Properties of leaves particleboard for sheathing application

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Abstract. Manufacturing particleboard (PB) made of leaves was carried out to make non-structural building components, such as insulation, partition, wall, and sheathing. Raw materials used dry leaves originated from plantation (palm oil leaves) and forest plantation (mahogany leaves). The adhesive used was interior type thermosetting commercial resins, namely 10% urea-formaldehyde (UF) based on oven dry leaves. Hardener used for UF resin was 1% and 3% ammonium chloride (NH4Cl) 20% (w/w), respectively. Technically, the target density of PB was 0.8 g/cm3 with the dimension’s size of (250 x 250 x 10) mm3. The pressure, temperature, and time of pressing of the hot press were 25 kgf/cm2, 120°C, and 10 minutes, respectively. After conditioning for one week, the PB then was evaluated their physical and mechanical properties according to Japanese Industrial Standard (JIS) A 5908 (2003). Results of this work showed: 1) Both types of PB (palm oil and mahogany leaves) were feasible to be produced for non-structural applications; 2) Addition of hardener enhanced the physical and mechanical properties of PB; 3) It was recommended to enhance the performance of the PB by manipulation of the raw materials and the design.

Keywords: leaves particleboard, physical and mechanical properties, non-structural component

1. Introduction

In the tropical country particularly Indonesia, plantation forest’s model such as industrial plantation forest, man-made forest, and community forest yields large quantities of waste which predominantly thinning and pruning volumes comprising small diameter wood of branch and twig, bark, and leaves.

Some efforts have been made to utilize these residues as substitution of wood products, particularly for producing particleboard. For instance, Nuryawan et al. [1] used sawdust of acacia (Acacia mangium) wood from industrial plantation forest in Riau province as the raw material of particleboard. They applied urea-formaldehyde (UF) resin mixed with the isocyanate as the adhesive for producing an interior type of particleboard. Similar work has also been conducted by Muhdi et al. [2]. They employed logging waste as the raw material of particleboard. Either part of thinning or pruning was also an object of research on particleboard with three species of wood have been utilized, namely acacia, eucalyptus (Eucalyptus deglupta), and sengon (Paraserianthes falcata) [3]. Recently, Ruhendi & Putra [4] exploited part of trunk and branch of jabon wood (Anthocephalus cadamba Miq) as the main component of particleboard.

Success story on utilization of waste from forest and plantation for making panel products have been published by our group research, for example: volume of thinning and pruning of acacia and...
eucalyptus wood [5]; small diameter and inferior logs [6]; residue of forest harvesting [7]; and waste of oil palm (*Elaeis guinensis*) trunk [8]. It was concluded that the particleboard could be effectively manufactured on an industrial scale using wood residue and lignocelluloses materials such as vascular bundles of oil palm trunk.

On the other hand, waste of plantation and forest comprise of not only lignocelluloses but also leaves. In this work, we attempted to make panel products particularly particleboard made of leaves of mahogany and oil palm. Because of the abundance of waste leaves originated from plantation and forest as well as the eagerness to utilize these residues, this research is dedicated to developing panel products made of non-wood. Furthermore, application of these products is for sheathing applications such as wall and ceiling panels, office dividers, bulletin boards, cabinets, furniture, insulator, coater, counter tops and desk tops [9].

The objective of this study was to evaluate the quality of the panel products made of leaves of mahogany (*Swietenia macrophylla*) and oil palm (*E. guinensis*). In addition, the discussions for improving the physical and mechanical properties have been presented.

2. Materials and Methods

2.1. Primary Materials

In this contribution, dry-leaves of mahogany (*S. macrophylla*) (Fig.1a,b) was collected from mahogany forest plantation at the university campus (Hutan Tri Dharma). So, the dry-leaves residue of oil palm plantation was compiled along the street of Jalan Tri Dharma at the university campus as well, which oil palm tree grows (Fig.1c,d). In fact, both of these materials were dried naturally by sunlight. In order to make uniform, these materials were then oven-dried under temperature of 103°C for 24 hours. Further, these materials have also been sieved under size of 4 mesh.
Figure 1. (a) Dry-leaves residue of mahogany forest  (b) Oven-dry mahogany leaves as the materials in this study   (c) Dry-leaves residue of oil palm plantation (d) Oven-dry oil palm leaves as the materials in this study.

2.2. Methods
In this research, the procedure of particleboard production was as follows:
1. Raw materials preparation
   The raw materials were consisted of leaves particle as explained in the primary materials with containing 5% moisture content, UF resins as adhesive, and ammonium chloride (NH₄Cl) as the hardener.
2. Blending process
   The amount of leaves particle needed for one board will be weighed after screening and drying. The particle will be put into a rotary blender and mixed with resin by means called a spray gun. The target of board thickness will be 1 cm and the density 0.80 g/cm³. UF resin’s solid content was 60%, and the level of resin was 10% based on oven dry particle weight. Both 1% and 3% hardener of NH₄Cl were added in the form of aqueous with concentration of 20%wt.
3. Mat forming and hot pressing
   After the blending process, the furnish (the mixture of leaves particle, adhesive, and hardener) will be hand formed into a mat. Both top and bottom surfaces of the furnish mat will be covered with aluminium foil sheets for hot pressing. Pressure value was 25 kg/cm², pressing time was 10 minutes, and pressing temperature was 120°C. During boards pressing, the day light will be inserted steel bar stop to meet the particleboard target thickness.
4. Conditioning
   After hot pressing, the particleboard samples will be conditioned in an ambient room for 2 weeks.
5. Testing
   After conditioning for 2 weeks, the particleboard will be cut into specimens and tested for physical and mechanical properties according to Japanese Industrial Standard (JIS) A 5908 (2003) [10] with three replications for each condition. The data were analyzed with simple statistics with standard deviation.

2.3. Physical properties
Investigation of physical properties was carried out in ambient temperature at Forest Products Laboratory, Faculty of Forestry, University of Sumatera Utara (Medan, Indonesia) with at least three replications, consisted of determination of density, moisture content (MC), water absorption, and thickness swelling. Both density and MC specimen’s size were 10 cm x 10 cm. The dimension of test piece of water absorption and thickness swelling was 5 cm x 5 cm. Weight and dimensions were measured using electronic balance and callipers. Moisture content was determined by gravimetric analysis. All of the testing was according to Japanese Industrial Standard (JIS) A 5908 (2003) [10].

2.4. Mechanical properties
Mechanical test was conducted using the Tensilon UTM (Universal Testing Machine) in ambient temperature for at least three replications. The mechanical test consisted of bending strength and internal bond strength. Bending strength was determined through measurement of MOE/ modulus of elasticity and MOR/ modulus of rupture, respectively. All of the mechanical properties tests were also conducted at Forest Products Laboratory, Faculty of Forestry, University of Sumatera Utara (Medan, Indonesia).

2.5. Data analysis
Mean value from at least three data measurements both on physical and mechanical properties testing were presented including their standard deviations.

3. Results and Discussions
3.1. Physical Properties
Results of physical test were presented in Table 1. Air-dry density values of the specimens ranged between 0.53-0.62 g/cm$^3$. They fulfilled the Japanese Industrial Standard (JIS A 5908-2003). Unfortunately, the values were below on the target density. This phenomenon may be related to the spring back effect and the voluminous (bulky) leaves particles, therefore compression ratio was difficult to calculate.

Moisture content showed that all of the values met the standard. Leaves belong to lignocelluloses material because they have hygroscopic characteristic. They can bond or release water from the environment, and inherently they have hydrogen bonding.

Both thickness swelling and water absorption showed very high percentage after immersing in the water. This situation was reasonable since the used adhesive was interior type (UF resins).

### Table 1. Physical properties of leaves particleboard with 1% and 3% hardener

| Property                      | Mahagony leaves particleboard with NH$_4$Cl | Oil palm leaves particleboard with NH$_4$Cl |
|-------------------------------|---------------------------------------------|---------------------------------------------|
|                               | 1%                                           | 3%                                          |
| Density (g/cm$^3$)            | 0.62 ± 0.04                                 | 0.60 ± 0.03                                |
| Moisture content (%)          | 10.50 ± 1.10                                | 10.19 ± 0.35                               |
| Thickness swelling-2h (%)     | 9.82 ± 0.59                                 | 7.11 ± 2.44                                |
| Thickness swelling-24h (%)    | 29.34 ± 2.01                                | 20.86 ± 1.81                               |
| Water absorption-2h (%)       | 21.43 ± 2.69                                | 22.52 ± 3.82                               |
| Water absorption-24h (%)      | 93.01 ± 8.32                                | 84.01 ± 31.71                              |

### 3.2. Mechanical properties

Table 2 shows values of mechanical properties of leaves particleboard with different hardener content.

### Table 2. Mechanical properties of leaves particleboard with 1% and 3% hardener

| Property                      | Mahagony leaves particleboard with NH$_4$Cl | Oil palm leaves particleboard with NH$_4$Cl |
|-------------------------------|---------------------------------------------|---------------------------------------------|
|                               | 1%                                           | 3%                                          |
|                               | 1%                                           | 3%                                          |
| MOE (kgf/cm$^2$)              | 146±47                                       | 117± 35                                     |
| MOR (kgf/cm$^2$)              | 9.79 ± 6.46                                  | 6.55 ± 1.61                                 |
| IB (kgf/cm$^2$)               | 0.02 ± 0.01                                  | 0.07 ± 0.01                                 |

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All the mechanical properties were failed to satisfy the standard (JIS A 5908-2003). The failure of both MOE and MOR have to enhance by strengthen the raw material of leaves. The failure of internal bond has to be repaired using manipulation of the adhesive used. Improvement the quality on mechanical properties would be discussed in the next subchapter.

3.3. Enhancement of the leaves particleboard properties
In order to get better properties of the leaves particleboard, we attempted to mix the leaves with wood (sawdust) in various ratio [11], for instance ratio of mahagony leaves and sawdust 100:0; 75:25; 50:50; and 25:75. But the results showed statistically were not significant. Therefore this work has been stopped. In addition, we also tried to add the level of adhesives used [11]. The level adhesive used was increased up to 12%. The results showed statistically were significant. Therefore, this treatment then becomes a future work.

3.4. On going and future work to improve the quality of the leaves particleboard properties
3.4.1. Addition more hardener (NH₄Cl)
In this study, we applied 1% and 3% hardener for the particleboard however the properties were still not satisfied. Addition of hardener up to 5%; 7%; and 9% hopefully could improve the properties of the leaves particleboard as shown in temporary results of this experiment (Figure 2). NH₄Cl created acidic condition [12,13] hence UF resin (with increased level of adhesive up to 12%) will be more cured as shown in Figure 3. Furthermore, addition of hardener will make the UF resin more aqueous [14] thus the distribution of the UF resin into particleboard is more extend.

![Figure 2](image_url). Leaves particleboard of oil palm and mahagony with various hardener level (5%;7%;9%) of NH₄Cl
Figure 3. Result of measurement of pH of the furnish. Higher hardener level showed lower pH which indicated more acidic (a) 5%wt of NH\(_4\)Cl resulted in pH 7 (b) 7%wt of NH\(_4\)Cl resulted in pH 5 (c) 9%wt of NH\(_4\)Cl resulted in pH 3

3.4.2. Addition layers on both surfaces using veneer

For sheathing application, both surface of leaves particleboard should be layered as shown in Figure 4. Addition veneer layers on both surfaces of leaves particleboard will improve the MOE and MOR values including its dimension stability. The thickness of the veneer also must be considered. Previous report on the thickness of veneer layering on the particleboard [15] showed that the higher thickness of the veneer, the quality of the mechanical properties such as MOE and MOR increased.

Figure 4. (a) Construction of leaves particleboard with layers on both surface (face and back) (b) Oil-palm leaves particleboard with veneer layers (c) Mahagony leaves particleboard with veneer layers

3.4.3. Replacement UF resin with exterior type adhesive

UF resin is one of types interior adhesives thus it is prone to water or high moisture. In addition, because of formaldehyde based, UF resin will release formaldehyde emission during service used [16]. Therefore, good choice if we replace UF resin with exterior type adhesive such as isocyanate. Isooyanate can be used without addition of hardener because it reacts with water [17], can be applied using sprayer [18], and non-formalin based [19]. Application of isocyanate can reduce the amount of adhesive used as well as can combine the leaves particle with another material [20]. In our case, we attempted to reduce the amount of isocyanate up to 6% and tried to mix with recycle paper as shown in Figure 5.
Figure 5. Typical leaves particleboard bonded by isocyanate with different treatments such as layering on both surfaces using veneer and mixture with recycle paper.
4. Conclusions
The leaves particleboard has been successfully produced unfortunately their physical and mechanical properties were not satisfy. Therefore, some ongoing works have been carried out, for instances: 1) addition more hardener into the leaves particleboard; 2) addition layers on both surface of the leaves particleboard; 3) application of exterior adhesive such as isocyanate hence application for sheathing would be feasible.

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