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Mechanical Properties of Natural Materials from Kalimantan as Substitute Material for Reinforcement Buildings

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Abstract— **Kalimantan has abundant natural resources, including wood. The physical properties of wood have varying strength and flexibility and could replace concrete reinforcement steel. In this study, the mechanical properties and sound insulation of one of Kalimantan's natural fiber combined with polyester matrix were investigated. Natural fibers used were teak wood (Tectona Grandis) with sawdust and wood chips. Specimens were made using the hand lay-up method with a wood volume fraction variable of 25%, 35%, and 50%. Afterward, the bending, morphology, and sound insulation tests were carried out. In this study, it can be concluded that the higher wood volume fraction used, the higher the ability of sound insulation. Conversely, it reduces the modulus of elasticity. Besides, the form of sawdust fillers has a better ability than wood chip fillers in terms of sound insulation and the modulus of elasticity.**

Keywords—kalimantan; teak wood; natural fiber; bending; sound insulation.

I. INTRODUCTION

Stainless steel components as building materials are used increasingly for structures application, especially for new construction. Structural steels have a wide range of use in civil construction [1]. The use of stainless steel alloys in structural engineering applications is not a new idea. In addition, the cost of stainless steel depends on the cost of the alloying elements and rather expensive [2]. The development of building reinforcement materials gives many things a challenge for engineers and structural architects. Building material needs to have heterogeneity or diversity and to have a rough texture because it affects mechanical strength, for example in stone buildings. Fiber-reinforced polymers are the most widely produced composite material category [3]. Composite is an artificial material which has multi-phase, which has the desired combination for the best properties of the constituent phase. Composites are classified into particle reinforcement, fiber reinforcement, and structural. Composites composed of continuous matrices and discrete (reinforced) reinforcements in the form of particles, short fibers or whiskers are called particle composites [4]. The incorporation of natural fibers as reinforcing agents in thermoset and thermoplastic polymer composites has been obtained to increase applications in both the Engineering and Technology fields. Natural fibers such as coconut, sisal, hemp, hemp tree bark, eucalyptus pulp, banana, kenaf bark, pineapple leaves, abaca leaves, bamboo, palm oil, sugar cane fiber, and cotton are generally strengthened in a polymer system to complement certain specific properties in the final product. These natural cellulose fibers have a wide physical range and mechanical properties related to the source such as diameter, length, specific gravity, processing methods, and treatments regulating more extensive application.

Building and construction materials are the most attractive for applications, which are related to improving the functional properties of concrete, steel, wood, and glass, as the primary construction materials. The material is used as a structural component, to improve the properties of polymer composites, and to show cost-effectiveness, when compared to the total cost of composites especially when a high percentage of fiber is involved compared to steel fibers [5]. Tectona grandis. Linn (Teak) is a large and deciduous tree native to Asia, known as Sagwan in Hindi, Saka in Sanskrit and teak tree in English. Its increasing demand as the world's premium hardwood has initiated several countries in tropical belts to plant it on large plantations [6]. Responding to the increasing demand for teak wood as one of the high-quality commercial types of wood, East Kalimantan region has industries related to teak wood both by the public and private sectors. However, research on the characteristic of teak wood is still very limited. [7], especially those related to the use of side produce of the teak industries such as the sawdust from the wood cutting industry. The sawdust is usually only used as a substitute for firewood. The general public still does not know that wood sawdust can be used as sound insulation material. It can be made to have more economic value if wood sawdust can be used as a substitute for building reinforcements coupled with the nature of the sound insulation material which serves to reduce noise. The focus of this study is to determine the ability of sound insulation in natural fiber composite materials by varying the volume fraction and shape of the fiber by measuring Sound Transmission Losses at several frequencies and paying

attention to the modulus of elasticity. A microstructure perspective will also support the effect of mechanical properties.

II. Methods and Materials

In general, this research was carried out in several stages, namely the material preparation, sound insulation test, bending, and morphological test.

A. Material Preparation

This study used composite materials made from waste teak wood fiber which is taken from the building construction process and used polyester resin with the brand Yukalac 157 - BQTN (Mahakam Fiber Glass, Samarinda) as the adhesive agent. The fibers used in making composites were prepared with different categories, depending on the size of the sawdust. Selection was done by using sieve with different sizes. The size of sawdust and wood chips used were below 0.595 mm and 10 mm, respectively. The process of making wood shavings using planers and making sawdust using a chainsaw, then followed by sifting. The sifting of wood chips was done using a sifter. The filler was mixed with polyester resin plus a catalyst and then printed using the hand lay-up method. The hand lay-up technique is the primary method of composite manufacture [8]. The tools required for this method were minimum. First, the reinforced were placed then the polyester resin in liquid form is mixed thoroughly in suitable proportion with hardness (curing agent) and poured onto the surface of the mat in the mold. The matrix was uniformly spread with the help of a brush. The second layer of the mat was then placed on the polyester surface and rolled with a hand pressure to remove any air trapped. The process was repeated for each layer until the required layers were stacked. After curing at room temperature, mold was opened, and the developed composite part was taken out. There were two types of specimens in this test, namely specimens for sound insulation testing and specimens for testing modulus of elasticity. Morphological testing would be used from the fractured material bending test results. Specimens used for sound insulation testing refer to ASTM E90 having dimensions, as shown in Fig. 1. Whereas specimens used for testing modulus of elasticity refer to ASTM D790 standard having dimensions as shown in Fig. 2. Specimens made were varied by modifying wood volume fractions (25, 35, and 50%) and modification of the shape of the fibers (sawdust and wood chips).
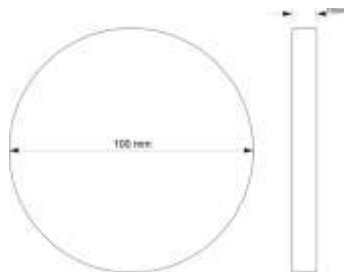

Fig. 1. The dimension of sound insulation testing samples based on ASTM E90 standard

Fig. 2. The dimensions of Bending Testing Samples based on ASTM D790 standard

B. Sound Insulation Test

Sound insulation testing used the transmission loss principle by measuring the reduced sound transmission received by the sensor after it has penetrated the material. The test was measured by a sound source at a specific frequency and a sound level meter behind the sample. The test results were compared with the intensity of sound in space in front of the sound source. The Frequencies used in the range was 125-4000 Hz.

The calculation method used to calculate the value of Sound Transmission Loss (STL) in testing is with the following equation [9].

$$STL = Li - Lo \qquad (1)$$

Where STL is the Sound Transmission Loss (dB), Lo is the sound level before passing the specimen (dB), and Li is the sound level after passing the specimen (dB). Values on Li and Lo were measured with a Sound Level Meter instrument.

C. Bending and Morphological Test

Modulus of elasticity testing was done by bending method in which the specimen is given exact loading in the middle of the specimen and then measured deflection of the specimen. After the bending test, morphological testing for fractography with OM (Optical Microscopy) and SEM (Scanning Electron Microscope).

III. Results and Discussion

A. Composite Manufacturing Results

In this study, the process of making composites was carried out by hand lay-up method with variations of sawdust and wood chips with a volume fraction of 25%, 35%, and 50%. Composites were printed according to ASTM D790 standards for the bending test, ASTM E90 for sound insulation test, and the results of fracture bending tests for OM and SEM tests.

Fig. 3. Bending test specimens with volume fraction for (a) sawdust and (b) wood chips

From Figs. 3-4, the visual results were obtained. The color of the composite with the sawdust reinforced composite was darker than the wood chips reinforced composite, this is due to the surface area which has a greater value and small particle size so that the sawdust reinforced composite has the ability to be able to fill the empty space in a polyester matrix. Thus with a good and homogeneous distribution makes the color possessed by the sawdust reinforced composite becomes darker than the wood chips reinforced composite.

Fig. 4. Insulation test specimens with volume fraction

B. Bending Results

From Fig. 5, it can be seen that the results of the calculation of modulus of elasticity (MOE) at three repetitions per volume fraction, then from these results obtained an average value. It can be seen that the highest elastic modulus value is owned by sawdust reinforced composites with a volume fraction of 25% by 5.09 GPa, and the lowest MOE was owned by wood chips reinforced composites with a 50% volume fraction of 0.29 Gpa. The MOE of pure teak wood is 1.08 GPa [10]. The results of data processing can also be seen trends that are owned by the comparison graph between the modulus of elasticity and also the volume fraction of the natural fiber composite of teak - polyester. Trends show that the strength of the MOE decreases

with increasing volume fraction, both in the sawdust reinforced composite or wood chips reinforced composite. However, the value held between the sawdust reinforced composite and wood chips reinforced composite has a significant difference.
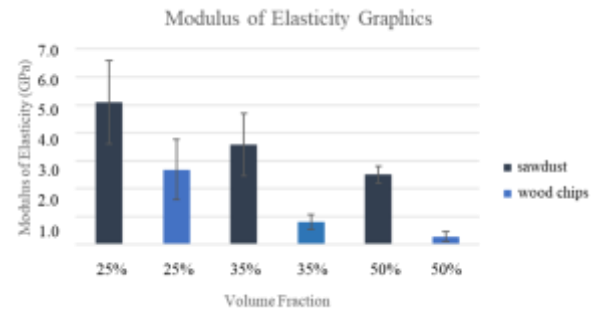

Fig. 5. Insulation test specimens with volume fraction

Fillers on composite materials have various influences, such as influence on mechanical properties in this study. The mechanical properties analyzed in this study are elasticity properties which will then be correlated with sound insulation properties in natural fiber composite materials of teak - polyester. The decrease in MOE in the volume fraction of 35% and also 50% can be caused by an increase in volume fraction. It seems increasing the volume fraction increases the cavity of the composite due to a matrix that does not bind the whole fillers. Cavities that occur will affect the decrease in flexural strength on the composite [11]. The existence of the cavity is a place where the stress concentration will be the place of initiation or the beginning of the crack so that the composite which experiences a MOE value should be low. The fractography discussion will be explained in the next section.

C. Sound Insulation Results

Sound insulation measurement has been done, which aims to determine the characteristics of composite materials according to the nature of sound insulation. Sound insulation testing uses a sound tube that uses a sound level meter as a measuring instrument. The sound tube is equipped with insulation to prevent sound leakage from outside or from inside so that the most accurate results are obtained and the sound source uses speakers that can be connected to the computer to regulate the frequency of sound used. The sound level meter has the accuracy in detecting noise from 30-130 dB.

From Fig. 6, it can be seen that the maximum value in the teak wood sample is at a frequency of 630 Hz with a value of 66.49 dB and the maximum value in the composite sample is in the sawdust reinforced composite sample with a 25% volume fraction of 79.91 dB at the frequency 500 Hz. The Sound Transmission Class (STC), the next will be known the performance of each composite material so that it can be correlated according to the application of the material, is obtained. The following STC value is attached in Table 1.

Then to analyze the effect of filler on the composite material used data from the sound insulation test results in order to determine the efficiency of the filler on the composite material. The effect of composite material composition can affect the ability of sound insulation. After testing the sound

insulation that adopts the ASTM E90 standard, the test results obtained in Table 1 and visualized in Figs. 6-9 which shows the effect of material behavior on sound propagating through composite material under dynamic and static frequency conditions.

Based on data from Table 1 and Fig. 7, it can be seen that the powder-strength composite material with a volume fraction of 25% has a maximum sound insulation value with a value of 79.91 dB at a frequency of 500 Hz, but at a frequency that exceeds or decreases from 500 Hz there is a significant decrease in value, so that this composite material is more efficient to be used in applications with static frequency sound sources.

The nature of sound insulation can be influenced by several factors, one of which is porosity. Porosity is a cavity or space inside a composite. Porosity can be formed through the manufacturing process (foam) or naturally. Previous studies have shown that porosity can be affected by the volume fraction of fibers in the composite. According to Liu, in his study, said that the nature of sound insulation would increase when finding the porosity in the composite [12]. Moreover, the nature of sound insulation will increase along with the increasing volume fraction of the composite fiber [13].

Based on ASTM E413, the minimum value required for car interior components according to ISO 717 standards is 33 [14]. In this study, composites that meet these qualification standards are powder-strength composites with a volume fraction of 35% and 35% with values of 33 and 35, and composite shavings with 50% volume fraction with a value of 36.
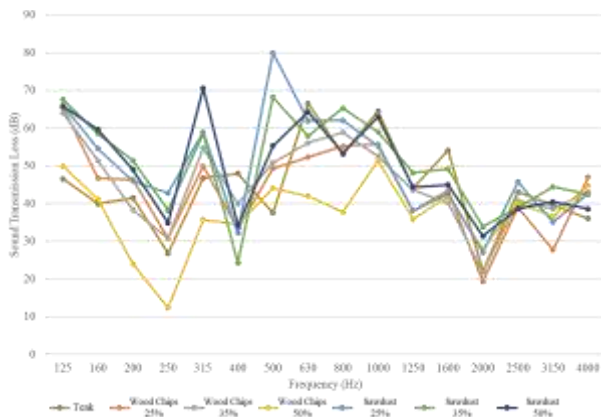
Fig. 6. Comparison Graph of STL Value

TABLE I. VALUE OF STC

Sample	STC Value	Quality
Teak Wood	23	Bad
Wood Chips 25% Composite	23	Bad
Sawdust 25% Composite	31	Bad
Wood Chips 35% Composite	25	Bad
Sawdust 35% Composite	33	Good
Wood Chips 50% Composite	36	Good
Sawdust 50% Composite	36	Good

D. Fractography

In Fig. 7, it can be seen that there are differences in the number of cavities or porosity formed. The highest volume fraction of 50% has a greater porosity compared to the volume fraction of 35% and also 25%. Therefore, with the number of voids or porosity formed, crack initiation will be more comfortable [15]. The voids that occur in the matrix are very dangerous because in that part the amplifier is not supported by the matrix, whereas the matrix will always transfer the stress to the reinforced. The cause is the emergence of cracks so that the composite will fail early. The strength of the composite against voids is proportional to the more void the composite will be more fragile, and if the composition of voids is less the composite will be stronger. Voids can also affect the bond between the particle and the matrix, which is a gap in the fiber or imperfect shape of the fiber which can cause the matrix to be unable to fill the space in the mold. If the composite receives a load, then the stress area will move to the void region so that it will reduce the strength of the composite.

To facilitate the fractography analysis, the SEM has been conducted as shown in Figs. 8-9. The magnification used for the instrument is from 250 until 300 times. From the images, the dominant defect that occurred after the bending test is debonding, interface gap, fiber pull-out, matrix cracking, and micro void. It seems the more volume fraction and shape, the more defect existed.
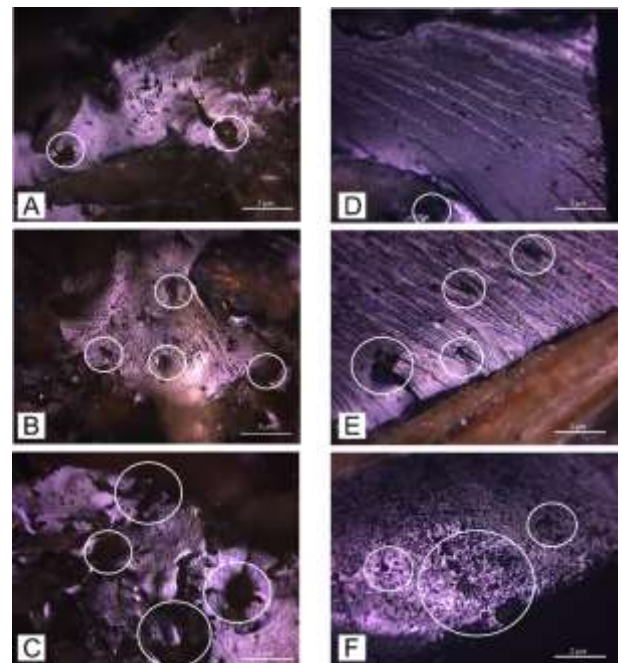
Fig. 7. OM test results for (a) Sawdust 25%, (b) Sawdust 35%, (c) Sawdust 50%, (d) Wood Chips 25%, (e) Wood Chips 35%, and (f) Wood Chips 50%

The factor of making composite specimens and distribution of fibers can cause a decrease in the flexibility value of composite hand lay-up manually [8]. It is because when the process of making composite materials with the manual hand lay-up method, there will be a tendency for fibers

to gather at a certain point and uneven fiber distribution. The decrease in the strength of the modulus of elasticity can also be caused by the reduced ability of the polyester matrix to be able to distribute stress along with an increase in the fiber volume fraction.

Based on the results of the data that has been shown in Fig. 5, there is a difference in the strength of the modulus of elasticity between the sawdust reinforcement composite and chip wood reinforcement composite. The sawdust reinforced composite owns the maximum value. The reinforcement of composites with filler particles causes an increase in stiffness, which results from rigid particles in soft elastomeric matrices and crosses bonds in the matrix particle interface [16]. The properties of fillers that affect mechanical properties include particle size, aggregate size, morphology or structure, and surface characteristics. The compatibility of the filler can only be achieved if the filler is well dispersed in the polymer matrix. The role of particles in particle composites is to divide the load so that it is distributed evenly in the material and inhibits the deformation of the plastic matrix contained between the particles. Composite with sawdust reinforcement also has a greater surface area compared to wood chips reinforced composites so that the powder-reinforced composite material will have a better ability to accept the stress distributed by the matrix along with an increase in the surface area of the fiber. This shows that the fill particle size also influences composite materials and particle size can also affect the ability to disperse and distribution on the material to increase uniformity in load distribution.
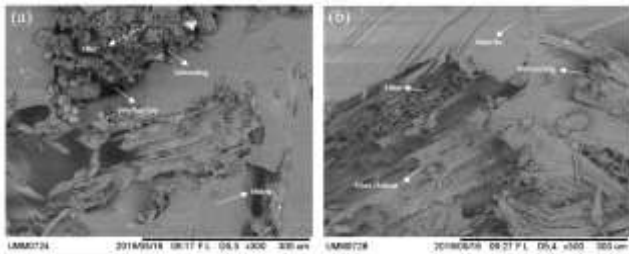

Fig. 8. SEM Images for 25% volume fraction (a) Sawdust Reinforced Composite and (b) Wood Chips Reinforced Composite
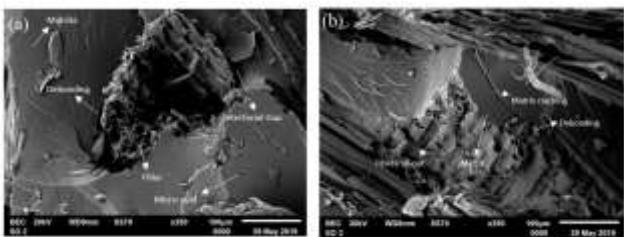

Fig. 9. SEM Images for 50% volume fraction (a) Sawdust Reinforced Composite and (b) Wood Chips Reinforced Composite

IV. Conclusion

The volume and shape fraction of fiber in teak reinforced composite materials affects the sound insulation properties. The STC value will increase along with the volume fraction in the composite. While the volume and shape of the fiber in the teak reinforced composite material affect the value of the modulus of elasticity (MOE). The MOE will decrease with increasing volume fraction in the composite.

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