Mechanical Properties of Three-Layered Particleboards Made from Different Wood Species

Muhammad Navis Rofii¹, Satomi Yumigeta², Shigehiko Suzuki², and T.A. Prayitno¹
¹Faculty of Forestry, Universitas Gadjah Mada, Yogyakarta
²Faculty of Agriculture, Shizuoka University, Japan

ABSTRACT

The most commonly used particleboard has three layers: two face layers and one core layer. Structures of these layers differ markedly. There are two different elastic bodies (surface and core layer) in the three-layered particleboards. This study is aimed to examine the effect of layer structure according to shelling ratio on mechanical properties of particleboards made from different wood species. The materials used in this study were hinoki (Chamaecyparis obtusa) strand and knife-milled Douglas fir (Pseudotsuga menziesii) particles as surface layer, and hammer-milled matoa (Pometia sp.) particles as core layer. Those wood particles were collected from wood companies. Adhesive used was MDI resin (methylene diphenyl diisocyanate) 6% content in mat. Pressing condition were: temperature of 180 °C, pressure of 3 MPa, pressing time of 5 minutes. The target density was 0.72 g/cm³ with board size of 340 mm x 320 mm x 10 mm. Factors used in this study were layer structure according to shelling ratio and wood species. The parameters of this study were: Young’s modulus, modulus of rigidity, modulus of rupture, modulus of elasticity, and internal bond. This study showed that all boards meet the requirements of JIS A 5908-1994. Improvement of mechanical properties of matoa particleboard could be conducted by adding surface layer using higher quality wood particles such as hinoki strands or Douglas fir particles. Higher shelling ratio at approximately 0.67 resulted higher performance of three-layered particleboard. Utilization of hinoki strand as surface layer resulted higher particleboard performance than that of Douglas fir. Dynamic Young’s modulus as non-destructive evaluation (NDE) test can be used to predict the elastic bending of particleboard by specific equation for adjustment the proper values with deviation of about 3-20%.

Keywords: three-layered particleboards, shelling ratio, wood species, mechanical properties

INTRODUCTION

All sawmills produce a lot of residue in the form of chips, sawdust and slabs. Wood waste materials such as flakes, particles, sawdust, planer shaving, which are residue from furniture industry can be utilized to manufacture many composites such as particleboard. Particleboard is mainly composed of wood particles and an adhesive. Wood particles are mixed or coated with an adhesive, and then formed into a mat that is further hot-pressed to form a panel products (Youngquist, 1999).

The most commonly used particleboard has three layers: two face layers and one core layer. Structures of these layers differ markedly. The face layers consist of fine particles, and the core layer is made of coarse particles. The face layers, made of smaller chips with a higher resin content,
have a greater compaction ratio and density, and in consequence better mechanical properties (Wilczynski and Kociszewski, 2010). Cai et al. (2004) reported that three-layer particleboards have better mechanical properties than single-layer particleboards made from eastern red cedar.

Important indicators of particleboard quality are their mechanical and physical properties. One of the most important properties of three-layer particleboard is certainly the bending strength. It is well known that wood species and particle size used influence the bending strength of three-layer particleboard. Suzuki and Takeda (2000) noted that surface layer property dominated the bending properties of the board. Since bending strength is influenced by the structure of surface layer, the most consideration should therefore be oriented towards the structure of that layer. It means that such wood species and particle size should be selected that can contribute to achieve higher bending strength (Ghalehno et al., 2010).

Matoa, one of hardwood species, has possibility to be used for particleboard production. Matoa particles are low quality because the original density is high. Moslemi (1974) and Maloney (1993) explained the negative effect of the high density of raw materials on the mechanical properties of particleboard. Therefore, in order to minimize the negative effects of the utilization of high density particles, particleboard can be produced by combining the low quality particles, such as matoa, and the high quality particles, such as hinoki or douglas fir. Hinoki is a softwood species which its structure is uniform and the original density is low (0.39 g/cm³). This is the second famous wood and most abundant tree species in Japan (Kojima et al., 2009) and its waste wood can be easily found from furniture industry in Japan. Kojima et al. (2010) also stated that the material properties of hinoki are better than or similar to that of Japanese cedar (Sugi). Douglas fir, also one of softwood species, is commonly used as material for particleboard production (Maloney, 1993).

Layering concept should be used as consideration to make high quality particleboard. It can be conducted by manufacturing particleboard in multilayer or mixing the different particles. According to Moslemi (1974), there are several options in order to obtain high quality particleboards according to layering such as: (a) a higher adhesive content in the face layer, (b) different particles in the face layer (smaller, thinner), (c) lower density wood species in the face layer, (d) processing techniques which reduce compression strength of the face particles, and (e) surface particle orientation kept constant. Bowyer et al. (2003) also stated that in order to produce a board with highest bending strength, the surface layer should be made denser than the core. It is thought that better bending strength can be achieved by utilization of hinoki strand in the surface layers in three-layer particleboard with hammermilled matoa particle as core layer. This is because of the higher slenderness ratio and lower density of hinoki strand which promote better adhesion and densification.

Several studies have been reported to investigate bending properties of wood and wood-based composites such as particleboard by non-destructive evaluation (NDE) test (Ross and Pellerin, 1988; Texeira and Moslemi, 2001; Hu et al., 2005a, 2005b; Moya et al., 2010). Since experimental work has shown good correlation between NDE and the static MOE of wood-based composites as noted from several studies by Texeira and Moslemi (2001), the possibility of the use of NDE test would be examined for three-layered particleboard with different particle type and wood species in this study.

There are two different elastic bodies (surface and core layer) in the three-layered particleboard made from matoa as core layer and hinoki/douglas fir as surface layer. It is hoped that better particleboard properties can be achieved by adding hinoki or douglas fir on surface layer. This study is aimed to assess the effect of layer structure according to surface portion or shelling ratio in enhancement the mechanical properties of 3-layer board with high density core layer (matoa).
and to determine the effect of particle type on the properties of particleboard made from different sources of wood particles

**MATERIALS AND METHODS**

**Materials and Boards Manufacturing**

Materials used in this study were hinoki (*Chamaecyparis obtusa*) strand and knife-milled douglas fir (*Pseudotsuga manuziesii*) used for surface layer and hammer-milled matoa (*Pometia sp.*) used for core layer (Fig. 1). Those wood particles were collected from wood company. Adhesive used was MDI resin (*methylene diphenyl diisocyanate*), 6% content in mat. A blending box was used to mix the particles and resin adhesive. The adhesive mixed wood particles were placed in a forming box by hand to form a one and three layer of wood particles mat. The resulting three-layered wood particle mat was hand-pressed with a flat plywood panel and then hot-pressed. Figure 2 illustrates the configuration of three-layered particleboard manufactured. pressing condition were: temperature of 180°C, pressure of 3 MPa and pressing time of 5 minutes. The target density was 0.72 g/cm³ with board size of 340 mm x 320 mm x 10 mm. Three particleboard panels were prepared for each experimental variable. After manufactured, the boards were kept into conditioning room during approximately two weeks.

![Figure 1. Materials used in the study; hammer-milled matoa particle (M), hinoki strand (H) and knife-milled douglas-fir particle (D)](image)

![Figure 2. Configuration of three-layered particleboard](image)

**Specimen Preparation and Boards Evaluation**

Prior the evaluation, the boards were cut into 280 x 280 mm in size, and then measured the density ($\rho$) by measuring its weight (g) and volume (cm³). The boards then tested for dynamic Young’s modulus (Ed) and dynamic modulus of rigidity (Gd). The boards then tested for plate shear strength/static modulus of rigidity (Gs) according to ASTM D-3044-94 (ASTM, 2006). The testing used FFT analyzer SA-78 to obtain the $f$ value. The boards were then cut into 280 x 50 mm in
size. The number of samples were five of each boards for determining the bending/longitudinal vibration (E1). The samples then measured its size and weight to obtain its density. The value of \( f_1 \) was measured by FFT analyzer then the E1 values were calculated.

After measuring the nondestructive evaluation of particleboards, the boards then prepared for static bending properties (MOE and MOR) and internal bonding (IB) evaluation. First was randomizing samples for static bending and IB to determine the number of samples for each testing. Furthermore, measuring weight and size to obtain current density of each samples. Bending test to get MOE and MOR of particleboards was conducted according to JIS A 5908 (JIS, 1994). Six specimens of each board were chosen for static bending test. Seven specimens measuring 50 x 50 mm of each board were chosen for IB test. Prior the testing, the samples were put in conditioning room and measured its density. The IB testing was conducted according to JIS A 5908 (1994) and the loading rate was controlled at 2 mm/min.

**RESULTS AND DISCUSSION**

There were two kinds of mechanical evaluation applied in this study. First was nondestructive evaluation (NDE) and second was static test. In this study, the NDE technique used wave frequency to determine the dynamic Young’s modulus (Ed), dynamic modulus of rigidity (Gd) and bending vibration (E1) as predicted values. Then the actual values were obtained by static bending test to obtain the MOE and MOR of particleboards. Relationship between NDE values and static bending test values then were determined. Mean values of mechanical properties of particleboards are summarized in Table 1.

<table>
<thead>
<tr>
<th>Spec</th>
<th>Name</th>
<th>Layer</th>
<th>Ed (GPa)</th>
<th>E1 (GPa)</th>
<th>G (GPa)</th>
<th>MOE (GPa)</th>
<th>MOR (MPa)</th>
<th>IB (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-L M</td>
<td>M 100</td>
<td>1</td>
<td>2.51</td>
<td>2.81</td>
<td>0.91</td>
<td>1.05</td>
<td>2.39</td>
<td>14.59</td>
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<td>H/M Comp</td>
<td>H/M 1/7:6/7</td>
<td>3</td>
<td>3.15</td>
<td>4.44</td>
<td>1.26</td>
<td>1.34</td>
<td>3.76</td>
<td>24.03</td>
</tr>
<tr>
<td>H/M Comp</td>
<td>H/M 1/4:3/4</td>
<td>3</td>
<td>4.01</td>
<td>4.98</td>
<td>1.57</td>
<td>1.64</td>
<td>4.25</td>
<td>33.14</td>
</tr>
<tr>
<td>H/M Comp</td>
<td>H/M 1/3:2/3</td>
<td>3</td>
<td>4.22</td>
<td>5.11</td>
<td>1.58</td>
<td>1.73</td>
<td>4.35</td>
<td>34.84</td>
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<tr>
<td>H/M Comp</td>
<td>H/M 1/2:1/2</td>
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<td>4.59</td>
<td>6.01</td>
<td>1.74</td>
<td>1.82</td>
<td>5.35</td>
<td>46.52</td>
</tr>
<tr>
<td>H/M Comp</td>
<td>H/M 2/3:1/3</td>
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<td>5.32</td>
<td>7.01</td>
<td>2.04</td>
<td>2.20</td>
<td>6.00</td>
<td>56.45</td>
</tr>
<tr>
<td>S-L H</td>
<td>H 100</td>
<td>1</td>
<td>5.31</td>
<td>7.52</td>
<td>2.09</td>
<td>2.02</td>
<td>6.60</td>
<td>63.73</td>
</tr>
<tr>
<td>Df/M Comp</td>
<td>Df/M 1/3:2/3</td>
<td>3</td>
<td>3.56</td>
<td>4.23</td>
<td>1.38</td>
<td>1.52</td>
<td>3.44</td>
<td>21.58</td>
</tr>
<tr>
<td>S-L Df</td>
<td>Df 100</td>
<td>1</td>
<td>4.10</td>
<td>5.43</td>
<td>1.24</td>
<td>1.64</td>
<td>4.53</td>
<td>34.33</td>
</tr>
</tbody>
</table>


**Young’s Modulus**

It can be seen from Table 1, that all boards manufactured meet the minimum requirement of JIS standard A 5908 (JIS, 1994) with the minimum value of 2.51 GPa for Ed and 2.81 GPa for E1 is resulted from single layer particleboard made of matoa and the highest of 5.31 GPa for Ed and 7.52 GPa for E1 were resulted from single layer particleboard made of hinoki. Statistical analysis by Anova resulted that Young’s modulus was affected by different shelling ratio and wood species. Higher shelling ratio resulted higher Ed and E1 value, and hinoki strand resulted higher Ed and
E1 value than that of douglas fir particle.

Figure 3. Young’s modulus of particleboards at various particle type and shelling ratio. Ed, dynamic Young’s modulus; $E_1$, flatwise bending vibration; circle, particleboard with hinoki strand as surface layer; triangle, particleboard with douglas fir particle as surface layer

Modulus of Rigidity

Modulus of rigidity or plate shear modulus (G) related to performance of a board when used as wall sheathing (Sumardi et.al., 2008). Gd is dynamic modulus of rigidity and Gs is static modulus of rigidity. Gd was determined by hit sound using FFT analyzer according to spectrum peak of wave frequency and Gs was determined by applying load on the edges of the boards then calculating the plate shear modulus using relationship between load and deflection. The highest Gd and Gs values were resulted from hinoki particleboard (2.09 GPa) and from hinoki with shelling ratio of 2/3 (2.20 GPa), respectively, while the lowest Gd and Gs values were resulted from matoa particleboard (0.91 GPa and 1.05 GPa, respectively). The G values meet the requirements for OSB as noted by Berglund and Rowell (2005) which requires a minimum shear modulus of 1.2 GPa, except for matoa particleboards. Figure 4 shows that there was no difference between Gd and Gs values, although Gs value were higher than those of Gd. Higher proportion of surface layer both hinoki and douglas fir increased the G values. Hinoki results higher G value than douglas fir.

Figure 4. Modulus of rigidity of particleboards at various particle type and shelling ratio. Gd, dynamic modulus of rigidity; Gs, static modulus of rigidity; circle, particleboard with hinoki strand as surface layer; triangle, particleboard with douglas fir particle as surface layer
Static Bending

The MOE and MOR are used to determine the static bending of flexural strength in this study. Anova results showed that the MOE and MOR in this study were significantly influenced by particle type, shelling ratio and interaction between them. Figure 5a shows the MOE values of particleboards. It can be seen that increasing shelling ratio of surface layer increased the MOE. It was agreed with the study of Suzuki and Takeda (2000), who stated that MOE in parallel direction increased with an increase in face layer ratio. In other hand, hinoki surface layer in this study used strands. According to the study of Sackey et al. (2011) for the MOE of hybrid boards, it indicates that the MOE was significantly affected by the proportion of strands in the boards. There was no significant increment of MOE after shelling ratio of 2/3. Increasing shelling ratio improves MOE-parallel, but the change of MOE is negligible after SR reaches approximately 0.7 (Xu, 2000).

![Graph a](image1)

![Graph b](image2)

Figure 5. Modulus of elasticity and modulus of rupture of particleboards at various particle type and shelling ratio. Circle, particleboard with hinoki strand as surface layer; triangle, particleboard with douglas fir particle as surface layer

Figure 5b shows the MOR values of particleboards manufactured. Similar to MOE values, it can be mentioned that increasing surface layer portion of hinoki strand and douglas fir increased the MOR. Generally, the increasing of surface layer portion of both hinoki strand or douglas fir particle increased the bending strength of particleboards. Utilization of hinoki strand as surface layer of three-layered particleboard with matoa core enhanced its bending properties higher than that of douglas fir particle.

Moslemi (1974) stated that the performance of particleboards is the reflection of particle characteristics. Slenderness ratio and flatness ratio of particles are important. The three wood
species used in this study have different characteristics related to its particle shape and size. According to the data, slenderness ratio influences the particleboards manufactured. Hinoki strands have the highest slenderness ratio followed by douglas fir and matoa, respectively. It results in different properties of single layer hinoki board especially on mechanical properties with great difference to that of douglas fir and matoa. A study conducted by Kojima et al. (2010) using hinoki particle resulted MOE and MOR of approximately 4.3 GPa and 40 MPa, respectively. It means that the bending properties of hinoki boards in this study were higher of approximately 50%.

**Internal Bonding**

Figure 6. shows the IB values of particleboards as the effect of layer structure and wood species. The increasing of shelling ratio of surface layer increased IB values. It can be seen on three-layered particleboards with hinoki strand as surface layer, but no difference to particleboards with douglas fir as surface layer. It implies that utilization of hinoki strand enhanced the IB properties of three-layered particleboards with matoa as core layer than that of douglas fir. This phenomenon might be related to the vertical density profile (VDP). The higher surface portion of hinoki strands in three layer particleboard with matoa core layer resulted greater difference between surface and core layer. This can cause variation in IB strength. Almost all of the IB specimens failed in the core layer. It implies that lower densification took place in the core layer. The low density core layer causes the low IB strength. By adding high density layer in surface layer with higher quality wood particles such as hinoki strand, it results higher IB strength of the boards.

**Relationship between NDE and Static Bending MOE**

Relationship between Ed and MOE, E1 and MOE can be seen in Fig. 7. According to Fig. 7a, it seems that there is no difference between Ed and MOE values on each point except that of single layer hinoki board. The same trend can be seen in Fig. 7b, but in that figure the E1 value as NDE is higher than MOE value as static bending test. Ed values were lower than MOE values with deviation of about 3 – 20% and E1 values were higher than MOE values with deviation of about 12 – 31%. Those figures show that both testing resulted a similar or no different values with high coefficient of determination (R²). This implies that NDE testing can be used successfully to predict the static bending of particleboards and in this case Ed value is more acceptable to predict bending strength of particleboards for determining the load limit.
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Figure 7. Relationship between NDE and static MOE of particleboards. $E_d$, dynamic Young’s modulus; $E_1$, Young’s modulus of flatwise bending vibration; circle, boards with hinoki strand as surface layer; triangle, boards with douglas fir as surface layer

CONCLUSION

In this study, enhancement the quality of particleboard made from low quality matoa particles was examined. The improvement can be conducted by adding surface layer of matoa core layer using higher quality wood particle such as hinoki strand or douglas fir particle. Surface portion or shelling ratio have substantial effects on mechanical properties of particleboard. Higher shelling ratio of surface layer at approximately 0.67 results higher performance of three-layered particleboards. Particle type and wood species significantly influences the properties of particleboard. Hinoki strands as surface layer contribute on higher enhancement of three-layered particleboard with matoa as core layer than that of douglas fir particles. Therefore, improvement of low quality materials for particleboard production can be conducted by adding high quality materials as surface layer. Dynamic Young’s modulus as non-destructive evaluation (NDE) test can be used to predict the elastic bending of particleboard by specific equation for adjustment the proper values. Comparison between nondestructive evaluation (NDE) results and actual static bending data showed that the NDE adequately predicted the static bending MOE with deviation of about 3 – 20%.

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