The Influence of Fiber Orientation and Treatment Variation of Natural Fiber Reinforced Composites on Tensile Strength and Toughness

Fandy Prihatna Suhada, Afira Ainur Rosidah*, Vuri Ayu Setyowati, Suheni
Institut Teknologi Adhi Tama Surabaya, Surabaya

Email: *afiraar@itats.ac.id

Received: 2023-04-14 Received in revised from 2023-05-23 Accepted: 2023-05-23

Abstract

Composites using natural fibers are being widely developed and researched, this is because natural fibers are easy to find and abundant. In this study, the natural fibers used were bamboo fiber and banana stems. Banana fiber has good mechanical properties and is easy to find, while bamboo fiber is easy to find and has a low density. In this study, the aim was to determine the effect of fiber orientation and treatment on the tensile strength and toughness of natural fiber reinforced composites using a polyester matrix. The variation of the fiber orientation used is 30° and 90°, and the fiber treatment used is alkali and bleaching treatment. Based on the research results, the 90° angle with fiber bleaching treatment has the highest tensile strength value, which is equal to 37.33 MPa with a modulus of elasticity of 5 GPa. As for toughness through impact testing, the highest value is 2.74 x 10^{-2} J/mm^2 at an angle of 90° with bleaching treatment.

Keywords: *composite; fiber orientation; bamboo fiber; banana stem; alkali; bleaching*

1. Introduction

Composite is a material with good mechanical properties compared to other alternative materials. In its fabrication, composites are classified as easier because they only combine two elements, namely fiber and matrix. Fiber is an element that is used as a reinforcement to determine the mechanical properties and the matrix is the main constituent part of the composite [1]. The use of natural fibers in composites has been widely used and developed. The commonly used natural fibers are bamboo fiber, banana fronds, hemp, and so on [2], [3].

Bamboo plants are giant, fast-growing grasses with woody stems that vary in character depending on various things, such as soil type, ambient temperature, and so on. Bamboo has 26-43% cellulose content. It has a tensile strength in the range of 140-230 MPa with a density of 0.6-1.1 g/cm^3 [2]. Many researches used bamboo as the reinforcement in composite with alkaline treatment, the resulting composite was able to reach 30.18 ± 7.26 MPa [4].

In addition, fiber from banana trees has relatively good mechanical properties, it is comparable to glass fiber. Banana fiber has high strength, light weight, small elongation, fire resistance, strong water absorption and biodegradability. The cellulose content ranges from 60-65%. Its tensile strength reaches 529-914 MPa with a density of 0.75-0.95 g/cm^3 [5]. Banana stem fiber which is used as reinforcement along with the polyester matrix is able to achieve a maximum tensile stress of 67.2 N/mm^2 [6].

In several studies, the use of one type of fiber is less than optimal in increasing the desired mechanical properties. Several researchers have developed hybrid composites using two or more types of fibers. Such as combining banana fiber and areca fiber, bamboo fiber and coconut fiber, and bamboo fiber and glass fiber. This hybrid composite effectively increases the mechanical strength of the composite around 10-20 MPa higher [7]–[9].

Natural fibers cannot be fabricated directly with a matrix, in the manufacturing process, natural fibers must be surface modified to make them compatible with the matrix. This modification process aims to increase the cellulose content so that the lignin and hemicellulose content is reduced or even lost. This modification involves alkaline chemicals, so this modification process is also called alkalization or alkaline process. Alkali solutions that can be used are NaOH and KOH [10]. The research of Nisa et al. proved that natural composites without alkali treatment led to lower tensile strength [11].

Besides alkalization, another process that has been proven to improve the mechanical properties of natural fibers is the bleaching process. This process can increase the tensile strength and brightness of the fiber. The chemical that can be used in this process is hydrogen peroxide (H_2O_2) which is environmentally friendly [12].

In the manufacture of composites, another major component needed is the matrix. The matrix used with natural fibers is polymer. Polymers that are widely combined with natural fibers such as epoxy and polyester [1], [7], [13]. Polyester is the most commonly used and easy to find. Polyester is a thermoset polymer with a liquid state and low viscosity. The addition of a catalyst is needed so that the polyester hardens at room temperature. This resin has long term heat resistance in the range of 110 – 140^oC [14]. Previous research stated that polyester resin has a tensile strength of 63 MPa with an elongation of 4.7% [15].

This study aims to determine the effect of fiber orientation and treatment on the tensile strength and toughness of natural fiber reinforced composites using a polyester matrix. The variation of fiber orientation used was 30^o and 90^o, and the fiber treatment was done by alkaline treatment with NaOH and bleaching with H_2O_2.

2. Method

This research used experimental method with the variation of 30^o and 90^o orientation, additionally, the variations in fiber treatment without treatment, alkali, and bleaching. The materials used in the experiment were NaOH for alkalization (SAP chemical), H_2O_2 for bleaching (SAP chemical), mold release wax, aquadest, polyester resin and catalyst, bamboo fibers, and banana stem fibers.

Fiber preparation is divided into three, namely:

a. Without Treatment

The fiber that has been cut is then washed using running water, then dried. After drying, it is washed again using distilled water, then dried. Fiber that has been dried without treatment can be seen in Figure 1.

(a) (b)

Figure 1. Bamboo fiber (a) and banana fronds (b) without treatment

b. Alkaline Treatment

The cleaned fibers were soaked in NaOH solution (1:20) for 2 hours. Then the fibers that have been soaked are rinsed with distilled water, then dried. Fiber that has been dried with alkaline treatment can be seen in Figure 2.

(a) (b)

Figure 2. Bamboo fiber (a) and banana fronds (b) alkaline treatment

c. Bleaching Treatment

The fibers that have undergone an alkaline process are soaked in H_2O_2 for 30 minutes. After soaking, the fibers rinse using distilled water, then dried. Fiber that has been dried with bleaching treatment can be seen in Figure 3.

Figure 3. Bamboo fiber (a) and banana fronds (b) bleaching treatment

After preparing the fiber, the next step is to make the composite. Making a composite of 2 layers, before making the composite, the weight of the fiber and the polyester matrix is calculated first. Coating the aluminum mold with mold release wax to prevent it from sticking to the mold, then mixing polyester resin and catalyst in a ratio of 40:1. The fibers were inserted into the mold in single arrangement and varied with an orientation of 30^o and 90^o as shown in Figure 4.

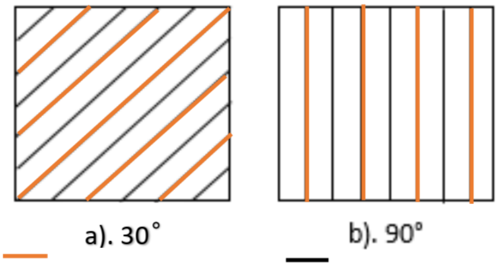


Figure 4. Fiber orientation of (a) 30^o and (b) 90^o (Orange line: bamboo; Black line: banana frond)

After the matrix and fibers are in the mold, pressure is applied to flatten the mold and remove any remaining air bubbles. The pressing process is left until the specimen dries in an open space for 8-10 hours. The tests carried out were tensile tests using ASTM D-3039 (see the dimension in Figure 5) and impact tests using ASTM D-256 (see the dimension in Figure 6).

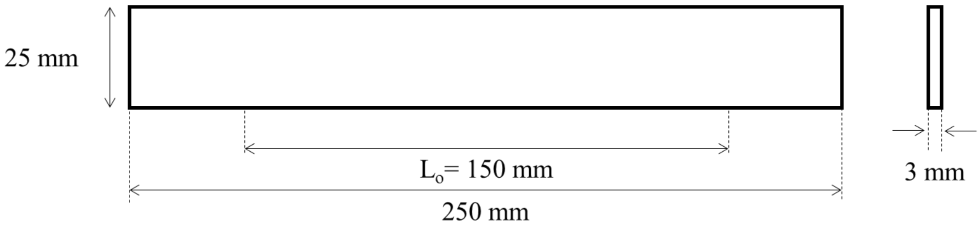


Figure 5. Dimension of tensile test specimen using ASTM D-3039

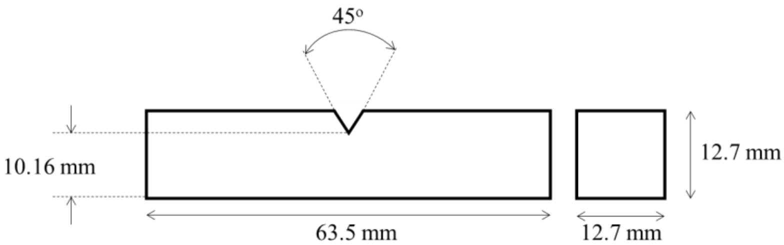


Figure 6. Dimension of impact test specimen using ASTM D-256

Then, the tensile strength (TS), elongation (ε), and elastic modulus (E) were calculated using the following formulas.

$$TS\ (MPa) = \frac{F_u(N)}{A_o(mm^2)} \tag{1}$$

$$\varepsilon\ (\%) = \frac{\Delta l\ (mm)}{l_o(mm)} \times 100\% \tag{2}$$

$$E\ (GPa) = \frac{\mathrm{TS}\ (MPa)}{\varepsilon} \tag{3}$$

Moreover, the impact strength was calculated using the following formula.

$$IS\ (\times 10^{-2} J/mm^2) = \frac{\mathrm{W\ (N) \times L(m) \times (\cos\beta - \cos\alpha)}}{A(mm^2)} \tag{4}$$

3. Results and Discussion

The Tensile Test Results

After the tensile test was carried out with each variation, the data were obtained as in Table 1, and illustrated in Figure 5 and Figure 6.

The cross-sectional area of the tensile test specimen is 75 mm^2 with 150 mm in length. After testing, the specimen elongation (Δl) and maximum force (F_u) were obtained. Then, the data was calculated to get the value of tensile strength (TS), elongation (ε), and elastic modulus (E).

Table 1. Tensile test results

Fiber Variation	Orientation (°)	A_o (mm^2)	l_o (mm)	Δl (mm)	F_u (N)	TS (MPa)	ε (%)	E (GPa)
Without fiber	-	75	150	0.92	840	11.2	0.61	1.83
Without treatment	30	75	150	1.25	1200	16.00	0.83	1.92
	90	75	150	1.24	2500	33.33	0.83	4.03
Alkaline treatment	30	75	150	1.12	1600	21.33	0.75	2.86
	90	75	150	1.14	2600	34.67	0.76	4.56
Bleaching treatment	30	75	150	1.16	1600	21.33	0.77	2.76
	90	75	150	1.12	2800	37.33	0.75	5.00

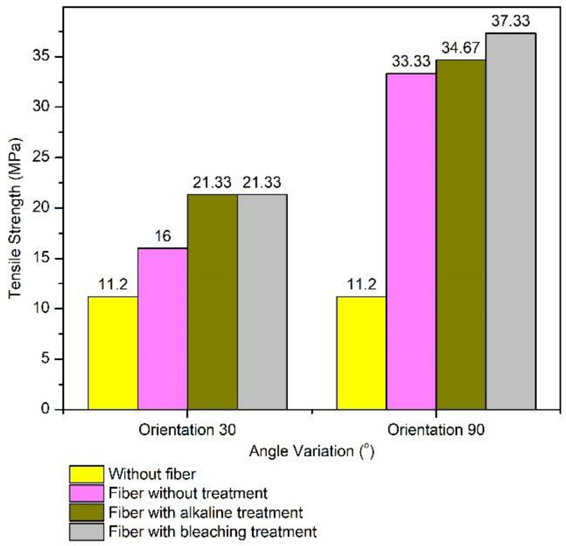


Figure 7. Tensile strength results from the tensile testing of composites with the variations of fiber orientation and treatment

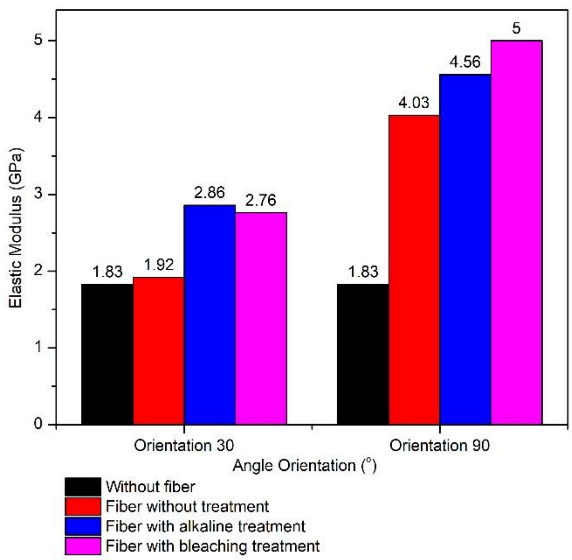


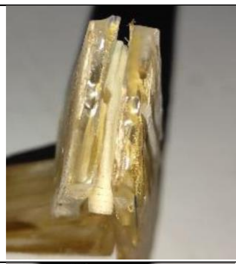
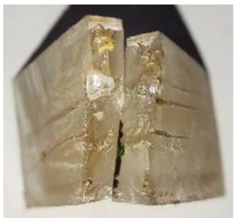
Figure 8. Elastic modulus results from the tensile testing of composites with the variations of fiber orientation and treatment

From Figures 7 and 8, the value of the tensile strength and elastic modulus of the composite is higher than that of the polyester matrix without fiber having a tensile strength value of 11.2 MPa and an elastic modulus of 1.83 GPa. The highest tensile test value was achieved by composites with the variations of orientation 90^o and using bleaching treatment, the tensile strength value was 37.33 MPa and the elastic modulus was 5 GPa. While the lowest tensile test value of composite is in the 30^o orientation without treatment that has tensile strength value of 16 MPa and elastic modulus of 1.92 GPa.

The value of the composite tensile test results with fiber bleaching treatment has a higher value compared to fiber with alkaline treatment. This is because the bleaching process using H_2O_2 can remove the remaining lignin layer from the previous process, that is alkaline treatment [16]. So that the fiber after bleaching has more compatible surface with the matrix, compared to the alkaline process. While the 90^o orientation produces a higher composite tensile test result compared to the 30^o orientation due to the load received by the specimen with vertical orientation fibers will be received by the matrix and transmitted to all fibers. Meanwhile, for composites with a horizontal orientation, the load will only be received by the matrix [17]. The same thing regarding the increase in the results of the tensile test for angular orientation was also shown in the previous study by Supriyadi et al [18].

The results of the tensile testing fracture show that the 90^o orientation results in a fracture indicating the presence of fiber pull out. This is caused by the direction of the fiber in the same direction as the load. Meanwhile, faults with a 30^o orientation show a fracture pattern in the matrix (Table 2).

Table 2. Tensile test fracture results

Orientation (°)	Fiber Treatment			
	Without fiber	**Without treatment**	**Alkaline treatment**	**Bleaching treatment**
30				
90				

The Impact Test Results

Impact testing shows the same trend as tensile testing. As seen in Figure 9, the highest impact strength value was produced by the composite with a variation of the 90° orientation and fiber bleaching treatment, where the impact strength value was 2.74 x 10^{-2} J/mm^2. While the lowest impact strength 1.1 x 10^{-2} J/mm^2 was found in composites with variations in the orientation of 30° and untreated fibers. The mechanical properties of the composite with the bleaching treatment had a higher value compared to the alkaline treatment, this was due to the smaller diameter of the fibers due to the bleaching treatment as described in the research by Arsyad, et al [19].

The impact strength of the composite with fiber bleaching treatment has a higher value, as well as the composite with an orientation of 90°. This is supported by the fracture morphology of the impact test results; it can be seen that the composite with alkaline treatment shows fiber pull out which indicates that it takes more energy to fracture. While the results of composite fractures with bleaching treated fibers showed a brittle type of fracture. The fracture morphology of the impact test results can be seen in Table 3.

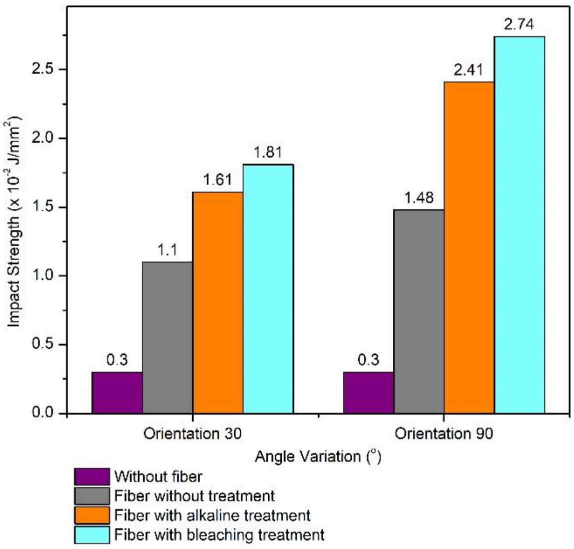
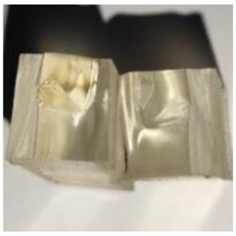
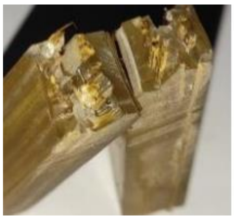


Figure 9. Impact testing results of composites with the variations of fiber orientation and treatment

Table 3. Impact test fracture results

Orientation (º)	**Fiber Treatment**			
	Without fiber	**Without treatment**	**Alkaline treatment**	**Bleaching treatment**
30				
90				

4. Conclussion

Based on research that has been done on composites with variations in fiber orientation and treatment, it can be concluded that composite with fiber bleaching treatment and 90^{o} orientation produces the highest tensile strength, with the value of 37.33 MPa and elastic modulus of 5 GPa. The results of the impact test showed the highest value for the composite with fiber bleaching treatment and an orientation of 90^{o}, which was 2.74 x 10^{-2} J/mm^{2}. The bleaching treatment can improve the mechanical properties of the fiber compared to the alkali, and the vertical orientation also improves the mechanical properties.

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