Optimization of Unsaturated Polyester Resin Matrix Composite Materials Reinforced Banana (Musa Balbisiana) Fronds Composition Towards Tensile Test

Novi Laura Indrayani1*, Riri Sadiana1, and Dicky Ramdani1

1Department of Mechanical Engineering, Faculty of Engineering, Universitas Islam 45, Bekasi, Indonesia

Abstract. This study aims to find out how the physical and mechanical properties of banana tree frond fibers are strengthened by a polyester matrix with various variations of fiber fractions. The study began by making three types of specimens with differences in volume fractions, namely 6% fiber + 94% matrix, 9% fiber + 91% matrix and 12% fiber + 88% matrix with the hand lay-up method. The results of making composites are carried out physical properties testing in the form of density testing, water absorption and thick development and mechanical testing with tensile tests. The results of the physical properties test show that the average density value of each volume fraction variation is above the JIS A509 – 2003 standard. The water absorption value and the thick development of the three fraction variations are still below the maximum limit. While in mechanical properties testing, the highest tensile strength value was obtained at a volume fraction of 12% fiber + 88% matrix with an average tensile strength value of 37.28 MPa.

1 Introduction

Composite is a material consisting of two or more materials where the properties of each material differ from one another, both chemical and physical properties. In many different industries in Indonesia, composite materials are used extensively for instance, in the automotive industry, where they are used to make tools, automobile bumpers and helmet shells, as well as in the maritime industry as a substitute for metal. In addition to having the qualities of a strong, lightweight and easily moldable material, composites are also simple to obtain and very inexpensive when compared to polypropylene materials.

The composition and distribution of the constituent elements, as well as the interactions between them, have a significant impact on the properties of composite materials [1, 2, 3]. Shape, size, orientation and distribution of the reinforcement (filler), as well as different matrix properties, are additional significant factors that may influence the properties of composite materials [4, 5, 6, 7]. One of the most crucial aspects of composite materials to research is their mechanical properties. For structural applications, mechanical properties are

* Corresponding author: novi_laura@unismabekasi.ac.id

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determined by the selection of materials [5, 6, 7, 8, 9]. The main role in fiber-reinforced
composites is to transfer stress between the fibers, provide resistance to adverse environments
and protect the fiber surface from mechanical and chemical effects. While the contribution
of fiber mostly affects the tensile strength of composite materials [5, 6, 7, 9].

Fibers can be generally classified into two categories; synthetic fibers and natural fibers.
Synthetic fibers like fiberglass are the most common types of fibers used in the production
of polymer composites. The ability of composites to be easily formed, have good mechanical
properties, lightweight and have corrosion resistance encourage players in the industrial
world to continue to develop, one of which is by combining composites using natural fibers.
As a result, the use of technology with composite materials is receiving more and more
attention. Natural fibers are thought to be more environmentally friendly than synthetic
fibers, have lower production costs, and generate less plant waste. Natural fibers, which are
made from plants in the immediate environment, are thought to be more environmentally
friendly because it is so simple to dispose of them after they have served their purpose.

One of the natural fibers that have the potential to be used as reinforcement for composite
materials is banana fiber (musa balbisiana). Banana stem fiber has better strength properties
compared to other alternative materials, the cellulose content is 63 – 64%, the hemicelluloses
is 20%, the lignin content is 5%, the average tensile strength is 600 Mpa, the average tensile
modulus is 17.85 GPa and the increase in fiber length is around 30.92 – 40.93 cm [6].
Sakthivel, 2013 conducted a study to test the mechanical properties of natural fibers
consisting of banana, coir and sisal fiber, found that composites made of banana stem fibers
were the best natural fibers among various combinations [2].

Based on the aforementioned research background, a polymer composite reinforced with
banana fiber (musa balbisiana) was created in this study using an unsaturated polyester resin
(UPR) matrix with volume fraction variations of 6%, 9%, and 12% after being immersed in
an alkaline solution of NaOH 5% for 60 minutes by using hand lay-up manufacturing method.
The expectation of conducting this research was to obtain a composite board made of banana
stem fiber and to determine the effect of fiber volume fraction on the mechanical properties
and physical properties of the material [5, 6, 7, 8, 11].

2 Material and methods

Materials and methods will affect the successfulness in this study. The design methodology
will be successful and valid if it chooses a material with the right mechanical properties. The
materials used in this study can be seen below.

2.1 Materials

The materials used in this study included: Yukalac 157 BQTN-EX Series - Justus Polyester
Resin, Methyl Ethyl Ketone Peroxide (MEPOXE) catalyst, Banana Fronds Fiber, 5% NaOH,
Aquadest and Miracle Gloss. Yukalac 157 BQTN-EX Series - Justus Polyester Resin in this
research act as matrix. The filler for composite reinforced materials in this study used a
banana fiber. Banana fiber can be used as an alternative to other composite reinforcement
materials. One method of optimizing banana leaf waste is to turn it into a product with market
value and application in any industry. In this study, distilled water (aquadest) and a 5% NaOH
solution were used as supporting chemicals. The lignin or gum content in the fiber is removed
using a 5% NaOH solution. Meanwhile, Miracle Gloss is a material that functions as a mold
coating so that the composite material is not sticky and sticks during the removal process
from the mold. The mold used in this study was made of glass with a volume size of 20 x 20
x 0.5 cm.
2.2 Methodology

In this study, several stages were carried out, starting out from the process of extracting banana fronds into fiber, followed by alkaline treatment of fibers using 5% NaOH solution, composition calculations, fiber weighing, printing of composite boards using the hand lay-up method, cutting and shaping of composite boards according to testing standards and processes that include tensile testing and physical properties.

2.3 Fiber extraction process

Banana fronds must first go through an extraction procedure to separate the fiber in the frond's inner layer from the outer layer before being used as reinforcement. The midrib's outer layer is brushed away during the extraction process using a wire brush, leaving only the fiber behind. Fig. 1 shows the fibers from banana fronds.

![Fig. 1. Banana fronds (a) and fiber (b)](image)

2.4 Alkali Treatment

The fiber is separated from the midrib, extracted and then given an alkali treatment by immersed in an alkaline solution of 5% NaOH for 60 minutes. Lignin content is intended to be removed by alkali treatment. The fibers are rinsed with clean water after soaking for 60 minutes and the fibers then dried in the sun until the texture dries. Fig. 2 depicts the fiber after it has undergone an alkaline treatment [11, 12, 13].

![Fig. 2. Fiber alkali treatment](image)

2.5 Composition Calculation

The composition calculation is carried out based on the total volume of the mold used, which is 20 x 20 x 0.5 cm with variations in the fiber volume fraction as follows;

a. Fraction Variation I (KSP I); 6% fiber and 94% matrix.

b. Fraction Variation II (KSP II); 9% fiber and 91% matrix.

c. Fraction Variation III (KSP III); 12% fiber and 88% matrix.

After calculating the composition, weigh the fibers in accordance with the results of the composition calculation. The process of weighing fibers aims to prevent errors in the volume
of fibers measurements because it will affect the mechanical properties of the composite board produced later.

2.6 Composite Board Molding

The fibers are then placed and arranged in a glass mold after being weighed in accordance with the calculated composition. Following the assembly of the fibers, the hand lay-up method is used to apply resin (matrix) as a composite binder. After being filled with resin and reinforcement, the mold is left at room temperature for 24 hours to dry. The glass mold can be opened and the composite board can be taken out of the mold after it has been left to sit for 24 hours. **Fig. 3** shows the composite boards created using glass molds.

![Composite boards created using glass molds](image)

**Fig. 3.** Composite board

2.7 Physical Properties Testing

Testing of the physical properties of the composite was carried out using three test methods which included density test, water absorption capacity and thickness swelling test. **Fig. 4** illustrates how specimens are created in accordance with the JIS A5908 - 2003 standard in order to test physical properties.

![Specimens created for physical properties testing](image)

**Annotation:**
- a. MOR and MOE test sample.
- b. Thickness swelling and water absorption test sample.
- c. Density test sample.
- d. Internal adhesive bonding test sample.

**Fig. 4.** Physical properties testing jis a5908-2003
2.8 Mechanical Properties Testing

The 20 x 20 x 0.5 cm molded composite board was then cut into eight pieces, each measuring 2.5 cm in diameter. The cutting is carried out to make it easier to form an ASTM D638 type 1 compliant tensile test specimen. Fig. 5 depicts the composite board after it has been cut. The creation of a tensile test specimen comes next, after the composite board has been cut into eight pieces.

![Composite board after cutting](image)

**Fig. 5.** Tensile testing specimen

Tensile testing is a measurement of the material to determine the value of the ductility and toughness of a material against the stress and increase in length that is experienced by the material. Tensile testing is carried out with the aim of knowing the value of the mechanical properties of the material which includes the value of tensile strength, flexural strength, ductility, elastic modulus and toughness of the material.

3 Result and discussion

3.1 Results and discussion physical properties testing

Material physical properties are material behavior related to physical characteristics or material conditions that are not caused by loading which are more aiming to the material structure. Tests for physical properties in this study included testing for density, water absorption and swelling which refers to the JIS A5908 – 2003 standard. Each test will be explained as follows.

The quantity of mass per unit volume is known as density. The strength of a material increases with its density. Table 1 shows data from the composite board density test results. Based on the data obtained from the results of the density test, the density values of the three composite boards were determined in general, showing that the density of the finished composite boards increased with the volume of the matrix used. This occurs because the total mass of the composite board produced in the same volume will increase with higher matrix concentration. JIS A509 – 2003 Standard, Based Particleboard and Decorative Particleboard requires a minimum composite board density value of 0.4 g/cm³ – 0.9 g/cm³. Based on the value obtained, all the resulting composite boards have passed the specified requirements.

<table>
<thead>
<tr>
<th>Volume Fraction (%)</th>
<th>Volume (mm³)</th>
<th>Mass (g)</th>
<th>Density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSP I</td>
<td>52.75</td>
<td>64.175</td>
<td>1.21</td>
</tr>
<tr>
<td>KSP II</td>
<td>51.75</td>
<td>61.95</td>
<td>1.197</td>
</tr>
<tr>
<td>KSP III</td>
<td>50.75</td>
<td>60.575</td>
<td>1.193</td>
</tr>
</tbody>
</table>

Water absorption is the ability of the composite board to absorb water during 24-hour immersion. According to Putra, 2011 water absorption can be calculated using the water
adsorption (WA) equation resulting from immersion [14]. Table 2 shows the value of the composite board's water absorption test results. The results showed that the increase in water absorption value increased as the volume of fiber used increased. This is due to the hydrophilic nature of banana fiber which can easily absorb water. The percentage of water absorption from the composite board increases with the number of fiber fractions. According to the JIS A509 - 2003 standard, a composite board's quality and durability will increase with a lower percentage of water absorption in the composite. Based on the results obtained from the water absorption test, all composite boards that is produced comply with the JIS A509 – 2003 standard.

Table 2. Water absorption test results

<table>
<thead>
<tr>
<th>Banana Fiber Composite (KSP)</th>
<th>Weight (g)</th>
<th>Absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>B1</td>
<td>B2</td>
</tr>
<tr>
<td>KSP I</td>
<td>15,0375</td>
<td>15,1375</td>
</tr>
<tr>
<td>KSP II</td>
<td>14,7625</td>
<td>14,975</td>
</tr>
<tr>
<td>KSP III</td>
<td>14,775</td>
<td>15,0375</td>
</tr>
</tbody>
</table>

Thickness expansion is the increase in the thickness dimension of a composite board due to water filling the composite board after 24 hours of immersion [6, 13, 14]. The thickness swelling test's goal is to figure out how much the composite board's thickness increased as a result of the immersion procedure. Table 3 shows the outcomes of the thickness swelling test. The results indicate that as the fiber fraction is increased, thickness expansion increases. This also happens in the water absorption test, where the expansion of thickness and the percentage of fiber absorption capacity for water both rise as the number of fiber fractions increases. A maximum thickness expansion limit of 12% is required by the JIS A509 - 2003 standard for composite board.

Table 3. Thickness expansion test results

<table>
<thead>
<tr>
<th>Banana Fiber Composite (KSP)</th>
<th>Thickness (mm)</th>
<th>Absorption (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>T1</td>
<td>T2</td>
</tr>
<tr>
<td>KSP I</td>
<td>5,46</td>
<td>5,50</td>
</tr>
<tr>
<td>KSP II</td>
<td>5,29</td>
<td>5,34</td>
</tr>
<tr>
<td>KSP III</td>
<td>5,1725</td>
<td>5,228</td>
</tr>
</tbody>
</table>

3.2 Results And Discussion

Tensile testing was used to test the mechanical properties and referred to the ASTM D638 Type 1 standard. Fig. 5 depicts the specimen’s states before (a) and after (b) the tensile test. Table 4 summarizes the data from the tensile test results and displays the average values of tensile strength, strain and elastic modulus for the three variables tested.

Fig. 4. Specimen states before (a) and after tensile test (b)
Table 4. Tensile testing test results

<table>
<thead>
<tr>
<th>Banana Fiber Composite (KSP)</th>
<th>Width (mm)</th>
<th>Thickness (mm)</th>
<th>Sectional (mm$^2$)</th>
<th>Max Load (kgf)</th>
<th>Tensile Strength (MPa)</th>
<th>Elongation (mm)</th>
<th>Strain (%)</th>
<th>Elastic Modulus (GPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>KSP I</td>
<td>14,856</td>
<td>5,383</td>
<td>79,979</td>
<td>114,544</td>
<td>14,08</td>
<td>2,507</td>
<td>2,180</td>
<td>2,545</td>
</tr>
<tr>
<td>KSP II</td>
<td>14,22</td>
<td>5,076</td>
<td>72,222</td>
<td>119,224</td>
<td>16,18</td>
<td>1,814</td>
<td>1,54</td>
<td>2,595</td>
</tr>
<tr>
<td>KSP III</td>
<td>14,74</td>
<td>5,203</td>
<td>76,702</td>
<td>288,797</td>
<td>37,28</td>
<td>1,599</td>
<td>1,460</td>
<td>3,263</td>
</tr>
</tbody>
</table>

3.3 Tensile Strength

The KSP III fraction variation yielded the highest tensile strength test value, with an average tensile strength value of 37.28 MPa. In order to fill in the gaps in the matrix and create a homogeneous bond between the filler and the matrix, this value has a fiber distribution that gets denser and denser over time. Due to this, when a tensile stress is applied to the test specimen, the filler can effectively reduce the received stress, resulting in a higher tensile strength value and a very noticeable difference. Tensile strength values decrease with decreasing fiber volume fraction that is used. An average tensile strength value of 16.18 MPa was found in the KSP II volume fraction, with the KSP I volume fraction having the lowest average tensile strength value, 14.08 MPa. According to SNI 03 - 2105 – 2006 standards, which outlines the specifications for the mechanical qualities of structural particle board, the composite board's minimum surface perpendicular tensile strength is 3.1 kgf/cm$^2$. Based on the test data obtained, all variations in the volume fraction of the banana fronds fiber composite have met the standards [6, 7, 8, 13].

3.4 Tensile Strain

After obtaining the tensile stress value, the tensile strain value can be obtained which can be found using the equation $\epsilon = \text{Engineering Strain} (%)$ [15]. The results that is obtained indicate that the fiber will be more ductile and less likely to break if the strain value is higher. The addition of fiber volume can reduce the tensile strain values and make the material stiffer, according to the calculated tensile strain values. This is in line with the statement which states that banana fiber has stiffer mechanical properties [16].

3.5 Elastic Modulus

The volume variation of KSP III yielded the highest elastic modulus value, with an average value of 3.263 GPa. Since the elastic modulus is a gauge of a material's stiffness, the higher its value, the less the material will deform in response to an applied force. The relationship between the elastic modulus and strain is inversely proportional. The strain value decreases as the material's elastic modulus increases. Based on the research data obtained, it can be concluded that the addition of fiber can increase the value of the modulus of elasticity so that the resulting material is stiffer [17].

4 Conclusions

Based on the results of testing the physical properties, the average density value for each volume fraction variation is above the standard value of JIS A509 – 2003. Meanwhile, the values for water absorption and thickness expansion are still below the maximum limit that is 6% for water absorption and 12% for thickness expansion. Furthermore, based on the
results of testing the mechanical properties of the material, the addition of the composite volume fraction has an effect on the increase in the value of the tensile strength and modulus of elasticity. The results of the tensile test are in accordance with the SNI 03 – 2105 – 2006 standards for composite boards. Meanwhile, the elongation value of the material decreases with increasing fiber volume fraction.

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References