Basic properties and nanostructure of wood from four fast growing species from a community forest
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Basic properties and nanostructure of wood from four fast growing species from a community forest

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Abstract Four fast-growing wood species, jabon (Anthecephalus cadamba), lento-lento (Arthrophyllum diversifolium), acacia (Acacia mangium) and pulai (Alstonia spp.), can be easily found in many areas of the South Sulawesi Community Forest. This research evaluates basic properties (physical, mechanical and chemical) and nanostructure of the woods of each species. Physical and mechanical properties were analyzed according to SNI 03-6847-2002 and ASTM D 143-2005, while the chemical components were analyzed according to TAPPI Standard. The nanostructure was determined by X-ray diffraction. The density, lignin, cellulose and nanostructure (the degree of crystallinity) analysis indicated that lento-lento and pulai would potentially produce a composite product superior especially binderless to that made from acacia and jabon wood. Acacia and jabon have a high density and a high lignin content with a low cellulose content.

Keywords Basic properties · Nanostructure · Jabon wood · Pulai wood · Lento-lento wood · Acacia wood

Background

Community plantation forests are an important timber resource for forest product industries. Their value is strongly related to the low productivity and scarcity of timber from natural forests. The most common uses of timber are as raw materials for packaging and energy resources. Many timber species from community plantation forests have the potential to be developed as forest products, such as composite board, energy and construction wood, and as a source of fiber. However, the resources to produce various forest products have not been optimized.

Each timber product requires that the raw material have a specific wood qualities, in terms of physical, mechanical, and chemical properties and wood anatomical structure. Anatomical structures have currently been evaluated, not only on macro and micro scales but also on the nano-scale. According to Booker and Sell (1998), nanostructures include the cell wall structure, the composition of the fibril cell walls [including the microfibril angle (MFA)], and the cellulose crystallinity. Basic information on the characteristic of nanostructure has not been studied in depth, especially for fast-growing species from community forests and for local species. Indeed, in the nano-technology era, the information is critically needed to support forest product development.

This study aims to analyze the characteristics of several fast-growing wood species from community forests that have potential uses in forest products industry. These characteristics can be used as the basis of analysis for timber utilization on a larger scale to support both development and sustainability.

Many fast-growing wood species are used for manufacturing forest products, including acacia, sengon, pulai, jabon and lento-lento. However, little data are available on the wood qualities of acacia, pulai, jabon and lento-lento, common species from community forests. This information, particularly with regard to nanostructure, is necessary to determine the wood quality of these four fast-growing wood species. Therefore, we focused on several basic properties and the nanostructure of the four species from a
community forest, with the ultimate goal of enhancing their value and utilization.

Materials and methods

Sample preparation

Samples comprised four fast-growing wood species from community forests: jabon, lento-lento, acasia and pulai. Three trees for each species for replicate samples. Samples were short logs (100 cm long) taken 50 cm from the ground. Sample derived from a sample of ±7 cm for physical properties testing, ±55 cm for mechanical properties and the remaining parts were used for the analysis of chemical components and evaluation of the nanostructures.

Analysis of basic wood properties

Basic wood properties, physical properties, mechanical properties, and chemical components were examined. The physical properties of the wood, including specific gravity, wood density and dimensional changes, were measured using SNI 03-6847-2002 (BSN 2002) in the air-dry condition. The mechanical properties of the wood, including modulus of elasticity (MOE), modulus of rupture (MOR), and compression strength parallel to grain, were assessed with reference to D 143-2005 (ASTM 2005). Analysis of the chemical components of wood, specifically benzene solubility in alcohol benzene and NaOH 1 %, holocellulose, cellulose, and lignin, relied on TAPPI (1996).

Nanostructure measurement

Nanostructure encompasses MFA, the length and width of the crystallites, and the degree of crystallinity. Nanostructure parameters were measured using X-ray diffraction (Shimadzu, XRD-7000) with a sample size of 0.5 cm x 1.5 cm and 50 μm thickness. The techniques used were symmetry transmission configuration, and horizontal goniometer position, and CuKα radiation (λ = 0.1541 nm) at 40 kV and 30 mA with a diffraction angle (2θ) measured from 10° to 40° at the speed of 2° s⁻¹. MFA was calculated using the following equation:

\[ MFA = 0.6 \times \frac{T}{T} \]

T values were obtained from the full width at half maximum (FWHM) calculation, with zero intensity and the angle of diffraction arcs with the inflection point (Stuart and Evans 1994). The degree of crystallinity is the ratio between the number of crystalline and amorphous regions and is expressed as a percentage. Width and length dimensions of the crystallites of each sample were measured at 200 reflection (2θ = 24.4) and 004 (2θ = 34.4). The average dimensions of the crystallites were calculated from \(D_{bil}\), the width \(b(2\theta)\) reflections, by using the Scherrer formula (Peura et al. 2008):

\[ D_{bil} = \frac{K \lambda}{\beta \cos(\theta_{bil})} \]

\(\lambda\) = target wavelength (copper = 0.154 nm), \(\beta\) = FWHM in radians, \(\theta_{bil}\) = half the scattering angle 2θ, K = constant for graphite (0.9 for the 200 reflections and 1.0 for the 004 reflections).

Results and discussion

Characteristics of the basic properties of the wood samples

The trees sampled to analyze the basic properties and nanostructure of the wood were on average 30 cm in diameter at breast height (dbh) and 15 m in total height. Information on the basic properties of the fast-growing species from community forests is listed in Table 1. Based on Indonesian Wood Construction Regulations (PPKL 1961), the values for the density and specific gravity of jabon are low (<0.4), lento-lento and acasia are moderate (0.4–0.6), and pulai is low to moderate. Specific gravity and density are two important parameters to measure the quality of timber that is used as raw material for forest products processing.

Tsoumis (1991) claimed that wood shrinkage is related to its density; the higher the density, the higher the shrinkage. Our study shows that acacia has the highest density, as well as the greatest tangential, and longitudinal shrinkage. Raw materials that are high in shrinkage are less favored in timber processing because timber with high shrinkage is unstable. The ratio between tangential shrinkage and radial shrinkage or T/R value for the four species that were sampled for this study ranged from 1.98 to 3.48. According to Panshin and de Zeeuw (1980), a T/R value between 1.4 and 2 indicates stable wood dimensions. Our study showed that the T/R value of jabon is 3.48 and that of acacia is 3.42 meaning that these two species have less stable dimensions and are not suitable as raw material for wood construction and furniture.

Chemical content was analyzed and included NaOH 1 % solubility, alcohol benzene solubility, holocellulose, cellulose and lignin. The chemical content of the four types of timber analyzed are presented in Table 1. The polymers cellulose, hemicellulose and lignin are the chemical components that construct the cell wall. These polymers influence the physical properties, especially the changes in dimensions. Cellulose in the cell wall contains hydroxyl
Table 1. The basic properties of pulai, jabon, lento-lento, and acacia woods

<table>
<thead>
<tr>
<th>Basic properties</th>
<th>Wood species*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pulai</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>0.56 (0.02)</td>
</tr>
<tr>
<td>Wood density (g cm⁻³)</td>
<td>0.41 (0.02)</td>
</tr>
<tr>
<td>Tangential shrinkage (%)</td>
<td>2.10 (0.34)</td>
</tr>
<tr>
<td>Radial shrinkage (%)</td>
<td>1.06 (1.35)</td>
</tr>
<tr>
<td>Longitudinal shrinkage (%)</td>
<td>0.12 (0.07)</td>
</tr>
<tr>
<td>Lignin (%)</td>
<td>25.68 (0.36)</td>
</tr>
<tr>
<td>Holocellulose (%)</td>
<td>67.94 (0.38)</td>
</tr>
<tr>
<td>Cellulose (%)</td>
<td>43.64 (0.86)</td>
</tr>
<tr>
<td>The extractive soluble in ethanol-benzene (%)</td>
<td>2.17 (0.29)</td>
</tr>
<tr>
<td>The extractive soluble in NaOH (%)</td>
<td>11.33 (0.76)</td>
</tr>
</tbody>
</table>

* Table data are average values followed by standard deviations in parentheses.

Fig. 1. MOE of samples from several wood species from a community forest.

Fig. 2. MOR of samples from several wood species from a community forest.

Fig. 3. Compression strength parallel to grain of wood from community forest.

and oxygen groups, which are attracted to water through hydrogen bonding (Siau 1984). This attraction causes the wood to reach the fiber saturation point, before the opposite occurs. Shrinkage occurs when water starts coming out of the cell wall (i.e., the wood is below the fiber saturation point), while swelling occurs when all cells are replenished by water.

Chemical components are significant parameters and play a vital role in production of composite board. High variation in chemical components will affect composite board processing, especially for production of binderless particleboard, which is highly dependent on the reactivity of chemical components. Table 1 also includes the extractives soluble in Ethanol-Benzene and NaOH 1%. The values showed that acacia, jabon, lento-lento and pulai have a high to low level of extractive solubility, respectively. The low extractive solubility level in pulai and lento-lento indicate that these two species have higher levels of cellulose, hemicelluloses, and lignin than acacia and jabon. Cellulose, hemicelluloses, and lignin are biomass substances that are important in determining the utilization of the timber species. The results of mechanical property measurements, including the MOE, MOR, and compression strength...
parallel to grain are presented in Figs. 1, 2 and 3. MOE is affected by specific gravity and wood density (Larson et al. 2001); the higher the wood density, the higher the MOE. Acacia and lento-lento tend to have higher specific gravity than jabol and pulai, so their MOEs also tend to be higher than those of acacia and lento-lento.

**Characteristic of the nanostructure**

Table 2 describes the nanostructure of the wood samples from the four species. Nanostructures analyzed in this study were MFA, the degree of crystallinity, and the width and length of crystallites. Zobel and Van Buijtenen (1989) indicated that timber with a high MFA will have a large longitudinal shrinkage. Changes in MFA will affect the final product manufactured from the timber, especially fiber-based products (Barnett and Bonham 2004). Our study shows that acacia has the highest MFA and has the largest longitudinal shrinkage.

MFA of a cellulose fiber is defined as the angle of the cellulose fiber to the stem axis (Stuart and Evans 1994). MFA influences mechanical properties, physical properties and chemical properties, particularly density, tensile strength, stiffness, swelling, and shrinkage (Stuart and Evans 1994; Butterfield 2003). Barnett and Bonham (2004) and Peura et al. (2008) agreed that MFA is inversely proportional to MOE. The relationship between MFA and MOE was a negative correlation, with high values in MFA and low values for MOE. The trend on for MFA and MOE in our study was inconsistent due to the high portion of juvenile wood from the selected sample; that is, fast-growing species. According to Bhat et al. (2001) as cited in Bhat (2003), the MOE of juvenile wood is 85% lower than that of mature timber. At the beginning of the tree growth period, fiber cells grow at a rapid pace, resulting in a low MFA and low MOE. At this stage, the proportion of juvenile wood is high. A consistent relationship between MFA and MOE occurs when the timber reaches maturity, with a high MFA and a low MOE.

According Winandy and Rowell (2005), during mechanical properties testing (MOEs), due to the excessive load, the cell wall layer is displaced (layer S1, S2 and S3). Hydrogen bonds between the microfibrils break, resulting in a change in the distance between the fibrillar elements. This causes a change in the width of the crystallites and the degree of crystallinity. Crystallinity is the most important of the mechanical wood properties (Peura et al. 2008).

Yunianti (2012) indicated that MOE is affected by the width of crystallites, the degree of crystallinity and wood density. Timber with a high MOE becomes stiff and difficult to break. Our study shows that pulai has a moderate MOE, low MFA, and a high degree of crystallinity. Acacia and lento-lento has a high MOE, moderate MFA and a high degree of crystallinity. Jabol has moderate values for MOE, MFA and the degree of crystallinity. These findings indicate that the wood strength or wood stiffness is affected not only by one or two parameters, but more, especially by the percentage of crystallinity area.

From the above description, jabol has less potential to be developed as a raw material for products that require dimensional stability and strength. Although acacia timber has a high strength, it also has a large MFA, large longitudinal shrinkage, and a T/R value that is greater than 2. Lento-lento is difficult to break and has low MFA (high dimensional stability), and the same is true for pulai. Both of these species, pulai and lento-lento, may therefore have potential as raw material for timber-based products.

**Conclusion**

Information on basic wood properties fast-growing species from community forests plays an important role in supporting optimal forest product development. Given the basic wood characteristics of pulai and lento-lento, these species can be utilized as raw material for composite board because have high biomass substance with low solubility. Acacia and jabol are not recommended for wood construction and furniture due to dimension instability.

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