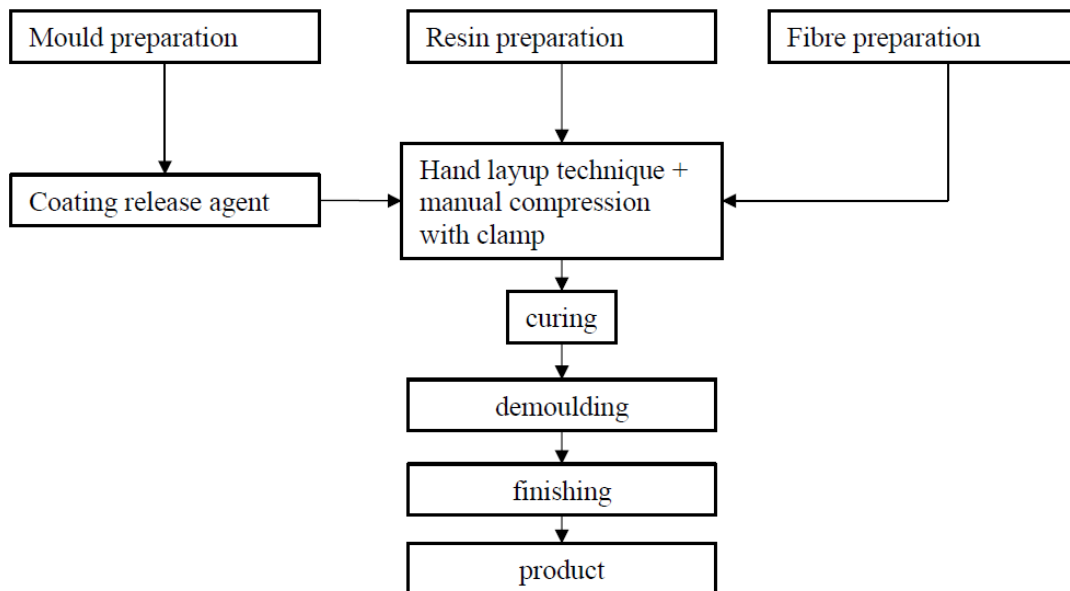



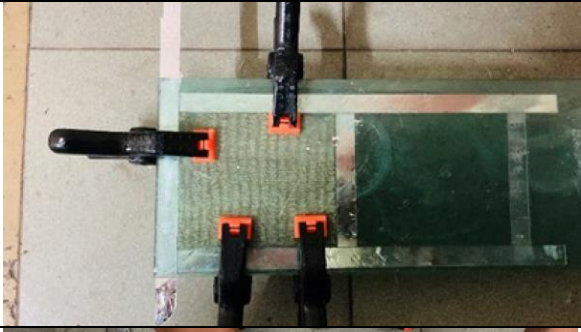



Figure 4. Flow chart of specimen fabrication process

The brief description of the fabrication process is shown in Table 2.

Table 2. Overview of fabrication process

Step	Visual representation	Description
1		<p>Mould release wax was applied by using microfiber cloth to the mould to prevent the resin from bonding with the mould and making it easier to demoulding.</p>
2		<p>Brush with finer tip was used in applying the resin to the mould to create the resin first layer.</p>
3		<p>Fibers weighing 8-9 grams or about 20% of the desired total weight are arranged layer by layer with a resin matrix interspersed.</p>
4		<p>The glass plate is then used to clamp the mold using 4 plastic clamps.</p>
5		<p>Composite demoulding after curing for 24 hours using a razor blade.</p>

6		Finish product then left for another 48 hours to achieve fully cured condition.
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In the testing phase, the tension tests of specimens were performed in Shimadzu universal testing machine at Fakulti Teknologi Kejuruteraan Mekanikal dan Pembuatan of Universiti Teknikal Malaysia Melaka by following ASTM D790 for bending test standard. The specimens were cut using Makita band saw with finer saw blade. The band saw and the Shimadzu Universal Testing Machine's setting for bending test can be seen in Figure 5. The ASTM D790's test method determines the flexural stiffness and strength properties of polymer matrix composites. Figure 6 shows the proper way to perform a 3-point bending test. The 3-points bending test was conducted on 3 specimens at room temperature. The support span-to-depth ratio used for the test is 16 : 1 with the loading speed of 2mm/min.



Figure 5. Band saw and universal testing machines with bending test setup

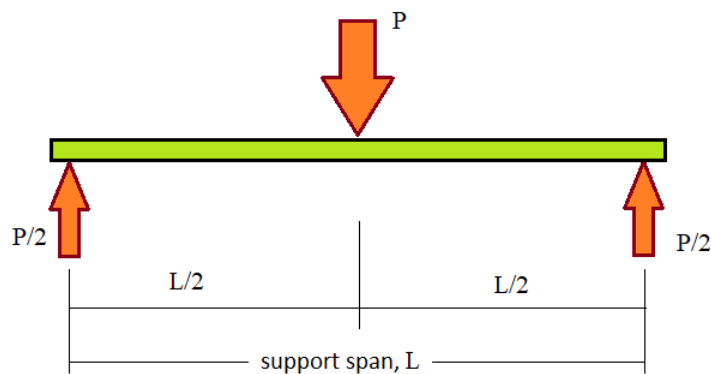


Figure 6. Setup for ASTM D790 standard

In the third stage, namely the analysis stage, the experimental results will be reported in a structured manner, analyzed and discussed. Comparisons will be made with reference to the work of other researchers. If the results are very different or appear to be unreasonable, an analysis of the factors that allow for error will be elaborated.

### Result and Discussion

There were 4 samples those were tested in the bending test. For each sample, 3 specimen were tested. Figure 7 shows the specimen condition after the test. We can see in this figure that only sample A and C break and disconnected while sample B, D, and E still attach after the test. We know that in a flexural test, a composite specimen is subjected in bending load. The load causes the outer fibers to be in tension while the inner fibers are in compression. When the specimen reaches its maximum strength, the outer fibers will break, but the inner fibers will still be intact, preventing a complete disconnection of the specimen. This is known as the *failure mode* of the composite.



Figure 7. Condition of specimens after bending test

Table 3. Bending test results

Sample	Specimen	Max force P (N)	Maximum flexural stress (MPa)	Average flexural strength (MPa)
A	A1	155.5	95.7	102.1
	A2	178.4	109.8	
	A3	164.0	100.9	
B	B1	200.8	123.6	138.0
	B2	221.9	136.5	
	B3	250.2	154.0	
C	C1	118.2	72.8	55.9
	C2	68.4	42.1	
	C3	85.9	52.9	
D	D1	102.8	63.2	71.6
	D2	141.8	87.3	
	D3	104.3	64.2	
E	E1	153.6	94.5	90.0
	E2	133.6	82.2	
	E3	151.7	93.3	

Figure 8 shows the average flexural strength of samples A, B, C, D and E. The flexural strength referred to here is the highest stress that the composite material can bear. As we expected, sample B, which is reinforced with 0° orientation of long continuous fiber obtains 138.0 MPa of flexural maximum stress. Compared to the neat epoxy – which is having 102.1 MPa – the flexural maximum stress of sample B is 35% higher. Both samples C and D have lower flexural maximum stresses which are 55.9 MPa and 71.6 MPa, respectively. The flexural maximum stresses of samples C and D are 45% and 30% lower than the neat epoxy, respectively.

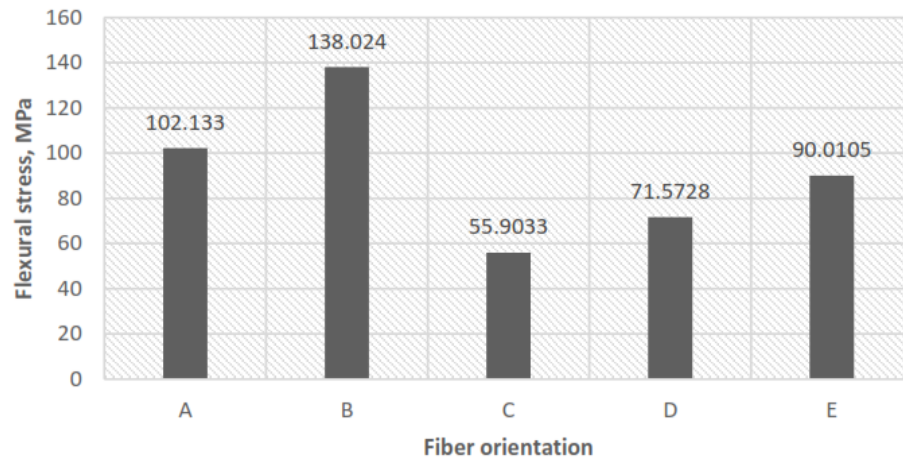


Figure 8. Average flexural maximum stress of samples A, B, C and D

The possible factors that may contribute to the differences in flexural maximum stress values among the samples are:

- Fiber orientation.** Sample B (zero degree banana fiber composite) has fibers oriented in one direction, which may cause higher bending stress values compared to other samples. Meanwhile, the other samples (C, D and E) have random fiber orientations which may not be as strong as the unidirectional orientation of sample B.
- Fabrication method.** Sample D (banana woven fiber composite) may be manufactured differently from the other samples, for example, the woven pattern allows better load distribution, resulting in higher bending stress values.
- Fiber volume fraction.** Fiber volume fraction, or the ratio of fiber volume to the total volume of the composite, can influence the properties of the composite. Although all samples have the same fiber content, slight variations in the fiber volume fraction may occur during the manufacturing process, which can cause variations in the bending stress values.
- Surface finish.** The surface finish of the sample can influence the bending stress results. If a sample has a rough surface, this can cause the bending stress value to be lower than a sample with a smooth surface.

Figure 9 represents the flexural modulus of samples A, B, C, D, and E. The values in this figure were generated by simple calculations in Excel based on test results. Sample B has the highest Young's modulus value compared to the other samples. This is because in continuous fiber composites with a length of 0°, the fibers are oriented in the same direction as the applied load, thereby helping to resist bending more effectively. The fibers can transfer loads more efficiently along the length of the fiber, providing a higher flexural modulus compared to random and woven composites.

Random fiber composites have fibers whose orientation is irregular, making it difficult for the fibers to transfer loads efficiently. Woven composites have fibers that interlock at an angle, which also makes it difficult for the fibers to transfer loads efficiently. Therefore, the flexural modulus of random and woven composites is lower than that of 0° long continuous fiber

composites. However, when compared with neat fibers, we estimate that samples C and D have a higher flexural modulus because these fibers function as reinforcement in the composite. The data obtained did not match expectations. There are several factors that cause neat epoxy to have a higher flexural modulus than random and woven composites because it is composed of a homogeneous mixture of epoxy resin and hardener, resulting in a more consistent distribution and a higher degree of cross-linking between molecules. This results in a stiffer and stronger material overall. In contrast, random and woven composites have more variable fiber distribution, which can result in weaker and less consistent properties.

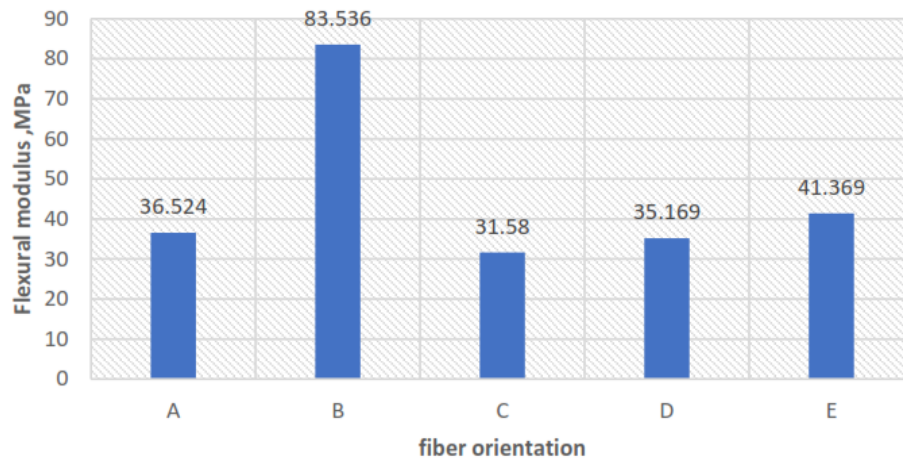


Figure 9. Flexural modulus of samples A, B, C, D and E

When comparing sample E, namely e-glass epoxy with random fiber orientation with sample C which has random fiber orientation, the flexural modulus for sample C is 31.6 MPa and for sample E is 41.7 MPa. This shows that the E, e-glass composite sample is stiffer than the banana fiber composite.

## Conclusion

Experimental studies have been carried out in this paper to determine the effect of fiber orientation of banana fiber/epoxy composites on their mechanical properties under bending loading. All specimens examined consisted of 20% fiber by weight with different fiber orientations and specifications. The findings of this research can be summarized as follows:

- Fibers in composite materials can increase stiffness significantly compared to the pure epoxy matrix. The fibers in composites function as reinforcement, providing additional strength and stiffness to the material.
- The data results for samples C and D are not as expected, porosity in the composite is likely one of the factors that reduces mechanical properties such as strength and stiffness. Therefore, it is very important to prevent or minimize the occurrence of porosity during the composite manufacturing process.
- Banana fiber reinforced composites can be used in applications that do not require high mechanical strength, for example in non-structural components or low loads. This composite is relatively cheap and environmentally friendly. In addition, banana fiber reinforced composites are biodegradable so they can be an advantage for certain applications such as single-use products.

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