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Effect of fiber length on tensile strength, impact toughness, and flexural strength of Banana Stem Fiber (BSF)-polyester composite for train body

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Abstract

The study aimed to determine the tensile and impact strength characteristics of the banana steam fiber (BSF)-polyester composite modified with NaOH treatment. The composites were made using the hand lay-up method, varying the length of the BSF fibers to 10 mm, 20 mm, and 30 mm. The fiber was modified by giving 2% NaOH for 1 day to improve the mechanical properties of the composite. The tensile strength tests were carried out using ASTM D638 standards. While impact tests were carried out using ASTM D6110 standards. The test showed the highest average tensile strength value at 30 mm fiber length, for 37.78 MPa. Meanwhile, the lowest value at 10 fiber length was 31.87 MPa. For the impact test, the highest average value was at 10 mm fiber length, for 0.016 J/mm2. And, the lowest value was at 30 mm fiber length variation, for 0.010 J/mm2. Fiber length has no significant effect on the flexural strength of the BSF composite.

Keywords*: Banana steam fiber; Composite; Mechanical Properties*

1. INTRODUCTION

Polymers are very useful materials in the world of engineering, especially in the construction industry. Polymers as building construction materials are widely produced with other materials to build composites (1), (2). For this need, polymer composites are developed, accompanied by various reinforcements.

The commonly used polymer materials in the manufacture of composites are thermoset polymers. The material selection is based on the fact that thermoset polymers have resistance to temperature and chemicals or solvents due to their liquid form and not too high viscosity so that they can make wet the surface of the fiber (3). Epoxy and polyester are thermoset polymers that are often used in the manufacture of polymer composites (4).

The important parameters affecting the properties of composite materials are the shape, size, orientation, distribution of the filler, and properties of the matrix (5). Mechanical properties are one of the most important properties of composite materials to study. For structural applications, the mechanical properties are determined by the selection of materials.

The mechanical properties of composite materials depend on the properties of the constituent materials. The main role of fiber-reinforced composites is to transfer stress between the fibers, provide resistance to adverse environments, and protect the fiber

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surface from mechanical and chemical effects (6). While the contribution of fiber largely affects the tensile strength of composite materials (7).

It has been carried out various explorations on the use of fiber as a composite material. Natural fibers have been proven to be able to replace synthetic fibers as reinforcement (8). The use of natural fibers as reinforcement has been widely practiced, such as the use of waru fiber (9), (10), abaca fiber (11), mendong fiber (12), curaua fiber (13) and many others that need to be investigated. Banana stem fiber has potential as a reinforcement for polyester composite materials (14). With an abundant amount and minimal utilization of the use of banana stems make this material has probability to be be used as a reinforcement material (15), (16).

Based on the previous data and explanation, the potential for banana stem (*musacea*) fiber as a new material in engineering materials, especially composites, is very potential to be developed. Therefore, this study aimed to determine the mechanical properties of the BSF-polyester composite, modified with NaOH treatment.

2. Methods

2.1 Banana Steam Fiber (BSF)

Banana stems are waste from banana plants that have been cut down for fruit and agricultural waste. The banana stem fiber comes from golden banana stems on the outside and ± 7 months old. First, dried fibers are taken one by one by hand. Then, the fibers are rinsed with clean water and dried naturally. After that, it was modified and soaked with an alkaline solution of NaOH 2%, NaOH liquid for 1 day. Furthermore, it dried at room temperature for ± 12 days.

Figure. 1. Banana stem fiber. (a) Banana stem; (b) BSF fiber; (c) NaOH Treatment

Table 1. BSF Chemical Composition

Cellulose (%)	Lignin (%)	Hemi cellulose (%)	Pectin (%)	Ash (%)
65,2	8,21	14,25	3,5	1,5

2.2 Polyester Resin

In the study, the matrix used a thermosetting polymer, with the type of Yukalac C–108–B polyester resin and MEKPO (Methyl Ethyl Ketone Peroxide) catalyst (17). The product is supplied by PT. Justus Kimiaraya Surabaya, Indonesia.

Table 2. Epoxy Properties

Properties	Polyester	Unit
Density	1,09	g/cm^3
Viscosity at 25ºC	150	Mpa.s
Tensile Strength	65	Mpa
Tensile Strain	2,0	%
Tensile Modulus	4000	Mpa
Flexural Strength	110	Mpa

2.3 Specimen Manufacture and Testing of Composites

The process of making specimens used a conventional method of hand lay-up. Composite specimens were made by weight fraction ratio with a ratio of 95% resin and 5% reinforcement with Chopped fiber composite form. Reinforcement varied with a fiber length of 10 mm, 20 mm, and 30 mm, and an average fiber diameter of ± 2 mm. Composite tensile and Flexural test specimens used an ASTM D 638-01 and ASTM D 790 standard. While the impact test used ASTM D 6110 standard. Composite Tensile and Flexural Test used a Lloyd Brand Universal Testing Machine, Model LR150K PLUS, Max Force: 150 kN (33721.34 lbf) and Mass (no Grips fitted): 900 kg (1984 lb). While impact test used a Charpy Impact Testing Machine, Capacity: 30 Kgf, Pendulum Weight: 26.01 Kg, Pendulum Diameter: 0.636 m, and Pendulum arm length: 0.750 m.

Figure. 2. Composite Tests and Specimens (a) Tensile and Flexural (b) Impact Test

3. RESULT AND DISCUSSION

3.1 Tensile Strength

Tests were conducted on five specimens in each variation of BSF fiber length of 10 mm, 20 mm, and 30 mm. From the results of the tensile test, it obtained a table of tensile test results as presented in Figure 3. Ultimate Tensile Strength tends to increase with increasing length, with the highest tensile strength in the 30 mm fiber length specimen with an average of 37.78 MPa. Also, the tensile strength has increased, starting with the 10 mm fiber length at 31.87 Mpa. Then, the 20 mm fiber length is at 33.90 Mpa. And, the highest is the 30 mm fiber length which is at 37.78 MPa. In short, the longer the fiber, the higher the tensile strength. The reason is since the longer the fiber, the wider the cross-sectional area of the fiber is covered by the resin so the impact on the mechanical bonding between the fiber and the matrix is getting better (18). Increasing the mechanical bounding in the interface area can improve the mechanical properties of the composite (19), (16).

Composite with a fiber length of 10 mm has higher yield strength than composite with a fiber length of 20 mm and 30 mm. The yield strength tends to decrease as the length of the specimen increases. From the table, the smallest yield strength is achieved at a fiber length of 30 mm which is equal to 4.03 MPa. In other words, the longer the fiber size of the specimen, the lower the yield strength. The difference in yield strength affects the elastic area of each specimen. The higher the yield strength, the larger the elastic area. And it applies vice versa, that the smaller the yield strength, the smaller the elastic area. In general, the specimen with the highest yield strength will have the longest change in length during the tensile test (14).

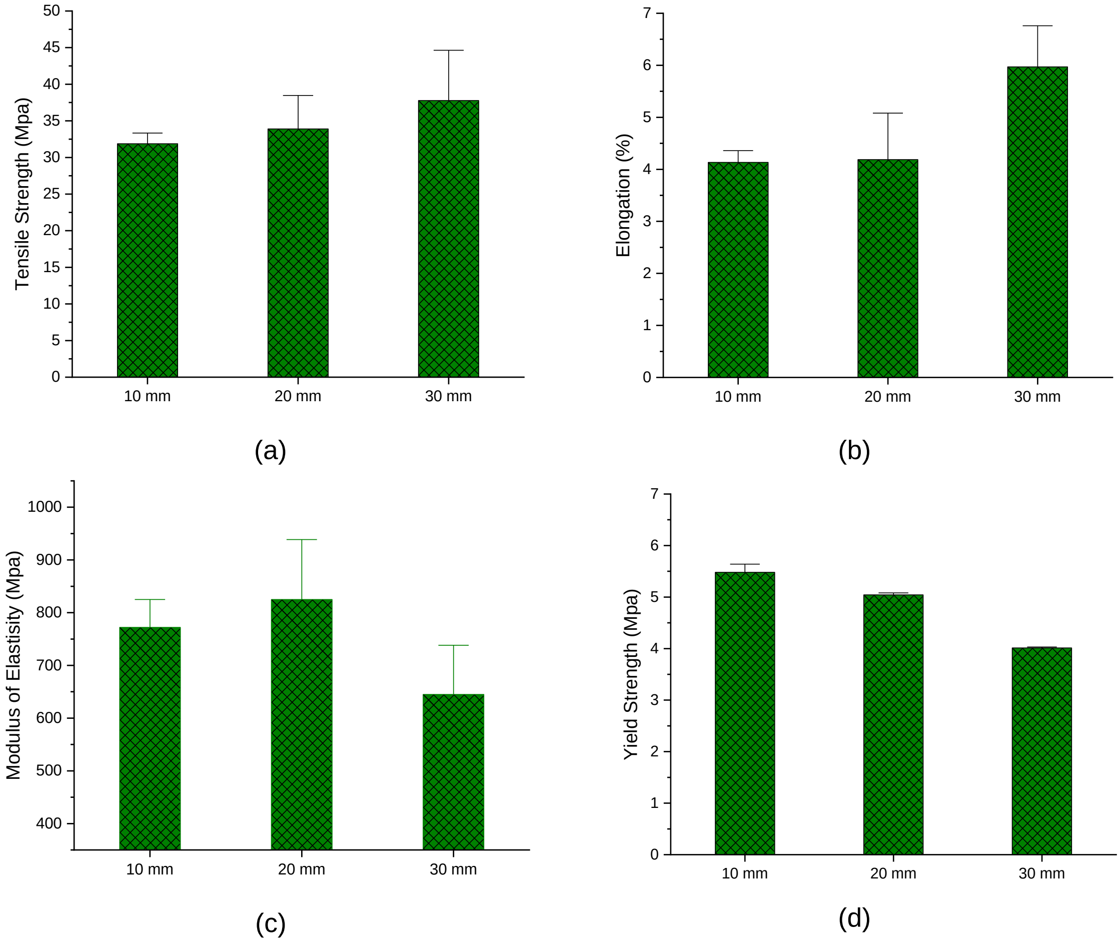
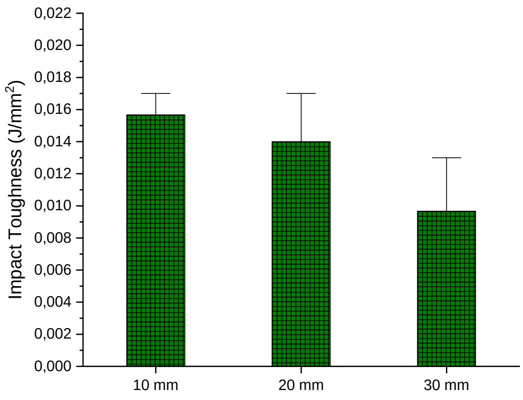


Figure. 3. (a) Tensile Strength (b) Elongation (c) Modulus of Elasticity (d) Yield Strength

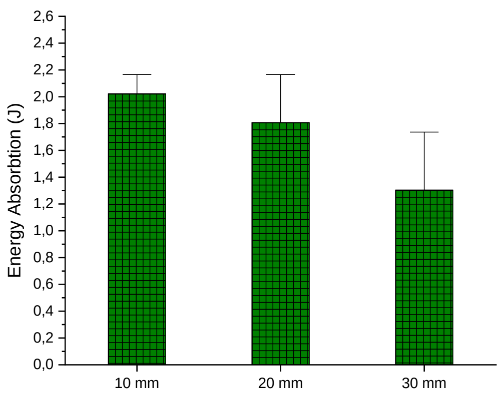
Figure 3b shows the largest strain in the 30 mm fiber length specimen with an average of 5.97%. Meanwhile, the smallest elongation is in the 10 mm fiber length specimen with an average of 4.13% at the lowest strain. The specimen with the highest elongation means it has a wide elastic area, so the specimen has the longest elongation, compared to the other specimens. Seen that the specimen with the largest elongation of 6.76% has the highest elongation of 3.38 mm. On the other hand, the specimen with the smallest elongation of 3.10% had the shortest elongation of 1.55 mm. Based on Figure 3c, the largest Elastic Modulus is at 825.08 MPA from a 20 mm length of the fiber, while the smallest elastic modulus is at a 30 mm length of fiber which is at 644.94 MPa (20).

3.2 Impact Toughness

Based on Figure 4a, the highest impact value is in the 10 mm fiber length specimen with an average of 0.016 J/mm^2. The 20 mm fiber length specimen has a smaller impact value than the 10 mm fiber length specimen with an average of 0.014 J/mm^2. Meanwhile, the lowest impact value was in the 30 mm fiber length specimen, with an average of 0.010 J/mm^2. Then, it concluded that the longer the fiber, the lower the impact value, because the bond between the matrix and the fiber is getting stronger so that the fiber will break at the fracture line (21). Concluding concerning the results of the impact test, the higher the absorbed energy, the higher the impact value. Based on Figure 4b, the absorption energy value decreases with increasing fiber length. The highest absorption energy value was found in the 10 mm fiber length specimen with an average of 2.022 J. Meanwhile, the lowest absorption energy value was found in the 30 mm fiber length specimen with an average of 1.304 J.



(a)



(b)

Figure 4. (a) Impact Toughness; (b) Energy Absorption

3.3 Flexural Strength

The value of the flexural test results from the BSF-Polyester Composite can be seen in Figure 5. It shows that the fiber length does not seem to have a significant effect on the flexural strength of the composite. The values of each composite with fiber lengths of 10 mm, 20 mm, and 30 mm are 62.4 Mpa, 64.5 Mpa, and 63.2 Mpa. This is the same as research that has been reported by Mohamed Abd Rahman et., al. where the flexural strength of composites with fiber lengths of 63 mm and 127 mm has an average strength of 63.99 MPa and 70.8 MPa (22), (20).

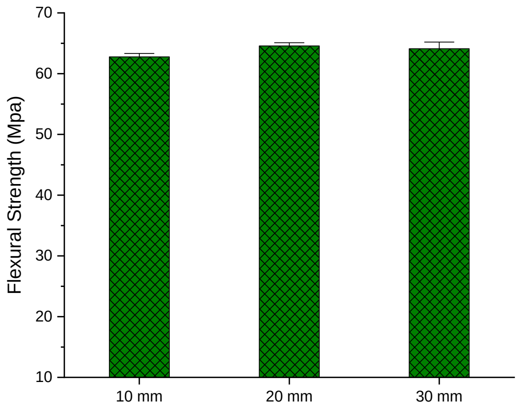


Figure. 5. Flexural Strength

3.4 Fracture Analysis

Confirmation results with the image of ImageJ show that fibers with 10 mm tend to have more cavities compared to fibers with a length of 30 mm. This may lead to a decrease in the tensile strength of the composite. The use of 30 mm length fiber can accept a stable load due to the bonding mechanism between the fiber and the wider matrix. The wide surface causes a lot of interlocking.

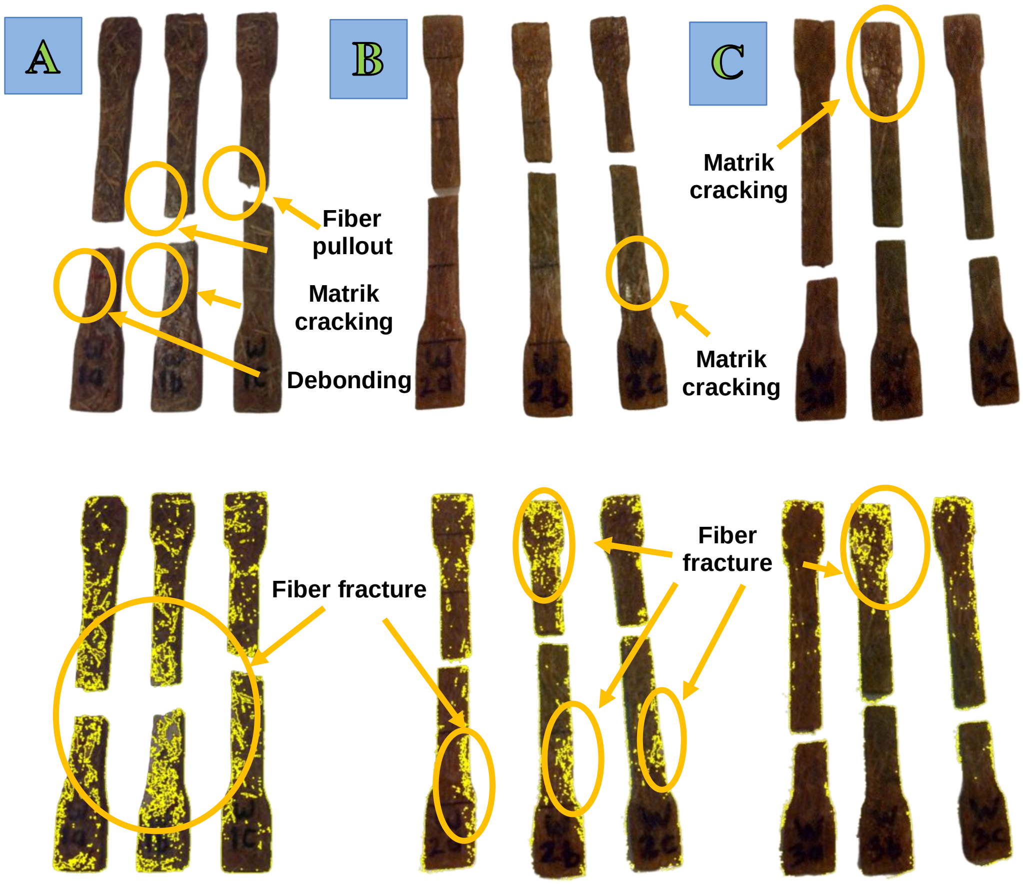


Figure 8. Fracture analysis using imageJ. (a) fiber length 10 mm; (b) fiber length of 20 mm; and (c) fiber length 30 mm

4. Conclusion

Based on the finding and discussion, it concluded that the fiber length of banana stem fiber-reinforced composites, with modified alkaline treatment, affects the tensile and impact test values. In the tensile test, the highest average value of the highest tensile strength was found in the 30 mm banana stem fiber of length specimen, with an average of 37.78 Mpa and the lowest was found in the 10 mm fiber of length specimen, with an average of 31.87 MPa. It increases continuously for variations in fiber length from 10 mm to 30 mm. Then, the longer the fiber size is used as filler, the tensile strength will increase. In the impact test, the highest impact value was in the 10 mm fiber length specimen with an average of 0.016 J/mm^2 while the lowest impact value was in the 30 mm fiber length specimen of 0.010 J/mm^2. From the results of the impact test, it concluded that the longer the fiber, the lower the impact value, because the bond between the matrix and the fiber is getting stronger which makes the fiber will break at the fracture line. Also, the impact test showed that the higher the absorbed energy, the higher the impact value.

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