

# Masturi\_MEX

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## The effect of polyurethane binder and glass fiber reinforcement on physical and mechanical properties of mahogany (*Swietenia mahagoni*) leaves waste biocomposite

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### ABSTRACT

In this work, the effect of polyurethane binder and glass fiber as reinforcement on the physical and mechanical properties of mahogany (*Swietenia mahagoni*) leaves waste as biocomposite was investigated. Mahogany leaves waste has been successfully synthesized into a strong and lightweight biocomposite material by using a polyurethane binder and glass fiber as reinforcement. The mass content of polyurethane was varied between 0.25–1.50 g to obtain the optimum conditions. The contents of glass fiber added were between 0.1–0.5 g for biocomposite reinforcement. The addition of polyurethane and glass fiber mass fraction on biocomposite from mahogany leaves waste affected the physical and mechanical properties. The optimum ratio of mahogany leaves waste and polyurethane binder to produce biocomposite showed a compressive strength of 41.59 MPa, a density of 1.060 g/cm<sup>3</sup>, water absorption of 6.98%, and a thickness development of 7.27%. The addition of glass fiber material was proven to increase the compressive strength of biocomposites to 57.68 MPa. The addition of glass fiber to biocomposites also succeeded in improving physical properties. The testing of glass fiber reinforced biocomposites resulted in a density of 1.140 g/cm<sup>3</sup>, water absorption of 5.42%, and thickness development of 8.18%.

**Keywords:** Biocomposite, Mahogany Leaves, Polyurethane, Glass Fiber.

### 1. INTRODUCTION

Composite are widely applied in various fields [1–3], one of which is a wood particleboard replacement [4]. Composite is a material that contains at least two different components, clearly separated one from another and uniformly filling its volume, produced in order to create particular

properties [1, 5]. Composites from natural materials are referred to as biocomposites, which are mostly used as packaging films in the industry [1, 4, 6]. Mahogany leaves are one of the natural materials, which is organic waste that can be developed into biocomposite material. The mahogany leaves were chosen because of its abundant availability in nature, and its suitable quality to be used as a wood substitute particleboard. The abundant cellulose

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content in mahogany leaves waste has the potential further development into new and more efficient materials, for example, composite as a substitute for wood in the form particleboard.

Composite particleboard has more advantages than ordinary wood boards. Its particle size and density can be adjusted to the necessity, free defects such as eye wood have isotropic properties, and quality can be regulated [7]. On the other hand, the composites are unable to restrain the shock loads and crash, non-weather-resistance, and low tensile strength [8]. The quality of the composite particleboard can be improved by providing fiber reinforcement. In general, fiber is divided into two kinds, natural and synthetic fibers. Synthetic fibers are fibers made from inorganic materials with specific chemical compositions. These fibers have many benefits, such as the relatively uniform properties and size, and the high compressive strength produced [9]. The synthetic fiber which often used is glass fiber. This fiber has been widely used as a reinforcement material for polymer composites. For example, glass fiber-reinforced on polyurethane composites have many applications in the areas of infrastructure (housing panels, bridge decks) and marine applications [10]. Moreover, it has a low price, high tensile strength, chemical resistance, and excellent insulation properties [11].

The factors affecting the properties of the composite include the type and shape of particles, density, compressive strength, filler, and binder used [12]. Another factor affecting the quality of composites is water absorption. The high density of composite shows a more compact bond between the particles so that the air cavity will be smaller. This condition makes it difficult for water and air vapor to fill the air cavity in the composite. Therefore the water absorption becomes small. Low water absorption indicates better composite stability [13]. In this research, microscopic studies approach was also carried out to determine the interaction between the compounds making up the biocomposite. This interaction can be observed by analyzing the FTIR spectrum in the band shift. Consequently, the van der Waals interaction energy could be obtained [14]. The interaction will be studied whether it affected the physical and mechanical properties of the biocomposites, which have been added to polyurethane binders and glass fiber reinforcement.

## 2. EXPERIMENTAL DETAILS

### 2.1. Materials

The mahogany (*Swietenia mahagoni*) leaves waste was collected from Universitas Negeri Semarang, Semarang, Indonesia. Commercial polyurethane polymers and glass fiber were purchased from Bratachem, Semarang, Indonesia, used as a binder and reinforcement materials, respectively. All the chemicals used in these studies were pure analytical reagents from Merck.

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### 2.2. Sample Preparation

The mahogany (*Swietenia mahagoni*) leaves waste was cleaned with water, then dried at 50–60 °C temperature for 60 minutes. The dried mahogany leaves were pulverized using a grinder machine.

### 2.3. Synthesis of Biocomposite/Polyurethane

First, 15 g powder of Mahogany leaves waste was weighed. Then, the mass fraction of polyurethane was varied by 0.25, 0.5, 0.75, 1.00, 1.25, and 1.50 g. Waste leaves are mixed with polyurethane until evenly distributed. Leave waste composites, and polyurethane polymers were pressed using a hydraulic press with a pressure of 4 tons for 15 minutes. Finally, the sample-produced was dried naturally for 24 hours.

### 2.4. Synthesis of Reinforced Biocomposite Using Glass Fiber

Leave waste that has been refined weighed with a mass of 15 g is kept constant. The mass of glass fiber is varied by 0.1, 0.2, 0.3, 0.4, and 0.5 g. Waste leaves are mixed with polyurethane and glass fiber until evenly distributed. Composites are pressed using a hydraulic press with a pressure of 4 tons for 15 minutes. The sample-produced was dried naturally for 24 hours.

### 2.5. Characterization Biocomposite

Characterization of the samples was carried out by compressive strength, density, water absorption, and thick development, the interaction between compounds, chemical content, and morphology of glass fiber cross-section. Compressive strength testing using Universal Testing Machine (UTM) was carried out in the Physics Laboratory of the Bandung Institute of Technology and followed by testing the density, water absorption, thick development, Fourier Transform Infrared (FTIR), Scanning Electron Microscopy/Energy Dispersive X-ray (SEM/EDX).

### 2.6. Statistical Analysis

The experimental data was performed using a one-way analysis of variance (ANOVA). Data were expressed as the mean  $\pm$  standard deviation ( $n = 3$ ). Homogenous groups and the least significant difference (LSD) were determined at the significance level of  $p \leq 0.05$ . All statistical analyses were performed using SPSS 24 software.

## 3. RESULTS AND DISCUSSION

In this study, the mahogany leaves waste used has moisture content of  $6.61 \pm 0.69\%$  (w/w) as a raw material for making biocomposites shown in Table I. The largest component of the mahogany leaves comes from total carbohydrates of  $74.18 \pm 1.12\%$  (w/w). Total carbohydrates are identified from amylose and cellulose. However, the iodine test results, mahogany leave powder did not show

**Table I.** Proximate composition of mahogany (*Swietenia mahagoni*) leaves waste in Indonesia.

Component	Mahogany leave waste in this study (%) <sup>a</sup>		
	West Java	Central Java	East Java
Crude protein	5.10 ± 0.80	5.17 ± 0.79	5.15 ± 0.79
Total carbohydrates	74.10 ± 1.12	74.18 ± 1.12	74.15 ± 1.12
Crude fat	4.10 ± 1.10	4.14 ± 1.15	4.15 ± 1.15
Moisture content	6.60 ± 0.65	6.61 ± 0.69	6.63 ± 0.60
Ash	9.80 ± 0.60	9.90 ± 0.65	9.90 ± 0.65

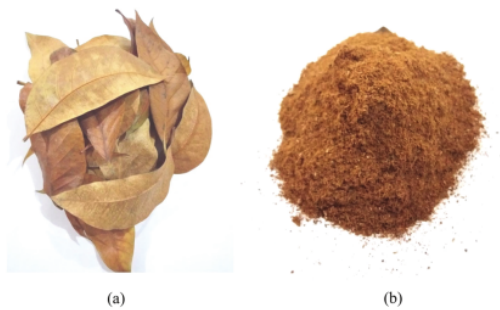
<sup>a</sup> *Notes:* Treatment means of the ANOVA test. Values were expressed as the mean ± standard deviation of three replications. The mean difference is significant at the  $p \leq 0.050$ . \*Means are significantly different in the different place in Indonesia at the  $p = 0.000$ .

a color change to blue or purple. This indicates that the total carbohydrate comes from the cellulose component. Biocomposite raw materials for mahogany leave waste are obtained from three provinces in Indonesia, namely West Java, Central Java, and East Java. Table I shows that the main component of mahogany leave waste can not differ much from the three provinces in Indonesia. The raw material of mahogany leave waste and its powder used in this study are shown in Figure 1.

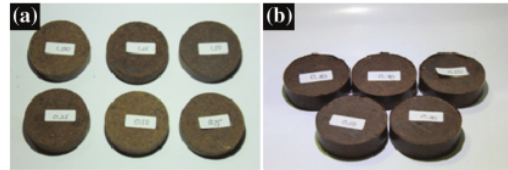
Biocomposites of leaves waste with glass fiber reinforcement morphologically has denser pores than biocomposites of leaves wastes without glass fiber reinforcement. It has shown in Figure 2.

### 3.1. Compressive Strength Test

The compressive strength distribution of leaves wastes as biocomposites with polyurethane polymers as a binder was ranged from 23.68 to 41.59 MPa. The highest compressive strength occurs in the polyurethane mass fraction of 1.25 g, resulting in 41.59 MPa, while the lowest compressive strength is in the fraction of 0.25 g, which is equal to 23.68 MPa are shown in Figure 3. Biocomposites with low polyurethane mass fraction have a small compressive strength.



**Fig. 1.** Pictures of mahogany (*Swietenia mahagoni*) (a) raw material of mahogany leave waste and (b) powder with a particle size of 0.149 mm and moisture content = 6.61 ± 0.69%.



**Fig. 2.** The morphology of (a) biocomposites/polyurethane and (b) reinforced biocomposites using glass fiber.

The addition of the polyurethane mass fraction increased the compressive strength of the biocomposite until it reaches the optimum conditions are shown in Figure 3(a). In this condition, interactions between particles are spread evenly across the entire surface area of the biocomposite. Filler particles and polyurethane interact effectively. The addition of a mass fraction of one phase resulted in the emergence of areas that did not interact [4, 15]. The maximum compressive strength obtained from biocomposites of mahogany leaves waste using polyurethane polymers was higher than the research of Fuqua et al. [9] that composites made from the powder of glass waste with polyurethane binders have a maximum compressive strength of 40 MPa [9].

The addition of the glass fiber mass fraction increased the compressive strength of the biocomposite, which was quite good. Compressive strength in Figure 3(b) occurs in the range of 38.39 to 57.68 MPa. The optimum mass fraction was obtained at a mass of 0.4 g with a compressive strength of 57.68 MPa. Under optimum conditions, the compressive strength of leave waste as biocomposites with glass fiber reinforcement better than that of rice husks composite having 12–16 MPa [16], composites of wood paper waste with polyvinyl chloride with 51.71 MPa [17] and particleboard composites using urea-formaldehyde polymers which reached a maximum of 16.77 MPa [18].

### 3.2. Density Test

Values range of density from 0.931 to 1.060 g/cm<sup>3</sup>, is shown in Figure 4(a). The lowest density was found in biocomposites with polyurethane mass fraction of 0.25 g, which were 0.931 g/cm<sup>3</sup>, while the highest density at a mass of 1.25 g was 1.060 g/cm<sup>3</sup>. The condition with the highest density was called by the optimum point, which was the composition condition of the binder and filler can interact adequately. The air cavity influenced the low-density value in the matrix layer.

The addition of the glass fiber mass fraction was caused the increase in the density of mahogany leaves waste biocomposite. The increase occurred due to the addition of new material in the biocomposite is shown in Figure 4(b). The smallest density value of biocomposite occurs in the addition of 0.1 g of glass fiber, that was 1.110 g/cm<sup>3</sup>, while the highest density value was found by adding

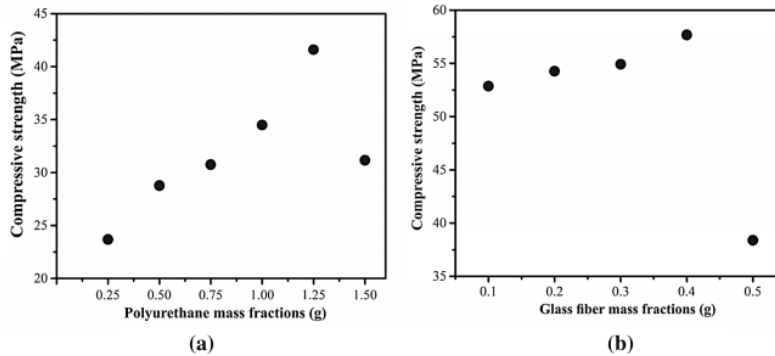


Fig. 3. Compressive strength of biocomposite from mahogany leaves waste in variations mass fraction of (a) polyurethane binder and (b) reinforced using by glass fiber.

0.4 g of glass fiber to the leave waste mass of 15 g and polyurethane mass of 1.5 g that was  $1.140 \text{ g/cm}^3$  are shown in Figure 3(b). Particleboard density depends on the material used, the pressure applied, and the porosity. The value of the density produced by the biocomposite of mahogany leaves waste with polyurethane polymers completed the requirements of the Indonesian National Standard of composite (SNI 03-2105-1996) [19] and American Standard Testing and Material (ASTM D3039/D3039M) that are equal to  $0.5\text{--}0.9 \text{ g/cm}^3$  [20].

### 3.3. Water Absorption Test

Figure 5 provides information about the highest water absorption shown in the lowest polyurethane mass fraction at the mass of 0.25 g. Biocomposite with high of polyurethane mass fraction has low water absorption of 6.98% at the polyurethane mass fraction of 1.25 g.

The addition of a polyurethane binder has resulted in inhibition of the rate of water absorption biocomposites. High-density of biocomposite has strong bonding between

particle and binder molecules, so the water molecules are difficult to leak cavities contained in biocomposite boards. Meanwhile, large cavities exhibit a range of valuable properties like a low density in composites such as Kausar [21], which tested the density of polyurethane foam [21]. The size of density composite effect on water absorption. The water absorption rate can be approximated using the equation model:

$$\frac{dN}{dt} = -\alpha N \quad (1)$$

$\alpha$  is the constant of water absorption in a biocomposite sample. After doing a mathematical calculation, a constant value of the water absorption rate of biocomposite was  $3.314e^{-1.01778t}$ .

Figure 5 shows the effect of adding glass fiber material to water absorption. Initially, glass fiber with a mass content of 0.1 g has 7.30% of water absorption. The following addition of glass fiber content has resulted in a decrease in water absorption, such as the water absorption of biocomposites with a glass fiber mass of 0.4 g was 5.42%.

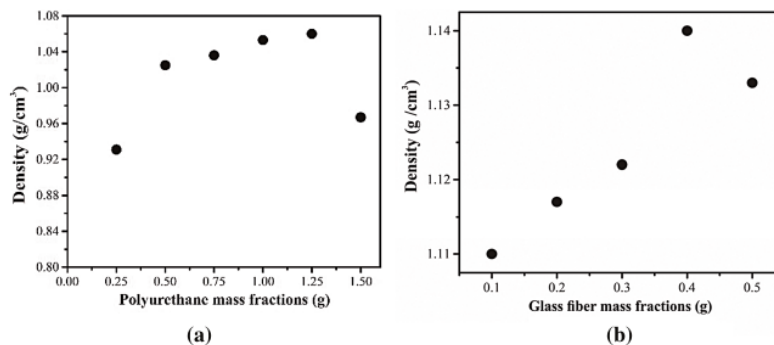


Fig. 4. The density of biocomposite from mahogany leaves waste in variations mass fraction of (a) polyurethane binder and (b) reinforced using by glass fiber.

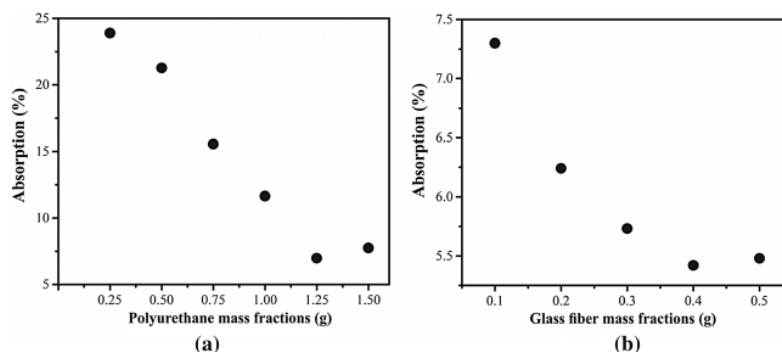


Fig. 5. Water absorption of biocomposite from mahogany leaves waste in variations mass fraction of (a) polyurethane binder and (b) reinforced using by glass fiber.

In occurs since the addition of glass fiber material into the biocomposite causes interference between the particles in the biocomposite. Further, the water absorption rate of glass fiber in biocomposite was approached by using equation model (1) of  $dN/dt = -\alpha N$ , so it gets a value of  $32.314e^{-1.01178t}$ .

The high water absorption indicates that the glass fiber was not spread evenly throughout the biocomposite surface. Furthermore, the crosslinking contained in the polyurethane reaction affected water absorption.

### 3.4. Thickness Development Test

As shown in Figure 6(a), biocomposites with a polyurethane mass fraction of 0.25 g had 24.17% of thickness development. The following addition of polyurethane mass fraction shows a decrease in thickness development. Optimum conditions occurred in biocomposites with a polyurethane mass fraction of 1.25 g, which developed 7.27% of the thickness. Thickness development decreases

proportionally to the addition of the polyurethane mass fraction.

The addition of glass fiber material affected the thickness development of biocomposites from mahogany leaves waste, as shown in Figure 6(b). Biocomposites with mass fraction glass fiber of 0.1 g had 12.50% of thickness development. The following addition of glass fiber mass fraction has decreased the thickness development. The optimum condition was found in the biocomposite of mahogany leave waste with 0.4 g of glass fiber, which only has 8.18% of thickness development. Thickness development before being given glass fiber has an average of 15.43%, whereas after being given a glass fiber reinforcement, the average thickness development was 9.656%. The addition of glass fiber to the biocomposite from mahogany leaves waste can improve the quality of the biocomposite particle-board. Indonesian National Standard (SNI 03-2105-2016) and American Standard Testing and Material (ASTM D 3039/D 3039M) [19, 20] requires that the strength of the composite board thickness be developed at the optimum

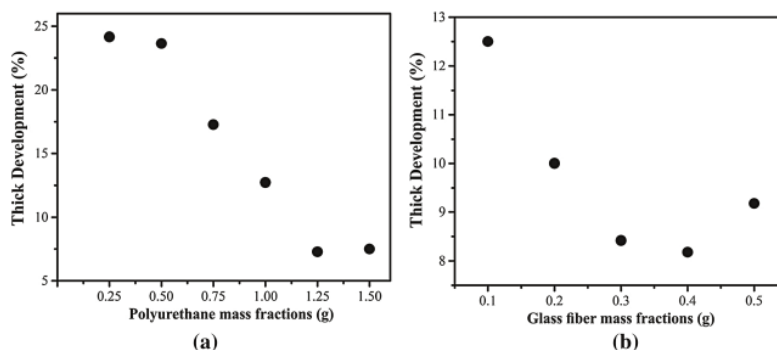


Fig. 6. Thickness development of biocomposite from mahogany leaves waste in variations in the mass fraction of (a) polyurethane binder and (b) reinforced using by glass fiber.

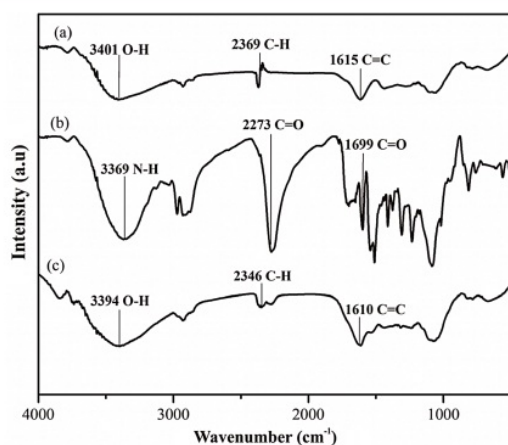


Fig. 7. FTIR spectrum of (a) mahogany leaves waste, (b) polyurethane binder, (c) biocomposite from mahogany leave waste with polyurethane binder.

condition  $\leq 14\%$ . The thickness development of biocomposite from mahogany leaf waste was averaged 9.656%. This shows that the biocomposite of mahogany leaf waste can be applied as composite particleboard.

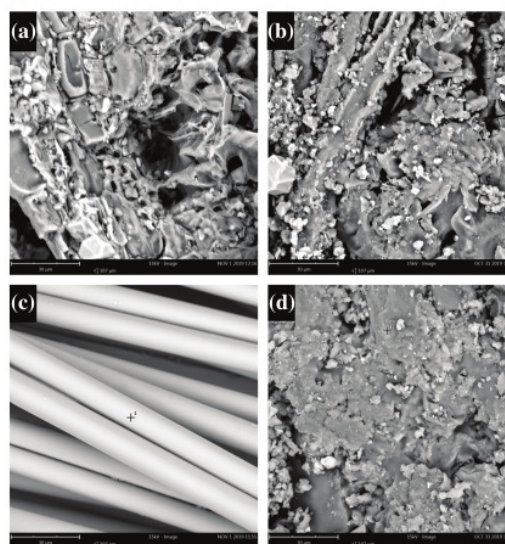


Fig. 9. SEM image of (a) mahogany (*Swietenia mahagoni*) leaves waste, (b) biocomposite of mahogany leaves waste using polyurethane binder, (c) glass fiber, and (d) biocomposite of mahogany leaves waste using polyurethane binder and glass fiber reinforcement.

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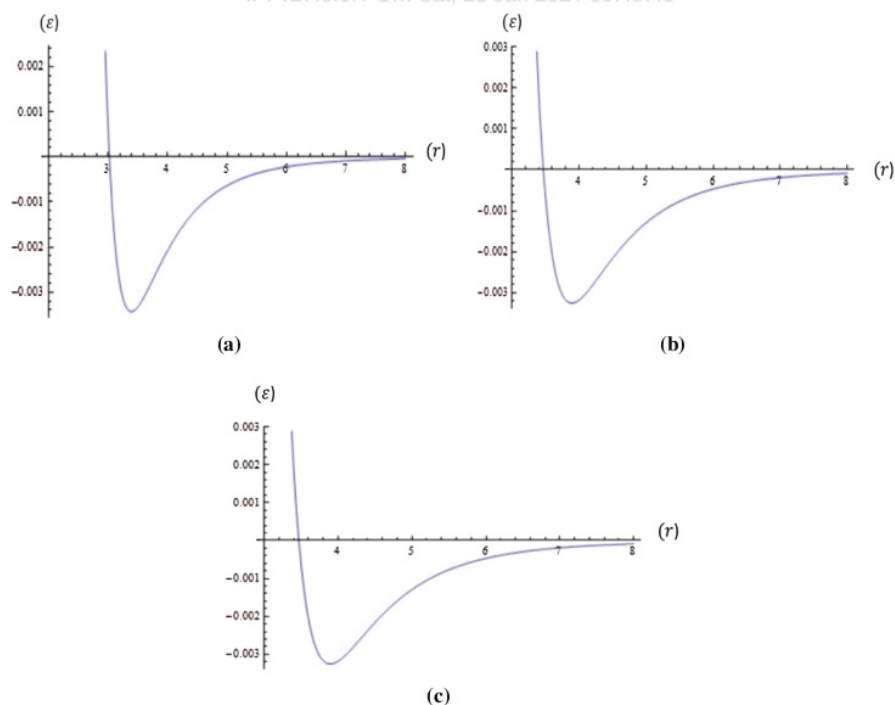


Fig. 8. Interaction of functional groups (a) NH with OH (b) C=O with CH and (c) C=O with C=C.

3.5. Interaction Between Biocomposite from Mahogany Leaves Waste Bonds with Polyurethanes Binder

The FTIR spectrum in Figure 7(a) informed the broadband at wave number  $3401\text{ cm}^{-1}$  is a typical O–H strain band [22]. This broadband was indicated hydroxyl groups that are typical of the hydroxyl group in cellulose [23].

The mahogany leaves waste also showed at the peak of  $1615\text{ cm}^{-1}$ , which identified as the C=C bond that showed functional groups of the aromatic conjugated carbonyl. These data suggest the presence of flavonoid compounds substituted by hydroxyl groups and bound to cellulose structure [24–25].

Figure 7(b) is the FTIR spectrum of a polyurethane binder, at a wavelength of  $3369\text{ cm}^{-1}$  there was a peak N–H bond [26]. C=O peaks are at wavelengths of  $2273$  and  $1699\text{ cm}^{-1}$ , which are carboxyl groups in polyurethane [27]. The FTIR spectrum shows that the biocomposite from mahogany leave waste was in the wavelength range of  $671.15$  to  $3839.14\text{ cm}^{-1}$ .

Polyurethane binder has two active functional groups, namely carboxyl and amino groups [4, 15]. The shift began to occur at wave number  $3369$  to  $3394\text{ cm}^{-1}$ , which identified the O–H bond (hydroxyl group) in Figure 8(a).

The distance of van der Waals interaction between the N–H bond of polyurethane and the O–H bond of the mahogany leaves waste. The atom vibrates from a distance of  $3.23$  to  $3.62\text{ \AA}$  with a balance point of  $3.38\text{ \AA}$ .

The next shift occurs at wavelengths of  $2273$  to  $2346\text{ cm}^{-1}$ , as shown in Figure 8(b). The carboxyl groups in polyurethane shift due to interference with CH bonds from compounds in mahogany leaves waste. O atom is electronegative while H atom is more electropositive so that between dipoles and dipoles, van der Waals interactions occur. The vdW energy from this shift is  $9.05 \times 10^{-3}\text{ eV}$ . The van der Waals interaction of O and H atoms ( $\sigma_{\text{O-H}} = 3.02\text{ \AA}$  dan  $\epsilon_{\text{O-H}} = 3,43 \times 10^{-3}\text{ eV}$ ) causes the atom to vibrate from a distance of  $3.06$  to  $4.46\text{ \AA}$  with a balance point of  $3.38\text{ \AA}$ .

The shift occurred at the C=O bond, as shown in Figure 8(c). The C=O bond shifted from  $1699$  to  $1610\text{ cm}^{-1}$  due to interference by the C=C bond on a compound of mahogany leave waste. The vdW energy of this shift is  $1.12 \times 10^{-3}\text{ eV}$ . The van der Waals interaction between the C and O atoms ( $\sigma_{\text{C-O}} = 3,47\text{ \AA}$  dan  $\epsilon_{\text{C-O}} = 3,25 \times 10^{-3}\text{ eV}$ ) produces atoms formed vibrated from a distance of  $3.52$  to  $4.34\text{ \AA}$  with a balance point of  $3.89\text{ \AA}$ .

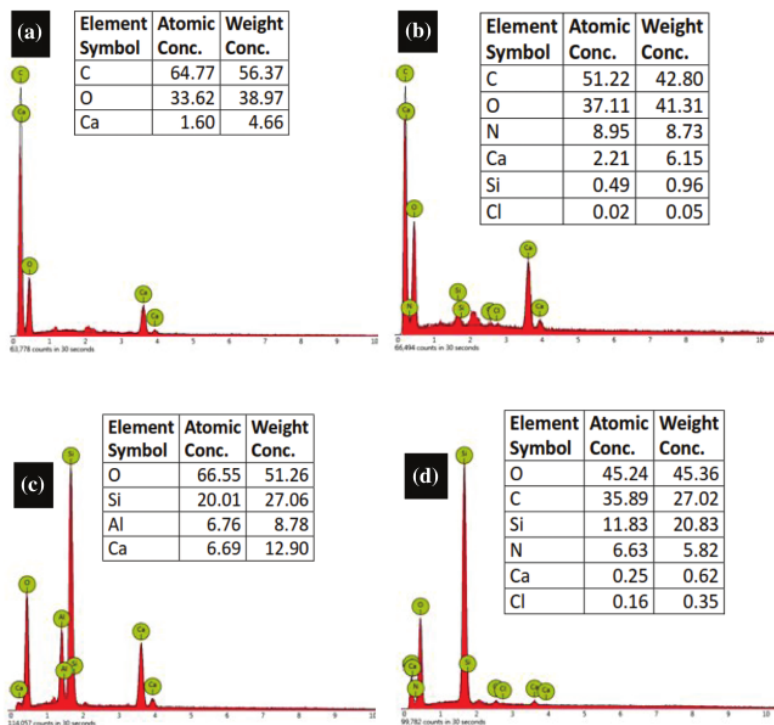


Fig. 10. EDX of (a) mahogany (*Swietenia mahagoni*) leaves waste, (b) biocomposite of mahogany leaves waste using polyurethane binder, (c) glass fiber, and (d) biocomposite of mahogany leaves waste using polyurethane binder and glass fiber reinforcement.



### 3.6. Biocomposite/Polyurethane/Glass Fiber

Surface scanning electron microscope (SEM) analysis was performed to see the morphology of the surface structure of the biocomposite produced (Fig. 9(b)) by comparing the initial morphology of the mahogany leaf waste shown in Figure 9(a). The use of polyurethane polymers used as binders from the morphology of the two images is clearly seen that the pores of mahogany leaves are becoming tighter. Polyurethanes act successfully as adhesives between molecules present in mahogany leaves, so that it can produce a biocomposite from mahogany leaf waste material.

However, there are still visible pores in the biocomposite produced. These pores will weaken compressive strength. Also, water can easily go into the biocomposite, make it fragile and not durable. To overcome this problem, biocomposite added glass fiber as an amplifier. The surface morphology of the glass fiber is shown in Figure 9(c). The addition of glass fiber has succeeded in closing the

pores of the biocomposite/polyurethane shown by a tightly closed and more compact morphology (Fig. 9(d)).

The success of biocomposite synthesis from mahogany leaf waste was also evidenced by the EDX results shown in Figure 10. It is clearly seen that the content of mahogany leaves (Fig. 10(a)) consists mainly of C 56.37 wt% and O 38.97 wt%, which can be derived from polysaccharide compounds, namely cellulose. The addition of polyurethane into the biocomposite reduces the element of C and O contents to 42.80 and 41.31 wt%, respectively. This reduction occurs due to the addition of polyurethane polymers into mahogany leaf material so that there is an interaction with the structure of polyurethane compounds, mainly from the N element into the cellulose structure, which is the largest component in mahogany leaves. This can be seen by the addition of N elements in the biocomposite of 8.73 wt% originating from the polyurethane structure. The glass fiber component is mainly Si at 27.06 wt% (Fig. 10(c)). The addition of glass fiber to the biocomposite/polyurethane was also

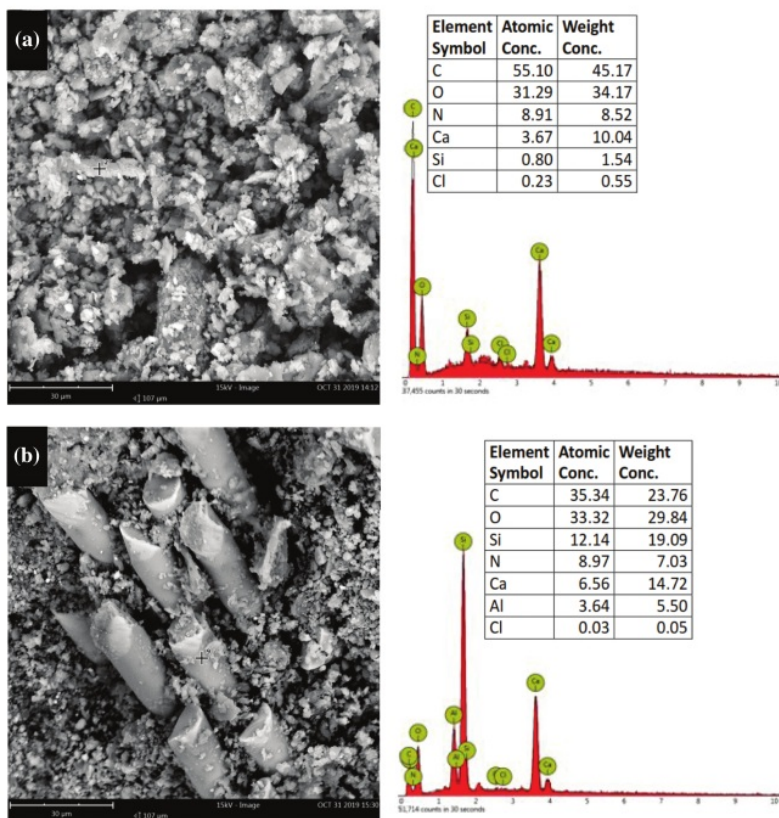


Fig. 11. SEM/EDX image cross section of (a) biocomposite of mahogany leaves waste using polyurethane binder and (b) biocomposite of mahogany leaves waste using polyurethane binder and glass fiber reinforcement.

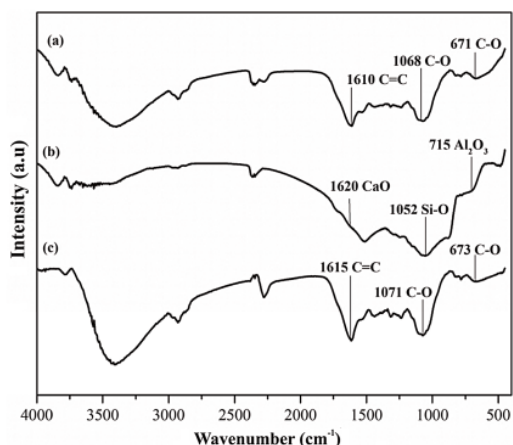


Fig. 12. FTIR spectrum of (a) mahogany leaves waste/polyurethane, (b) glass fiber (c) biocomposite from mahogany leaves waste/polyurethane/glass fiber.

shown by the results of EDX measurement, as shown in Figure 11. Figures 11(a) and (b) show mahogany (*Swietenia mahagoni*) leaves waste and glass fiber SEM-EDX spectroscopy, respectively. Further, the role of glass

fiber in this composite was confirmed by comparing biocomposite/polyurethane without glass fiber (Fig. 10(b)) and with glass fiber (Fig. 10(d)), where the glass fiber in the micro section cross-section was clearly observed that Si element content in the composite is 20.83 wt%.

The emergence of bonds and interactions in the biocomposite of mahogany leaves waste with the polyurethane binder, and glass fiber reinforcement was characterized using the FTIR spectrum. The peaks on the glass fiber are known to be  $1620\text{ cm}^{-1}$ , namely Ca-O [28],  $1052\text{ cm}^{-1}$ , namely Si-O [29], and  $715\text{ cm}^{-1}$ , namely  $\text{Al}_2\text{O}_3$  [30]. The addition of glass fiber to the biocomposite from mahogany leaves waste/polyurethane gives the peak shift in the wavelength range, as shown in Figure 12.

The biocomposite peak of biocomposite from mahogany leaves waste/polyurethane/glass fiber has experienced a shift from  $1615$  to  $1620\text{ cm}^{-1}$ , as shown in Figure 12. The disruption of glass fiber material in the biocomposite from mahogany leaves waste/polyurethane/glass fiber caused a peak shift of  $5\text{ cm}^{-1}$  from the previous position. This disturbance was related to energy:  $\Delta E = hc\Delta l = 1.27 \times 10^{-3}\text{ eV}$ , where  $h$  = Planck constant and  $c$  = fast propagation of electromagnetic waves in a vacuum.

After mixing the glass fiber with the biocomposite from mahogany leaves waste/polyurethane, there was a shift

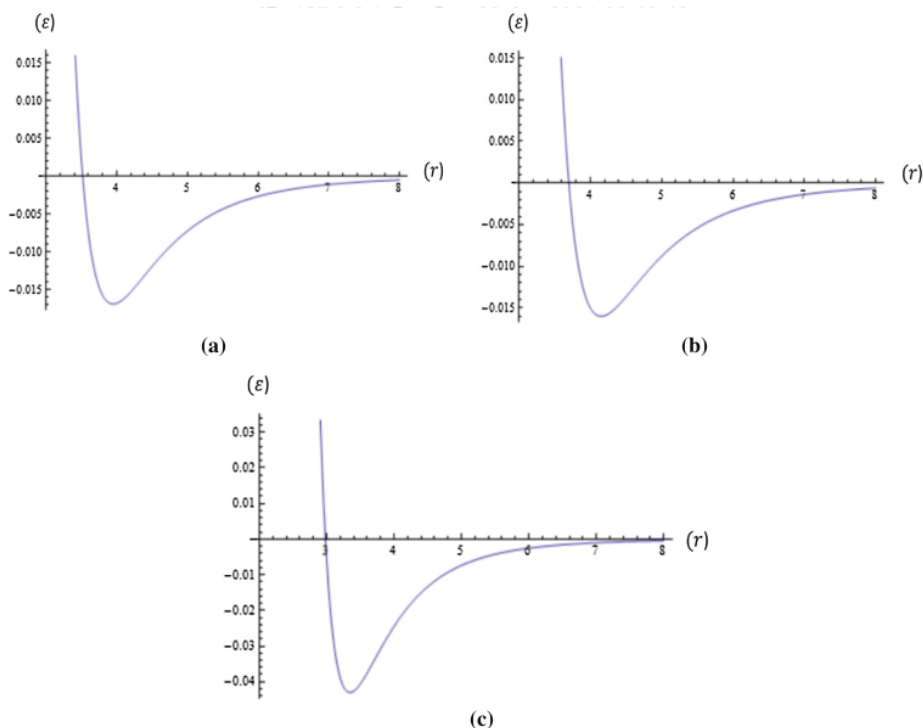
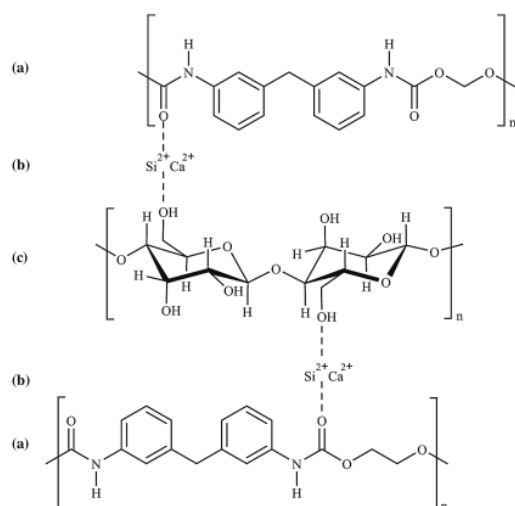


Fig. 13. Interaction of functional groups (a) Ca-O with C=C (b) Si-O with C-O and (c) Al-O with C-O.



**Fig. 14.** Illustration of van der Waals interaction (represented by a dashed line) between, (a) polyurethane's carbonyl group, (b) mineral in glass fiber, and (c) cellulose as the main of polysaccharide in mahogany leaves.

in the peak position. This shift indicates the van der Waals interaction between Ca–O and C=C, as shown in Figure 13(a). The interaction of Ca and C atoms ( $\sigma_{Ca-C} = 3.52 \text{ \AA}$  dan  $\epsilon_{Ca-C} = 1.69 \times 10^{-2} \text{ eV}$ ). The VdW energy of this shift was  $6.21 \times 10^{-4} \text{ eV}$ . The atom was experienced vibrations from a distance of 3.53 to 7.63  $\text{\AA}$  with a balance point of 3.95  $\text{\AA}$ .

The biocomposite gives a peak of  $1068.24 \text{ cm}^{-1}$  originates from the CO bond in the acetate group, whereas the peak  $1052.41 \text{ cm}^{-1}$  in glass fiber is the Si–O bond. This shift indicated the van der Waals interaction between silica and CO with the values of  $\sigma_{Si-O} = 3.07 \text{ \AA}$  and  $\epsilon_{Si-O} = 1.06 \times 10^{-2} \text{ eV}$  (Fig. 13(b)). The vdW energy of this shift was  $1.97 \times 10^{-3} \text{ eV}$ , which experienced vibrations from a distance of 3.53 to 6.31  $\text{\AA}$  with a balance point of 3.95  $\text{\AA}$ .

The peak of  $671 \text{ cm}^{-1}$  in biocomposite originates from the C–O bond, while the  $715 \text{ cm}^{-1}$  peak in glass fiber was the Al–O bond. Mixing glass fiber with biocomposite from mahogany leaves waste/polyurethane is a shift in the top position. This shift indicates the van der Waals interaction between Al and CO (Fig. 13(c)), where the value of  $\sigma_{Al-O} = 2.98 \text{ \AA}$  and  $\epsilon_{Al-O} = 4.30 \times 10^{-2} \text{ eV}$ , the vdW energy of the shift this was  $5.46 \times 10^{-3} \text{ eV}$  so that vibrations occur between 2.99 to 5.26  $\text{\AA}$  with a balance point of 3.34  $\text{\AA}$ .

Interaction between atoms was proven to be able to improve the physical and mechanical properties of mahogany leaves waste/polyurethane/glass fiber. This greatly affected the quality of the particleboard to be more durable, strong, and not easily damaged.

The increase in compressive strength biocomposites is governed by the interaction of forces in the main

compounds between mahogany leaf waste, polyurethane polymers, and glass fiber. Effective interactions can increase the strength of biocomposites. This van der Waals interaction arises between leaf waste with polymers or other additives, where optimal interaction occurs when all-polymer surfaces interact with the surface of leaf waste particles, and it makes maximum composite strength [31–33]. In this study, this interaction is illustrated in Figure 14, which illustrates the interaction between cellulose, which is the main component of polysaccharides in mahogany leaf waste with polyurethane polymers having carbonyl groups, and the Si<sup>2+</sup> and Ca<sup>2+</sup> cations which are the main components of glass fiber.

The interaction mainly occurs because the cation Si<sup>2+</sup> and Ca<sup>2+</sup>, which are components of glass fiber, become a bridge between the two polymers, namely cellulose in mahogany leaf and polyurethane. Oxygen in the hydroxyl group at C-6 of the cellulose compound is the most reactive functional group due to the presence of free electron pairs on the oxygen atom and its smallest steric barrier, making it possible to interact with Si<sup>2+</sup> and Ca<sup>2+</sup> cations. Because the cation load is 2+ so it is still able to interact with carbonyl groups in polyurethane polymers. The carbonyl group in polyurethanes is the most reactive functional group because it is the most electronegative among the other groups. This interaction is usually referred to as van der Waals style interaction, which plays a role in regulating composite strength [34–36].

#### 4. CONCLUSION

Mahogany leaves waste can effectively be processed into a lightweight and strong biocomposite material using polyurethane as a binder. Polyurethane was proven to be able to improve the physical and mechanical properties of biocomposites. The ratio optimum of mahogany leaves waste, and polyurethane binder showed a compressive strength of 41.59 MPa, a density of  $1.060 \text{ g/cm}^3$ , water absorption of 6.98%, and thickness development of 7.27%. The addition of glass fiber material was proven to be able to increase the compressive strength of biocomposites to 57.68 MPa. The addition of glass fiber to biocomposites also succeeded in improving physical properties. The testing of glass fiber reinforced biocomposite obtained a density of  $1.140 \text{ g/cm}^3$ , water absorption of 5.42%, and thickness development of 8.18%.

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