Physical and Mechanical Properties of Natural Fiber Polyester Laminate Composites

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Abstract. The utilization of natural fibers as reinforcing composites has been widely used. Indonesia has natural fibers abundantly such as ijuk fiber (Arenga pinnata), sisal fiber (Agave Sisalana) and coconut fiber (Cocos Nucifera). Random orientation application of the fiber in composites affected to the lower properties. Therefore, the particular orientation of fibres were applied in manufacturing of composite by laminating the short fiber with Polyurethane (PU) adhesive. The size and moisture content (MC) of fiber were 14 – 15 cm and ±10%, respectively. The resin content of PU was 5% by weight of the laminate sheet. The mixture of fibers and PU adhesive was cold pressed for 5 minutes with a thickness of 0.5 - 1 mm. The laminate sheet of PU-adhesive fibers then mixed with unsaturated polyester resin layer by layer. The fiber laminate composition of composite was varied such as 1, 2 and 3 layers. The hand layup method was used in the manufacturing of the composite. The physical and mechanical testing like density, moisture content, water absorption, thickness swelling, flexural test (adapt to ASTM D 790 standard) and tensile test (adapt to ASTM D 638 standard) were carried out. In addition morphological analyses were investigated on composite samples. The results research showed that the net density of polyester, ijuk fiber sheet, sisal fiber sheet, and coconut fiber sheet were 1.21, 0.9, 0.53 and 0.22 g/cm³. The range of composite density was 0.99 - 1.15 g/cm³. The single layer composite had lower thickness swelling and water absorption than those of the three layers composite. The highest tensile strength of three layers of sisal fiber composite was higher (33.84 MPa) than that of the three layers of coconut fiber composite (12.04 MPa). The flexural strength of double layers composite from fiber sisal was higher (63.16 MPa) than that of three layers coconut fiber composite (28.65 MPa).

1. Introduction
Along with advances in technology, the need for the necessary technological support materials is also increasing. The types of materials used are not only limited to metal, wood, plastic, but also composite materials, both metal-based, ceramic and polymer-based composites. Reinforcing materials and composite matrices are derived from synthetic materials derived from petroleum and non-petroleum natural materials. Along with the depletion of petroleum production as a plastic raw material, the development of natural materials as composite materials is increasing. The reinforcement mechanism in composite material determines its strength, stiffness, and ability to withstand loads. Fiber is the most commonly used material for composite reinforcement systems and is integrated with matrix material [1]. Synthetic materials commonly used as reinforcement for polymer-based composite materials are glass fiber [2], carbon fiber, nylon fiber, Kevlar fiber, and others. The limitations of petroleum
production from year to year allow exploration of non-fossil materials, one of which is by using biological materials as reinforcement for polymer composite materials that have good mechanical physical characteristics, chemical resistance, and environmental friendliness. Among the natural fiber materials commonly used as composite reinforcement are flax fiber[3], sisal[4], jute[5], coconut fiber[6], banana[7], kenaf [8], cotton, sugar palm fiber, hemp [9], palm fruit fiber and others. The main advantages of natural fibers are their availability, biodegradability, renewability, low cost, low density, and high specific properties. The use of natural fibers is focused on replacing synthetic fibers. The polymer used as a matrix in composite materials with natural fiber reinforcement is usually a thermoset polymer, although it is possible to use thermoplastic polymers. Thermoset polymers can be used to make composite materials by various methods, namely hand lay-up, spray lay-up, compression molding, filament winding. This polymer makes it possible to use long natural fibers continuously [10]. Polymer materials commonly used as a matrix in composite materials are epoxy [11], polyester resin [12], PVA [13], polyurethane [14] and others. The problems that are often faced in the development of natural fiber composite materials are the low fiber-matrix adhesion, water resistance, the low composite strength in terms of stiffness, tensile strength, flexural strength which affect resistance to loading and difficult to make composites on random fiber orientations [15]. The use of fiber sheet in the fabrication of natural fiber-based composites is possible to increase the fiber-matrix adhesion, increase water resistance, increase composite stability and increase the efficiency of the composite fabrication process.

2. Materials and Methods

2.1. Materials

The material used in this study were Ijuk (Arenga Pinnata) fiber, Sisal (Agave Sisalana) fiber and Coconut fiber (Cocos Nucifera) from home industry in Sukabumi, West Java, Indonesia. Polyurethane adhesive from PT. Anugrah Raya Kencana, Indonesia as a primarily adhesive fiber sheet. Unsaturated polyester Yukalac 157 and MEKPO (methyl ethyl ketone peroxide) as hardener from PT. Justus Kimia Raya, Indonesia were used as matrix.

2.2. Methods

Fiber used with a size of 4-15 cm and ±10% in moisture content. The PU adhesive used was 5% by weight of the laminate sheet. The mixture of fibers and PU adhesive was cold pressed for 5 minutes with a thickness of 0.5-1 mm. The laminate sheet of PU-adhesive fibers then mixed with unsaturated polyester resin layer by layer. The concentrations of fiber laminate used were 1, 2 and 3 layers for each composite. The manufacture of polyester-laminate hybride composite fibers using the hand layup method. The mold used is 85 mm x 200 mm x 4 mm in size. The natural fibre polyester-laminate composites were conditioned at room temperature (27°C, RH 60%) for 2 x 24 hours. The tests carried out include physical testing, namely measuring density, moisture content, water absorption, thickness swelling, and mechanical testing, namely flexural test (adapt to ASTM D 790 standard) and tensile test (adapt to ASTM D 638 standard) were determined using 3 specimens from composite boards sample. Mechanical test using Universal Testing Machine (UTM) Shimadzu AG-X 10 kN with speed 5 mm/min for tensile test and 10 mm/min for flexural test. In addition, morphological analyzes were carried out on composite samples using Dynolite 4000 optical microscope.

3. Result and Discussion

The physical and mechanical properties of the composites were tested before making natural fiber laminated composites. The data obtained are as shown in Table 1. The density value of all-natural fiber sheets is less than 1 g/cm³. Its value is smaller than that of a single natural fiber from reference that is 1.45 g/cm³, 1.13 g/cm³ [14] and 0.87-1.2 g/cm³[16] for sisal, ijuk and coconut fiber, respectively. It is also seen that the water content for the fiber sheet is less than 10%. The ideal moisture content for natural fibers, when mixed with thermosetting polymers, is less than 10% [10].
Table 1. Physical-mechanical properties of natural fiber sheet and polyester matrix.

| Materials           | Density (g/cm$^3$) | Moisture Content (%) | Thickness swelling (%) | Water Absorption (%) | Tensile Strength (MPa) | Tensile Modulus (GPa) | Strain (%) |
|---------------------|--------------------|----------------------|------------------------|----------------------|------------------------|----------------------|------------|
| Net Polyester       | 1.21               | 0.50                 | 0.00                   | 0.00                 | 26.78                  | 1.8                  | 1.89       |
| Ijuk fiber sheet    | 0.90               | 5.88                 | 3.94                   | 26.64                | 7.68                   | 0.6                  | 2.16       |
| Sisal fiber sheet   | 0.53               | 5.72                 | 4.40                   | 45.96                | 23.72                  | 1.41                 | 2.86       |
| Coconut Fiber sheet | 0.22               | 8.48                 | 4.18                   | 129.75               | 5.28                   | 0.25                 | 7.1        |

The tensile strength value of natural fiber sheet ranges from 5.28 to 23.72 MPa, which is smaller than the tensile strength net polyester value, which is 26.78 MPa. It can be seen that the strain of the fiber sheet is higher than the net polyester strain value up to 2-3 times. According to the rule of mixture (ROM), composite properties are a combination of matrix and reinforcement properties. It can be seen that the natural fiber sheet has higher an elongation value than the matrix, so that the elongation of the composite made later lies between the fiber and matrix. With a higher elongation value, the composite made becomes more resilient and is no longer brittle. This is in line with the explanation of Gibson, 1994 [17].

3.1. Physical Properties of Composites Materials

The physical properties of natural fiber laminated composites, namely the density value, moisture content, water absorption, and thickness expansion value are shown in Table 2. It can be seen that the density values for all test objects are in the range of 1.03-1.14 g/cm$^3$. This value is lower than the density value of polyester and higher than the density of fiber sheet. It can be understood that the composite formed is a combination of the properties of fiber sheet and polyester, so that the value range is between the density values of the two materials.

Table 2. Physical Properties of Composites Materials

| Material Composites | Kind of Fiber | Amount of Layer | Density (g/cm$^3$) | Moisture Content (%) | Thickness swelling (%) | Water Absorption (%) |
|---------------------|---------------|-----------------|--------------------|----------------------|-----------------------|----------------------|
| I1L                 | Ijuk          | One layer       | 1.12               | 1.65                 | 0.00                  | 1.71                 |
| S1L                 | Sisal         | One layer       | 1.04               | 2.18                 | 0.00                  | 1.50                 |
| C1L                 | Coconut       | One layer       | 1.07               | 2.27                 | 0.00                  | 5.25                 |
| I2L                 | Ijuk          | Two layers      | 1.14               | 3.33                 | 0.36                  | 2.31                 |
| S2L                 | Sisal         | Two layers      | 1.07               | 3.35                 | 0.64                  | 4.54                 |
| C2L                 | Coconut       | Two layers      | 1.03               | 3.11                 | 0.61                  | 5.10                 |
| I3L                 | Ijuk          | Three layers    | 1.10               | 4.06                 | 0.80                  | 3.12                 |
| S3L                 | Sisal         | Three layers    | 1.15               | 4.34                 | 0.86                  | 5.01                 |
| C3L                 | Coconut       | Three layers    | 0.99               | 3.91                 | 2.73                  | 5.97                 |

The value of the moisture content of the composite ranges from 1.65 to 4.34%, the value is between the moisture content polyester and fiber sheet values. This value is also better than the results of Atiqah et al., 2017[14] study which was above 6%. Likewise, the thickness swelling value which indicates the value of the stability of the composite dimensions, the majority of the values of the composites are below 1% which indicates that the composite dimensions are very stable, more stable than the fiber sheet value. Water absorption is also below the value of 12% which indicates that the composites made tend to be compact and slightly void. This water absorption value is better than the results of Ismadi et al, 2020 research [10] on ramie fiber-epoxy composites which are in the range of
6.72-10.20% and Atiqah et al, 2017[14] which used 50% palm fiber and polyurethane which is above 8%. The thickness swelling value and water absorption increased along with the addition of the fiber sheet layer. The value of thickness swelling and water absorption of composites sequentially from the lowest is ijuk fiber sheet, sisal fiber sheet and the highest is coconut fiber sheet.

3.2. Mechanical Properties of The Composites Materials.

The influence of fiber loading on flexural strength and flexural modulus of the composites is shown in Figure 1.

![Figure 1](image1.png)

**Figure 1.** Flexural strength of composites with variation of fiber sheet laminate. IFsC: composite of ijuk fiber sheet; SFsC: composites of sisal fiber sheet; CFsC: composite of coconut fiber sheet

It can be seen that the composite flexural strength value tends to decrease with the addition of fiber sheet, except for sisal fiber sheet which reaches the optimum value in the composition of 2 layers of fiber sheet. The highest value of flexural strength achieved was 63.16 MPa in the composite reinforced with two layers of sisal fiber sheet. And the lowest value is 28.65 MPa in the composite reinforced with three layers of coconut fiber sheet. However, the flexural value is better than the results of Neves et al, 2020[9] research on hemp and epoxy fibers, which are in the range of 34 MPa and Benyahia et al, 2013[18] on natural fibers and polyester which are in the range of 16-33 MPa.

Composite flexural modulus values are presented in Figure 2. It can be seen that the flexural modulus of composites reinforced with natural fiber sheets tends to decrease as the number of layers increases. The value of flexural modulus reinforced by fibers and coconut fibers is below the value of the flexural modulus of net polyester. Meanwhile, the flexural modulus of composite with sisal fiber sheet has a higher value than net polyester, with a value of 3.28 GPa for composites reinforced with 2 and 3 layers.

The value of flexural strain on the composite is shown in Figure 3. It can be seen that the value of flexural strain tends to increase with the addition of the number of fiber sheets. The flexural strain values sequentially were composites reinforced with ijuk fiber sheet, sisal fiber sheet and coconut fiber sheet. The highest value was achieved by the composite reinforced with 2 layers of coconut fiber sheet, which was 5.4%. This value is higher than the strain net polyester value.
Figure 2. Flexural modulus of composites with variation of fiber sheet laminate. IFsC: composite of ijuk fiber sheet; SFsC: composites of sisal fiber sheet; CFsC: composite of coconut fiber sheet

Figure 3. Flexural strain of composites with variation of fiber sheet laminate. IFsC: composite of ijuk fiber sheet; SFsC: composites of sisal fiber sheet; CFsC: composite of coconut fiber sheet

Figures 4 and 5 show the tensile strength for composites reinforced by natural fiber sheets. It can be seen that the value of the tensile strength of the composite reinforced by sisal fiber sheet increases with the increase in the number of layers of fiber sheet. For composites reinforced by coconut fiber sheet, the optimum value is 17.11 MPa on 2 layers of coconut fiber sheet. Overall, the highest value was achieved by composites with 3 layers of sisal fiber sheet, which was 33.84 MPa. This tensile strength value is higher than the research of Gazali et al, 2017[19] which is in the range of 12-15Mpa.
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Figure 4. Tensile strength of composites with variation of fiber sheet laminate. IFsC: composite of ijuk fiber sheet; SFsC: composites of sisal fiber sheet; CFsC: composite of coconut fiber sheet.

The tensile modulus value of fiber sheet composites reaches the optimum value for the number of bilayers fiber sheets. The highest was achieved by bilayers of sisal fiber sheet, which was 3.07 GPa and the lowest value was 1.78 GPa in the composite reinforced by a single layer coconut fiber sheet.

Figure 5. Tensile modulus of composites with variation of fiber sheet laminate. IFsC: composite of ijuk fiber sheet; SFsC: composites of sisal fiber sheet; CFsC: composite of coconut fiber sheet.

The tensile modulus value above is higher than the research of Ramesha et al, 2013 [2] which was in the range of 0.5-0.9 GPa and Ghazali et al, 2017[19] on coconut fiber reinforced composites, which was 0.4-0.8 GPa.

3.2.1. Morphological Features of The Composites Materials
The cross-sectional image of the composite was shown in Figure 6. The cross-sectional image was taken at a magnification of 50 times. From the picture, it can be seen that the composite with 1 layer of fiber sheet looks compact, full of matrix and no cavities are found. This causes the value of the thickness swelling composite with a single fiber sheet to be 0% and the water absorption is relatively small. The appearance of 2 and 3 layers of fiber sheet has begun to show cavities. And it can also be seen in the thickness swelling and water absorption values which
are increasing along with the increase in the number of fiber sheet layers. This increasing water absorption value is probably stored in the cavity formed between the layers of the composite.

![Images of composites with varying layers and types of fibers](image)

**Figure 6.** Morphological features of Composites (50 x magnification).

The appearance of the composite fracture also shows that an increase in the number of layers causes an increase in the fiber pull out phenomenon in the composites. In addition, high porosity of the composite affect to the high absorption of the water hence the water absorption of the composite tend to increase [20].

**4. Conclusion**

The addition of fiber sheet to the composite can increase the efficiency of the composite fabrication process. The addition of sisal fiber sheet has an optimum effect on the composite compared to the addition of layers of ijuk fiber sheet and coconut fiber sheet. Two layers sisal fiber sheet-reinforced composite has optimum mechanical properties values. The water absorption and thickness swelling values of the all composite types were relatively small and were below 10%.
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