Effect of Wood Species and Layer Structure on Physical and Mechanical Properties of Strand Board

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Abstract

The objectives of this research were to evaluate the effect of wood species and layer structure on physical and mechanical properties of strand board made from *Paraserianthes falcataria*, *Maesopsis eminii* and *Acacia mangium* woods collected from planted forest in Bogor district, Indonesia. The densities of *P. falcataria*, *M. eminii* and *A. mangium* woods were 0.36, 0.41 and 0.46 g cm^{-3}, respectively. Three types of layer structures namely perpendicular, parallel, and random orientation were applied. Methylene diisocyanate (MDI) resin with 7% resin amount (w/w) was used. The physical and mechanical properties of strand board were evaluated based on CSA 0437.0 standard. The results indicated that strand board manufactured from wood with lower density (*P. falcataria*) had higher mechanical properties (modulus of rupture, modulus of elasticity and internal bond) and lower dimensional stability (water absorption and thickness swelling) compared to strand board manufactured from higher density (*A. mangium*), vice versa. Strand orientation strongly affected the physical and mechanical properties of board with perpendicular orientation showed superior performance as compared to parallel and random orientation. Physical and mechanical properties of oriented strand board (OSB) made from fast growing tree species met the requirement of CSA 0437.0 standard for grade O-1 OSB panels.

Key words: layer structure, methylene diisocyanate resin, strand board, tropical wood species,

Introduction

Fast growing tree species have become a popular planted forest commodity not only in Indonesia but also in other Asian countries. In Indonesia, most of the fast growing tree species were initially selected to provide the raw materials for fuel and pulp and paper production due to their small diameter logs characteristics. Fast growing tree species also have relatively lower quality compared with wood supplied from primeval forest. The tendency occurred because wood density will decrease when trees stimulated to grow ten times faster (Johnson & Jayawickrama 2002). An experiment reported that the effect of intensive environmental treatments in pine plantation is positive and significant: trees grow faster. Nevertheless, this faster growth affects lumber strength, stiffness, dimensional stability, pulp yields, and paper properties (Clark *et al*. 2006).

Currently, wood extracted from community forest in Indonesia, particularly sengon wood (*Paraserianthes falcataria*) is a very popular species and in great demand by the timber industry as a raw material for pallets, jointed board and composite board. The high demand of *P. falcataria* led to a sharp increase of the wood price in the last 5 years and made this species as popular tree to be planted in community forest. Planting a massive amount of tree in monoculture system is less favorable ecologically than in polyculture system. Insect infestation and plant disease (i.e., karat puru) on *P. falcataria* plantation planted in monoculture system occurred in community forests in Java nowadays. As a result farmers failed to harvest the the *P. falcataria*. In long-term result, it is worried that people interest in tree farming will decrease with the above incident.

Since it has comparative advantages, OSB is preferred over solid wood in many applications. OSB uses the wood resource very efficiently, because it can be manufactured from a wide range of fast growing tree species and from relatively small diameter trees (Cloutier *et al*. 2007, Okino *et al*. 2004, Papadopoulos & Traboulay 2002) and about 85-90% of the logs can be used to make high quality structural panels, and the residues (*i.e.* bark, saw trim, and saw dust) can be converted into energy, pulp chips or bark dust.

There are many other fast growing tree species comparable to *P. falcataria* that can be used as a raw material for timber industry. But only several species are known in the market. This is due to a lack of technological information on the wood species. From the information above, the development of structural composite board especially oriented strand board (OSB) from mixed fast growing tree species is important to be performed in order to support the efficiency of natural resources utilization, to support the development of timber industry and to preserve ecological balance in Indonesia.

Species is one of the most significant factors in the OSB process. It interacts virtually with every other variable that can be imagined in the process. The most important species variable governing board properties is the density of the wood raw material itself. The density has been the important factor in determining which species are used for manufacture of OSB. In general terms, the lower-density woods will produce panels within the present desired density ranges, usually with strength properties superior to the higher-density species (Maloney 1993). Furthermore, the properties of strand board particularly its mechanical properties (i.e., modulus of elasticity and modulus of rupture) were much affected by strand orientation or layer structure (Nurhaida *et al.* 2008, Nishimura & Ansell 2002).

The objective of this study was to evaluate the effect of wood species and layer structure on the physical (i.e. moisture content, density, water absorption and thickness swelling) and mechanical (i.e. modulus of rupture, modulus of elasticity, and internal bond) properties of strand board.

Materials and Methods

Strand preparation

Strands were prepared from *P. falcataria* (P), *Maesopsis eminii* (M), and *Acacia* *mangium* (A) wood collected from the arboretum of Faculty of Forestry, Bogor Agricultural University, Bogor, Indonesia. The trees ages range 7-15 years and the diameters range 15-25 cm. The wood densities were 0.36, 0.41 and 0.46 g cm^{-3} for *P. falcataria* (P), *M. eminii*, (M) and *A. mangium* (A), respectively. Strands were produced using a laboratory disk flaker. Their average dimensions determined from 100 strands, were 60-70 mm in length, 20-30 mm in width and 0.2-1.4 mm in thickness. Strands were screened and sorted by using a sieve before being treated. Commercial Methane di-Isocyanate (MDI, Type H3M) adhesive was used to bond the strands. The amount of MDI adhesive used was 7% based on oven dry (OD) weight of strand. The moisture content (MC) of strand was 7%.

Board manufacturing

Three layers strand board were produced with the size of 30 by 30 by 1.0 cm3 and the target density was 0.7 g cm^{-3}. Seven percent of liquid MDI resin content was applied to strands using a pressurized spray gun in a box-type blender. No wax or other additives were used. Hand-formed mats were pressed for 7 min at a temperature of 180 °C using a maximum pressure 2.5 N mm^{-2}. Three kind of wood species (i.e. (P), (M), and (A) and three types of layer structure (i.e. parallel, perpendicular and random orientation) of strand board panels were produced. The face-core-face ratio was 1:2:1). Three boards were prepared for each treatment.

Evaluation of physical and mechanical properties of strand board

Prior to testing, all boards were fully conditioned at a relative humidity (RH) of 65% and a temperature of 25 ºC for 1 week. All boards were tested according to JIS A 5908-2003 for particleboards to determine its physical properties (i.e., density, moisture content (MC), water absorption (WA), and thickness swelling (TS)) and mechanical properties (i.e., modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), and screw holding power (SHP)). The physical and mechanical properties of strand board obtained were compared to CSA 0437.0 standard for grade O-1 OSB panels.

The dimension of specimen for evaluation air-dry density and MC of board was 100 by 100 by 10 mm^3. The specimens were immediately weighed and dried in the oven at 103 ± 2 °C until they reached constant weight. The dimension of specimen for WA and TS tests are (50x50x10) mm^3. The specimens were immediately weighed. Average thickness was determined by taking several measurements at specific locations. After 24 h of submersion, specimens were dripped and wiped cleaning of any surface water. The weight and thickness of specimens were measured. The strength of strand board was tested by using a Universal Testing Machine. Evaluation of MOE and MOR were performed both in their long dimension parallel and perpendicular to the major axis of panel using specimen with dimension of (200x50x10) mm^3. The three-point bending was applied over an effective span of 150 mm at the loading speed of 10 mm min^{-1}. IB was evaluated using specimen with dimension of (50x50x10) mm^3. Steel plates were bonded to each face of the specimen using epoxy resin adhesive for about 6 h to ensure a good glue bond. The maximum load at the point of delamination was determined for each specimen. The IB test was performed at the loading speed of 3 mm min^{-1}.

Data analysis

The experimental design was a completely randomized factorial design. The results of the properties tested were submitted to an overall analysis of variance (ANOVA). The homogeneity of the means among combinations was tested using the Duncan's Multiple Range Tests. The results were also compared to CSA 0437.0 standard for grade O-1 OSB panels (APA 2004).

Results and Discussion

Species is one of the most significant factors in the OSB process. It interacts virtually with every other variable that can be imagined in the process. In commercial OSB mills, supply of similar wood species as raw material sometimes could not be attained. As solution, some manufacturers mixed different raw materials to produce the boards. Hence, evaluation dimensional stability and strength of strand board prepared from 3 different wood species (*P. falcataria*, *M. eminii*, and *A. mangium*) and 3 types of layer structure (i.e., parallel, perpendicular and random) were observed.

Physical properties of strand board

The physical properties of strand board were evaluated using density, MC and TS after immersed in cold water for 24 hours parameters. The values of density of strand board ranged from 0.49-0.61 g cm^{-3}. The lowest and the lowest values of density were achieved on board prepared from *P. falcataria* wood strand in random and perpendicular layer structures, respectively. The results revealed that wood species did not significantly affect density values. However, different layer structure of board significantly affected the density values.

The values of MC of strand board ranged from 7.04-9.24%. The lowest value of density was achieved on board prepared from *M. eminii* wood strand in perpendicular layer structure, while the lowest one was achieved on board prepared from *P. falcataria* wood strand in parallel layer structures. Statistical analysis revealed that both wood species and layer structures factors significantly affected the MC parameter. Strand board prepared from *P. falcataria* strands which has lowest density among others tend to resulted in higher MC value. Meanwhile, strand board constructed from perpendicular layer structure tends to result in lower MC value.

The values of TS parameter of strand board after immersed in water for 2 and 24 h ranged from 2.80-7.70% and 8.92-15.46%, respectively. The lowest TS values of OSB after immersed in water for 24 h was achieved on strand board prepared from *A. mangium* wood strand in perpendicular layer structure, while the highest one was achieved on strand board prepared from *P. falcataria* wood in random layer structure. Statistical analysis revealed that wood species factor significantly affected the TS of strand board after immersed in water for 24 h. The most important species variable governing board properties is the density of the wood raw material itself.

P. falcataria, *M. eminii*, and *A. mangium* strands have density about 0.36, 0.41 and 0.46, respectively. The results revealed that strand board made from lower wood density (*P. falcataria*) yielded higher TS value, conversely strand board made from higher wood density (*A. mangium*) yielded lower TS value (Table 1). Hsu (1987) stated that TS and water absorption (WA) parameters are the sum of three components, i.e. reversible swelling of the wood itself, spring back of compressed wood, and separation of furnish.

Table 1 Physical properties of strand board prepared from various wood species and layer structures

Treatments	Density (g cm^{-3})	Moisture content (%)	Thickness swelling (%)	
			2 h	24 h
P. falcataria				
- Parallel	0.51 (0.01)	8.64 (0.39)	6.73 (1.07)	14.61 (2.47)
- Perpendicular	0.61 (0.02)	8.81 (0.42)	6.81 (1.77)	14.26 (2.35)
- Random	0.43 (0.03)	8.67 (0.04)	7.40 (1.32)	15.46 (0.67)
M. eminii				
- Parallel	0.52 (0.03)	8.73 (0.23)	7.70 (0.56)	11.54 (2.29)
- Perpendicular	0.54 (0.01)	7.04 (0.19)	2.84 (0.46)	9.05 (0.66)
- Random	0.50 (0.05)	8.69 (0.29)	6.23 (1.80)	11.32 (1.48)
A. mangium				
- Parallel	0.58 (0.03)	9.24 (0.20)	5.10 (1.43)	9.79 (2.41)
- Perpendicular	0.57 (0.01)	8.41 (0.24)	3.11 (0.56)	8.92 (1.41)
- Random	0.52 (0.02)	8.60 (0.13)	3.51 (1.00)	10.27 (1.37)

Note: Values in parentheses are standard deviation

At the same target density, a lower wood density resulted on higher compression ratio. A higher compression ratio of the final boards will increase the WA and TS values. The stress inside the panel is particularly released when submitted to water immersion. It is more pronounced as the spring back effect is higher. All the TS values obtained in this experiment met the requirements of CSA 0437.0 standard for grade O-1 OSB panels, except for OSB prepared from *P. falcataria* strand in random layer structure which had TS value 15.46%.

Mechanical properties of strand board

Table 2 showed the values of mechanical properties (i.e., MOR, MOE, IB, and SHP) of strand board prepared under various wood species and layer structures. The values of MOR in parallel direction ranged between 251-514 kg cm^{-2}. The highest and the lowest values of MOR in parallel direction occurred in strand board both prepared from *P. falcataria* strands in perpendicular and random layer structures, respectively.

Table 2 Mechanical properties of strand board prepared under various wood species and layer structures

Treatments	MOR (kg cm^{-2})		MOE (kg cm^{-2})		IB (kg cm^{-2})	SHP (kgf)
	//	⊥	//	⊥		
P. falcataria						
- Parallel	375 (55)	96 (7)	4681 (232)	37106 (7077)	3.06 (0.98)	95 (6.62)
- Perpendicular	514 (72)	298 (68)	58289 (3982)	22803 (3380)	7.98 (1.83)	87 (10.15) 92
- Random	251 (50)	251 (50)	19049 (2981)	19049 (2981)	3.30 (0.65)	(26.31)
M. eminii						
- Parallel	439 (69)	110 (6)	7384 (897)	51176 (7501)	2.50 (1.23)	108 (6.99) 118
- Perpendicular	370 (71)	230 (36)	54179 (5547)	19261 (3263)	9.71 (3.27)	(4.20) 119
- Random	283 (68)	283 (68)	27007 (2889)	27007 (2889)	3.48 (0.41)	(16.10)
A. mangium						
- Parallel	473 (101)	102 (8)	9186 (766)	62810 (16112)	7.59 (1.27)	123 (21.07)
- Perpendicular	482 (109)	264 (18)	54052 (10175)	17553 (1344)	8.78 (2.51)	86 (18.21) 138
- Random	267 (65)	267 (65)	29506 (7467)	29506 (7467)	6.38 (2.41)	(32.59)

Note: //: Parallel to the grain direction; ⊥ = Perpendicular to the grain direction; Values in parentheses are standard deviation

The values of MOR in perpendicular direction ranged 96-298 kg cm^{-2}. The highest and the lowest values of MOR in perpendicular direction occurred in strand board both prepared from *P. falcataria* strands in perpendicular and parallel layer structures, respectively. Statistical analysis for MOR values in parallel direction showed that random layer structure and parallel layer structure has similar values of MOR. However they are significantly different with MOR value in perpendicular layer structure.

For MOR values in perpendicular direction, statistical analysis showed that random layer structure and perpendicular layer structure has similar values of MOR. However they are significantly different with MOR value in parallel layer structure. Furthermore, OSB prepared from different wood species resulted in similar values of MOR both in parallel and perpendicular layer structures. Almost all MOR values both in parallel and perpendicular direction met the requirements of CSA 047.0 standard for grade O-1 OSB panels, except MOR value of strand board prepared from *P. falcataria* strands in parallel layer structure.

The values of MOE showed almost similar trend as occurred in MOR. The values of MOE in parallel direction ranged between 4681-9186 kg.cm^{-2}, while in perpendicular direction ranged between 17553-558289 kg cm^{-2}. The highest and the lowest values of MOE in parallel direction occurred on strand board both prepared from *P. falcataria* strands in perpendicular and parallel layer structures, respectively. Statistical analysis showed that wood species did not affect the values of MOE both in parallel and perpendicular direction. Statistical analysis for MOE values in parallel direction showed that random layer structure and parallel layer structure has similar values of MOE in parallel direction However, they are significantly different with MOE value in perpendicular layer structure. For MOE values in perpendicular direction, statistical analysis showed that strand board prepared from random layer structure and perpendicular layer structure has similar values of MOE. However, they are significantly different with MOE value in parallel layer structure. All MOE values in perpendicular direction met the requirements of CSA 047.0 standard for grade O-1 OSB panels. However, only MOE value of strand board prepared from parallel layer structure met the requirements of CSA 047.0 standard for grade O-1 OSB panels.

The properties of strand board particularly its mechanical properties (i.e., modulus of elasticity and modulus of rupture) were much affected by strand orientation or layer structure (Nishimura & Ansell, 2002). Similar result was reported by Nurhaida *et al*. (2008).

The values of IB ranged between 2.50-9.71 kg cm^{-2}. The highest and the lowest values of IB occurred on strand board prepared from *M. eminii* strands in perpendicular and parallel layer structures, respectively. Statistical analysis showed that wood species did not affect the values of IB. Statistical analysis for IB values showed that random layer structure and parallel layer structure has similar values of IB. However, they are significantly different with IB value in perpendicular layer structure.

All IB values of strand board prepared from *A. mangium* wood and IB values of strand board prepared from *P. falcataria* and *M. eminii* strands in perpendicular layer structures met the requirements of CSA 047.0 standard for grade O-1 OSB panels (Table 2). Mechanical properties of strand board prepared under various wood species and various layer structures.

The values of SHP ranged between 86-138 kgf. The highest and the lowest values of SHP occurred on strand board prepared from *A. mangium* strands in random and perpendicular layer structures, respectively. The value of SHP of strand board prepared from *A. mangium* and *M. eminii* strands are same, but they are different with SHP values of strand board prepared from *P. falcataria* strands.

Conclusion

P. falcataria, M. eminii, and *A.mangium* woods can be used as raw material for strand board with satisfactory properties in term of density, MC, WA, TS, MOR, MOE, IB and SHP parameters. The physical and mechanical properties of strand board were much affected by layer structures. Strand board with perpendicular layer structure resulted in more excellent physical and mechanical properties (i.e., density, MC, WA, TS, MOR, MOE, IB and SHP) compared to strand board prepared from parallel and random layer structures.

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