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# Study on the Influence of Fiber Orientation to the Tensile Strength in Banana Fiber Reinforced Polyepoxydes Composite

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**Abstrak**

Dalam penelitian ini, komposit dengan perkuatan serat pohon pisang dipelajari kekuatannya terhadap beban tarik. Serat diekstraksi dari kulit pohon pisang, kemudian diolah dengan NaCl dan dikeringkan. Matriks yang digunakan adalah resin epoksi. Dalam pembuatan komposit, penggunaan resin diusahakan sebanyak 20% beratnya. Beberapa sampel komposit dibuat dengan orientasi serat yang berbeda yaitu 0°, acak, dan ditenun. Kemudian sampel diuji kekuatannya terhadap beban tarik. Hasil pengujian menunjukkan bahwa kekuatan tarik komposit serat pohon pisang ini tidak mengalami peningkatan dan beberapa sampel tidak sesuai yang diharapkan dibandingkan dengan kekuatan tarik resin epoxy.

**Kata kunci:** komposit, serat kulit pohon pisang, epoksi resin, kekuatan tarik

***Abstract***

*In this research, the tensile strength of composite with banana tree fiber reinforcement was studied. Fiber is extracted from banana tree bark, then treated with NaCl and dried. The matrix used is epoxy resin. In the manufacture of composites, the use of resin attempted as much as 20% by weight. Several composite samples were made with different fiber orientations namely 0°, random and woven. Then the strength of sample is tested against tensile loads. The test results showed that the tensile strength of the banana tree fiber composite did not increase and several samples were not as expected compared to the tensile strength of the epoxy resin.*

***Keywords****: composite, banana tree bark fiber, resin epoxy, tensile strength*

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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 Musacae 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).

The purpose of this study was to examine the effect of banana fiber orientation on its mechanical strength due to tensile loading. For this purpose, several composite samples were made with banana fiber reinforcement with various orientations. Then the samples were tested in a tensile 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 tensile 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 tensile 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 tensile strength than samples B and C, and samples with fiber reinforcement will have better tensile 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 |

**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.

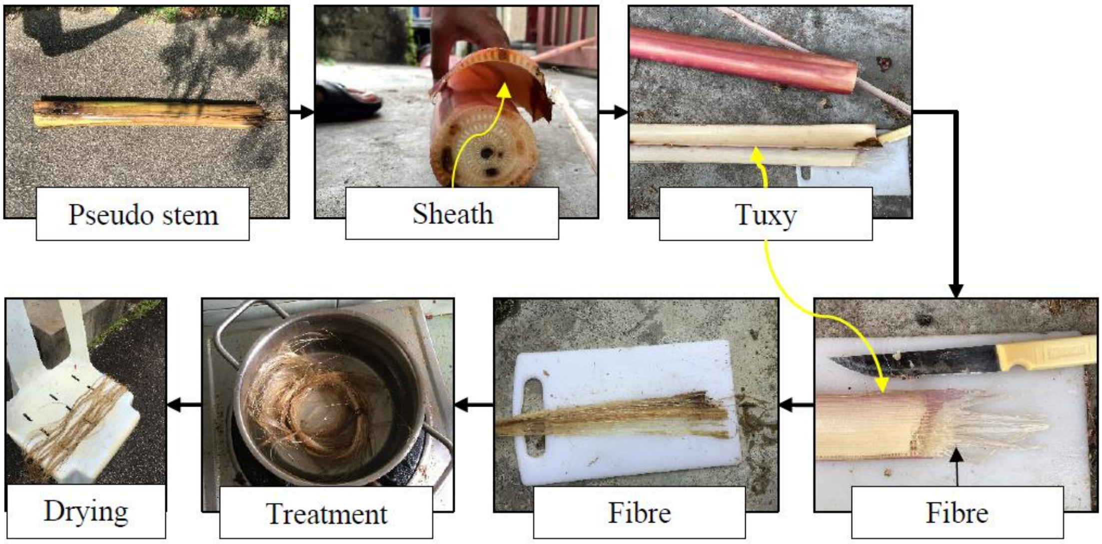



Figure 1. Overview of pseudo stem fiber extraction

**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.

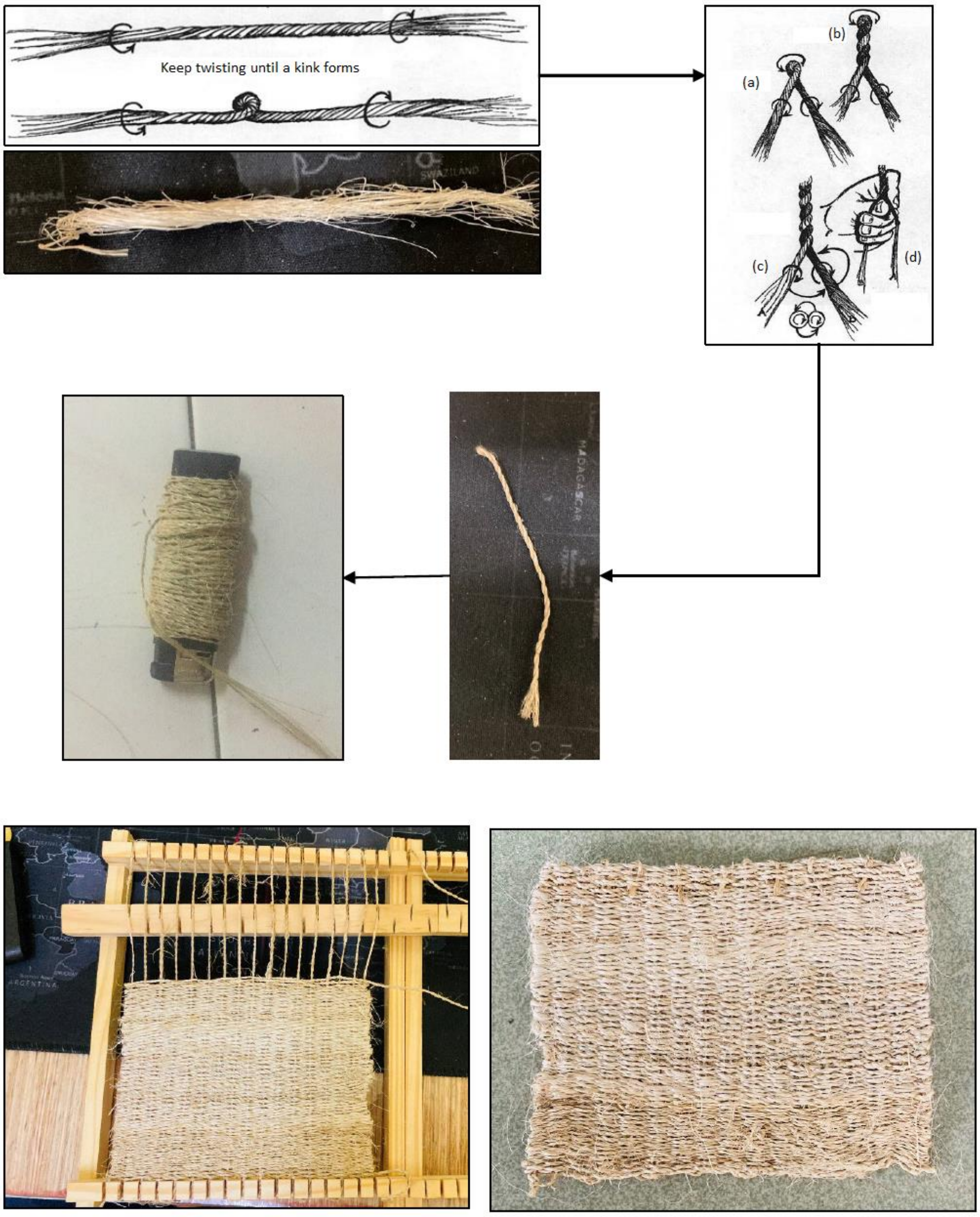



Figure 2. Overview of woven making process

**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.

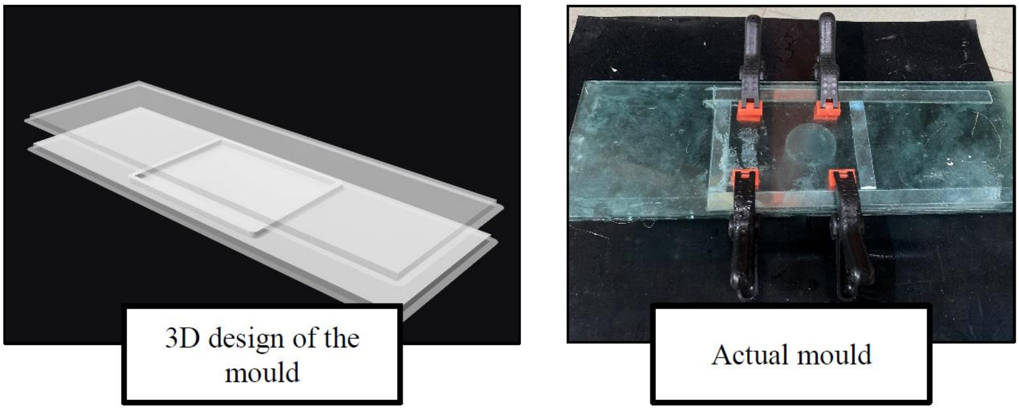



Figure 3. Overview of composite mould

**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 D3039 standard for tensile tests.

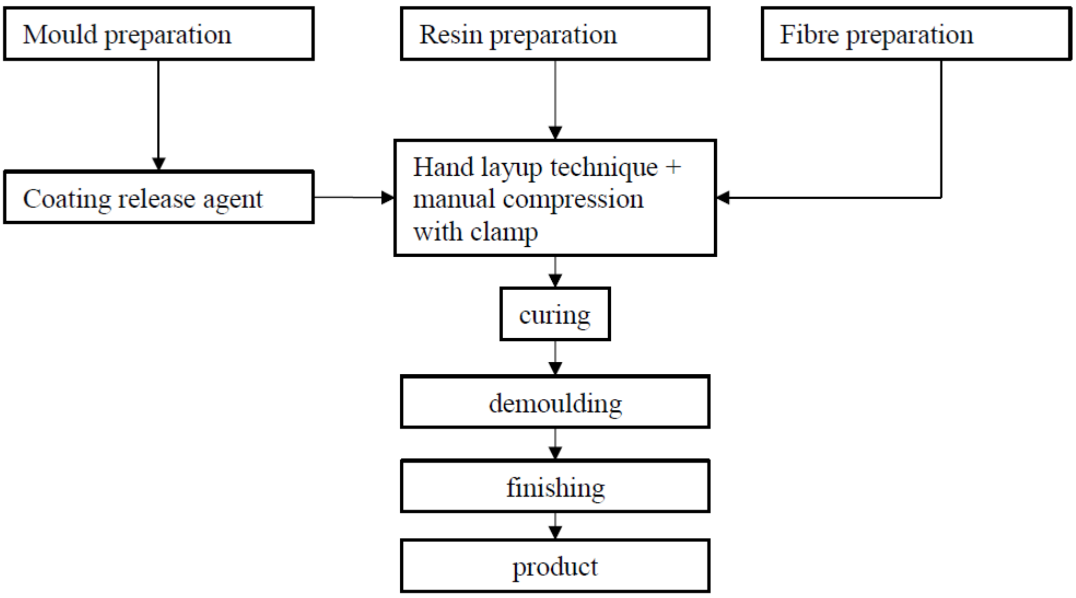
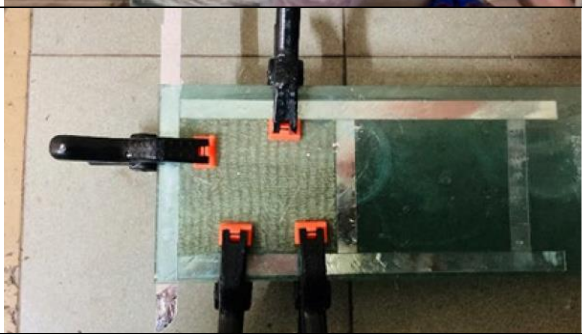



Figure 4. Flow chart of specimen fabrication process

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

Table 2. Overview of fabrication process

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

| | | |
|---|---|---|
| 6 |  | Finish product then left for another 48 hours to achieve fully cured condition. |

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 D3039 for tensile test standard. The specimens were cut using Makita band saw with finer saw blade. The band saw and universal testing machines can be seen in Figure 5.


Figure 5. Band saw and universal testing machines

The loading speed of the universal testing machine is set to 2 mm/min. Three samples were provided for each type of composite tested.

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 tensile test. For each sample, 3 specimen were tested. Figure 6 shows the specimen condition after the test. Data and graphs obtained from the Shimadzu universal testing machine and its software are shown in Figure 7.

Figure 6. Condition of specimen after tensile test

Table 3. Tensile strength results

| Sample | Specimen | Max tensile load (kN) | Tensile strength (MPa) | Ultimate tensile strength (average) |
|---|---|---|---|---|
| A | A1 | 2.298 | 51.1 | 50.3 |
| | A2 | 2.304 | 51.2 | |
| | A3 | 2.188 | 48.6 | |
| | [The Engineering ToolBox, visited 29/8/2023] | | 26 - 85 | 26 - 85 |
| B | B1 | 2.312 | 51.4 | 51.6 |
| | B2 | 2.331 | 51.8 | |
| | B3 | 2.321 | 51.6 | |
| C | C1 | 1.230 | 27.3 | 26.3 |
| | C2 | 1.326 | 29.5 | |
| | C3 | 0.996 | 22.1 | |
| D | D1 | 1.441 | 32.0 | 30.7 |
| | D2 | 1.276 | 28.4 | |
| | D3 | 1.422 | 31.6 | |

From the universal testing machine we can find out the maximum tensile loads $F_{max}$ before the specimen breaks. They are listed in the third column of Table 3. If these loads are divided by the initial cross-sectional area of the specimen $A$, the maximum tensile stresses will be obtained which are the engineering tensile strengths of the specimens $\sigma$ as written in the fourth column of Table 3.

$$\sigma = \frac{F_{max}}{A} = \frac{1000 \times F_{max}\ [kN]}{(15\ mm\ \times 3mm)} = 22.2 F_{max}\ \ [MPa]$$

Three specimens for sample A made of 100 percent poly-epoxide were tensile tested. The specimens broke at loads of 2.298, 2.304 and 2.188 kN. If these loads are averaged, it can be seen that the tensile strength of the poly-epoxide used in this research is 50.3 MPa. This value is well within the stated epoxy resin tensile strength value range of 26 to 85 MPa.

In the tensile test of the three sample B specimens made of 20% continuous banana fiber in the longitudinal direction and 80% poly-epoxide, the specimens fractured at loads of 2.312, 2.331 and 2.321 kN. With the highest average load, the tensile strength of sample B is 51.6 MPa. So with 20% weight % banana fiber reinforcement, the resulting composite experienced an increase in tensile strength of (51.6 – 50.3)/50.3 = 2.58% compared to the strength of the resin used. Compared to research that has been conducted by previous researchers (Irawan et al, 2015) obtained results of 62.3 MPa for the tensile strength of composites with banana fiber reinforcement. The tensile strength results in our study were around 83% of their value. This value is of course still reasonable, because of the different treatment methods to get the banana fiber and also the possibility of different types of banana trees. We use Berangan banana fiber, while the type of banana fiber they use is not mentioned. In their research, the treatment to produce banana fiber was by soaking it in 90% alcohol for 30 minutes, while the banana fiber that we used was soaking it in NaCl salt water. The fiber content they use is 40% volume fraction, while we make the composite with 20% weight fraction.

Sample C which was made of 80% poly-epoxy as resin and 20% long banana fiber in random directions was represented by specimens C1, C2 and C3. In the tensile test the specimens broke at loads of 1.230, 1.326 and 0.996 kN. By averaging it, it can be obtained that the tensile strength of sample C is around 26.3 MPa. So by strengthening the long banana fiber 20% by weight in a random direction the resulting composite decreased in tensile strength by 47.7% compared to the strength of the resin used.

In sample D, the composite was made of 20% by weight of plaited banana fiber and represented by specimens D1, D2 and D3. The specimens fractured at a tensile load of 1.441, 1.276 and 1.442 kN. By averaging these three values and then dividing by the cross-sectional area of each specimen, the tensile strength of sample D is about 30.7 MPa. So with the reinforcement of 20% weight of woven long banana fiber, the resulting composite will experience a decrease in tensile strength of 29.7% compared to the strength of the resin used.

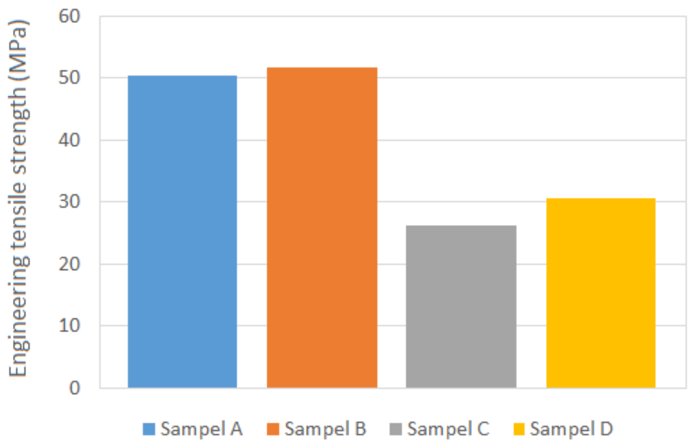



Figure 7. Tensile strength of samples A, B, C and D

The resulted tensile strength of the samples are plotted in Figure 7. Sample B with 20% by weight of continuous fiber with uniform longitudinal orientation has the highest tensile strength. Also, sample B has better tensile strength than the resin, although only by about 3%. Samples C and D turned out to have a worse tensile strength than the tensile strength of the poly-epoxide resin. This was really unexpected, because at first we thought that the tensile strength of fibrous composites would definitely be better when compared to the resin alone. In this case further research is needed using a microscope, for example to examine the net cross-sectional area of the specimen being tested. In samples C and D, small air bubbles occurred in the specimen. Of course these air bubbles will reduce the net cross-sectional area of the specimen being tested. Since the actual net cross-sectional area is less than the rough estimate of 3 mm x 15 mm, the maximum stress that occurs which is the tensile strength will be greater than that listed in Table 4. Sample D with woven fibers has better tensile strength compared to the sample C whose fibers are randomly oriented. This is in accordance with what we estimate before conducting research. However, what we didn't expect was that the composite with woven fibers was weaker than the composite with parallel longitudinal fibers under tensile loading.

**Conclusion**

Tensile testing of polyepoxide composites with banana fiber reinforcement in various orientations has been carried out in this research. The experimental results show that the composite with uniform longitudinal fiber orientation has the greatest tensile strength. Its tensile strength is much greater than that of composites with woven fiber reinforcement. It was also found that the composites with random fiber reinforcement and woven fiber reinforcement had lower engineering tensile strength than the polyepoxide resin.

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