

## Alternative Materials for Strandboards Made with Waste Veneer from Industrial Plywood In Indonesia

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The objective of this study was to investigate the physical and mechanical properties of strandboard made from the residual veneer material of rubber wood (*Hevea brasiliensis* Müll. Arg.) and falcata wood (*Falcataria moluccana*). The study investigated five different ratios of rubber and falcata (100:0; 75:25; 50:50; 25:75; 0:100). Random strandboards were made at a target density of 600 kg m<sup>-3</sup> using phenol formaldehyde (PF) as resin. All panels were tested through static bending (MOE/MOR). The internal bonding, thickness swelling, and water absorption of the strandboards were also examined. Results showed that the incorporation of the rubber and falcata ratio of 25:75 was substantially greater than the other ratios. The samples using other ratios for MOR, MOE, and physical properties obtained slightly lower mean values compared to the sample with the ratio of 25:75 (rubber and falcata). Based on these results, strandboards obtained from rubber and falcata have the potential to be commercialized.

*Keywords:* Strandboard; Veneer waste; Rubber wood; Falcata wood; Plywood industry

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### INTRODUCTION

Numerous studies have been performed to develop alternative material to replace wood strands with oriented strandboard (OSB). Falcata (*Falcataria moluccana*) and rubber wood (*Hevea brasiliensis* Müll. Arg) are possibly ideal sources for strand-based phenol-formaldehyde resin (Oh and Kim 2015). These are fast-growing plants and widely considered as the most important species to have been planted in Indonesia. However, the application of these species is mostly limited to fuel wood and traditional uses such as chair manufacturing.

To develop higher value applications of fast-growing trees, plywood products have been produced in some industries in Indonesia. However, the efficiency of raw materials is very low, ranging from 30% to 35%. Waste production from the plywood industry is very high; so far, the waste from the plywood industries that used fast-growing timber species has ranged from 65% to 70%. The rest of the waste has included core logs, round up, and veneer. Wasted veneer, which reached 7 million m<sup>3</sup>/year (Ministry of Forestry, Republic of Indonesia 2014), has the potential to be utilized as a composite product. One type of composite product that can be made is OSB. Strandboard is a kind of substitute for plywood panels for interior and exterior uses as sheathing, flooring, and I-joint material. Spelter *et al.* (1997) found that the cost of wood fibers has more than doubled in the past 20 years. They observed that production growth and decreasing quality wood supply have spurred the development of alternative materials to replace wood fibers for OSB

production.

Many attempts have been made to mix various materials by using different species of fast-growing trees to make OSB with desirable properties. Eucalyptus and poplar (Castro and Paganini 2003), poplar and beech (Burdurlu *et al.* 2007), and Japanese sugi and Douglas-fir (Hayashi and Miyatake 1991; Hayashi *et al.* 2002; Goto *et al.* 2004), eucalyptus and beech (Aydın 2004), rubber wood (Malanit and Leamsak 2007), and related layer elements (Rofii *et al.* 2013 and 2016) have been used. Han *et al.* (2005) investigated the use of mixed sugarcane and hardwood oriented strandboard bonded with phenol-formaldehyde resin, finding that sugarcane and wood flakes can be combined to produce 3-layer OSB with desired mechanical properties. Malanit and Laemsak (2007) observed that rubber wood strandboard improved the bending strength and stiffness in the aligned direction. However, strandboard development of waste mix veneer from the plywood industry is very limited, especially from fast-growing wood. Therefore, more research and information concerning the available raw material from wasted veneer is needed.

The objective of this study was to develop comparative properties of mixed rubber wood and falcata wood OSB bonded with PF resin. The effects of various wood combinations on the mechanical and physical properties on OSB were investigated.

## EXPERIMENTAL

### Materials

Strand veneer from veneer waste of rubber wood (*Hevea brasiliensis* Müll. Arg.) and falcata wood (*Falcataria moluccana*) (50 mm x 10 mm to 20 mm x 3.2 mm) used in this research was procured from the plywood industry in Tangerang, Banten, Indonesia. The density of falcata and rubber wood was 300 kg m<sup>-3</sup> and 600 kg cm<sup>-3</sup>, respectively (Abdurrohman *et al.* 2004). Commercial phenol-formaldehyde (PF) resin with solid contents of 50% were obtained from PT. Pamolite Adhesive, Probolinggo, Indonesia.

### Board Fabrication

After the strand veneer was dried, PF was applied to the strand veneer rubber wood and falcata wood in a drum mixer. The density and thickness of the target board were 600 kg m<sup>-3</sup> and 10 mm, respectively. The PF resin without wax was added to the strand with solid content levels of 6.0%, based on the oven dried weight of the strands. Randomly oriented homogenous boards were made with varied ratios of rubber and falcata content: 100:0, 75:25, 50:50, 25:75, and 0:100.

Boards were manufactured by hot pressing at 130 °C using a maximum pressure 2.5 MPa for 10 min with an additional 40 s of press closing. The board dimensions were 350 mm x 350 mm x 10 mm with a target density of 600 kg m<sup>-3</sup>. Three replicates were used for each condition, and a total of 15 boards were manufactured. The panels were trimmed and conditioned for 2 weeks under room conditions at 25 °C and 65% ± 5% RH until they reached equilibrium before testing.

### Physical and Mechanical Property Test

The panels were evaluated according to BS standard EN 300 (BS 2006). The tests included modulus of rupture (MOR), modulus of elasticity (MOE), internal bond (IB), thickness swelling (TS), and water absorption (WA). Three specimens from each board, 343 mm x 74 mm x 10 mm were cut for the static bending test (*i.e.*, MOR and MOE)

Tests in the dry condition were conducted in a three-point bending mode over an effective span of 288 mm at a loading speed of 5.88 mm/min. Three specimens of 50 mm x 50 mm x 10 mm for each condition were tested for IB strength at a testing speed of 0.98 mm/min. The TS and WA tests were carried out on specimens of 50 mm x 50 mm x 10 mm after being soaked in water for 2 h and 24 h at 20 °C. After each soaking, excess water was wiped off the specimen before its thickness and weight was measured. TS was estimated by Eq. 1,

$$TS = \frac{T_f - T_i}{T_i} \times 100\% \quad (1)$$

where  $T_i$  is the initial thickness and  $T_f$  is the final thickness. WA was determined on the basis of initial oven-dry measurements using Eq. 2,

$$WA = \frac{W_f - W_i}{W_i} \times 100\% \quad (2)$$

where  $W_i$  is the initial weight and  $W_f$  is the final weight. Experimental data of the panels at various ratio levels were used to calculate the effect of the proportion of wood basic density on the physical and mechanical properties, based on the compaction ratios (CR) of the panels:

$$CR \text{ Panel} = \frac{\text{Panel Density}}{PDR + PDF} \quad (3)$$

*DR*: density of Rubber (0.6 g/cm<sup>3</sup>)

*DF*: density Falcata (0.3 g/cm<sup>3</sup>)

*P*: proportion of material (100%, 75%, 50%, 25%, 0%)

where *PDR* was the raw material proportion of wood rubber density and *PDF* was the raw material proportion of wood falcata density.

## Data Analysis

A one-way analysis of Variance (ANOVA) and Duncan's multiple range test were used to analyze the data. All statistical tests were performed using SAS at a 95% confidence level.

## RESULTS AND DISCUSSION

### Density Profile

During the hot pressing process, the interaction between heat, moisture, and pressure gave rise to non-uniform deformation of the elements, which resulted in an uneven density distribution along the thickness direction of the board. Typically, this density profile resembles a "U-shape" with the peak density near the board surface, and the lower density in the core region (Kelly 1977).

A near-uniform density profile was noted throughout the thickness of the rubber panels with slightly higher densities at the surface, while the surface densities of falcata panels were significantly higher than those of the core (Fig. 1). The board density of the mixed strand (rubber and falcata) was relatively uniform compared to the other boards. The board density ranged from 530 kg m<sup>-3</sup> to 650 kg m<sup>-3</sup>. The board that produced from low density materials (falcata) results board with differences density between surface and core layer significantly. It was considered that different material density (falcata and rubber)

would affect the density profile of the panels, although the strands used in this study were prepared similarly.

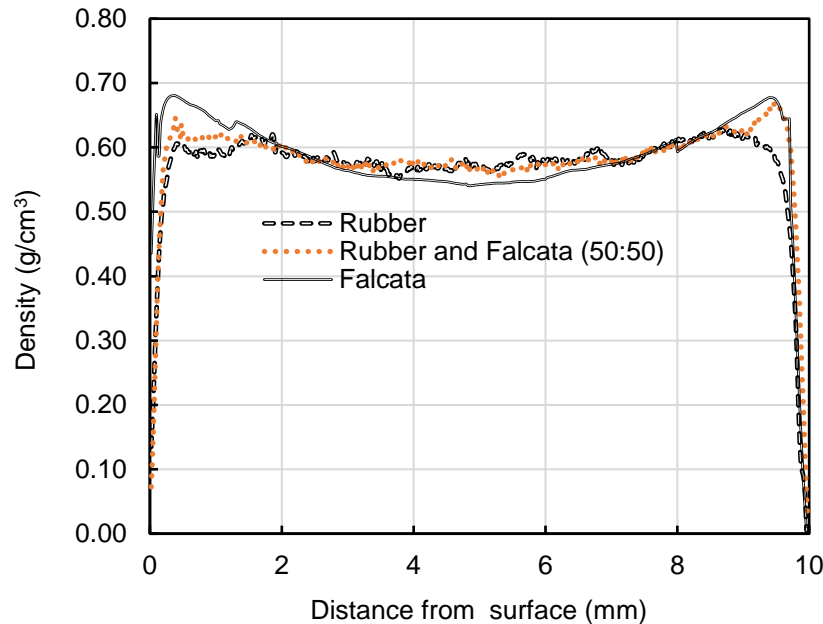


Fig. 1. The density profile board tested of the mixed strand (rubber and falcata)

### Mechanical Properties

The mechanical properties of OSB panels are presented in Fig. 2, which illustrates the relationship between the rubber/falcata weight-ratio and MOR/MOE of the specimens tested under air-dried conditions. The MOR/MOE increased with increasing amounts of falcata strand in the board. Statistical analysis indicated that the amounts of falcata wood significantly increase the mechanical properties ( $F= 17.65$ ,  $df = 4$ ,  $P < 0.05$ ) of the specimens. By increasing the amounts of falcata wood in the board from 0% to 75% the values of MOR are increasing from 3.42 MPa to 8.64 MPa, respectively. The boards with 75% and 100% falcata strand content had good results, although they did not meet the requirements set forth by the standards for commercial panels, as outlined in BS EN 300 (2006).

The 75% falcata and 25% rubber strands, having greater values of modulus elastic and rupture, were more suitable for strandboard manufacturing. At this density, the compaction ratio ranged from 1.09 MPa to 1.75 MPa (density falcata  $300 \text{ kg m}^{-3}$ ); on the other hand, the CR for the rubber strand was only 1.0 MPa. Wood basic density is the most important property to be considered in OSB production; it should range from  $300 \text{ kg m}^{-3}$  to  $500 \text{ kg m}^{-3}$  in order to result in panels with a high CR, which is the ratio given by the mean apparent board density divided by the mean wood basic density (Maloney 1993).

Compaction ratio (CR) is closely related to the physical and mechanical properties of all composite boards. Better mechanical performances of the boards are expected with higher CR, while its effects on physical properties may vary (Bufalino *et al.* 2012). Using only falcata to construct panels resulted in a smaller MOE than was found in the other panels. This indicated that a high compaction ratio decreased the strength of the panel (Fig. 2), (with ratio  $0.55 / 0.30 = 1.75$  (Table 1)). The use of wood with different densities is one solution to increase strength.

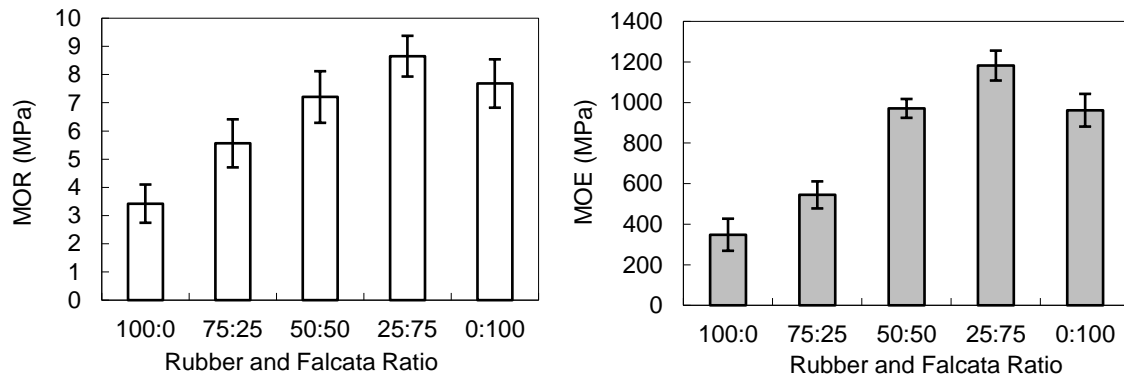


Fig. 2. Modulus elasticity and rupture distributions

Table 1. Several Properties of Board Tests

Parameters	Rubber and Falcata Ratio (%)				
	100:0	75:25	50:50	25:75	0:100
IB (N/mm <sup>2</sup> )	0.38 (0.03)	0.39 (0.05)	0.41 (0.03)	0.44 (0.04)	0.40 (0.05)
Panel Density (g/cm <sup>3</sup> )	0.65 (0.30)	0.61 (0.05)	0.59 (0.03)	0.55 (0,03)	0.53 (0.03)
Proportion of wood basic density*	0.60	0.53	0.45	0.38	0.30
CR panel ratio	1.09	1.16	1.32	1.46	1.75
MOR (MPa)	3.42 (0.68)	5.56 (0.85)	7.20 (0.92)	8.65 (0.72)	7.68 (0.86)
MOE (MPa)	347.89 (79.13)	544.39 (66.68)	970.87 (46.49)	1,182.11 (73.76)	961.82 (80.66)

\*Based on Eq. 3

### Effect of CR Ratio on the Internal Bond

Internal bonding is a parameter test that is of great importance to panel products such as particle boards, fiber boards, strandboards, *etc.* The IB is the best single measure of the quality of manufacturing because it indicates the strength of the bonds between strands. The results showed that all the panels met the requirement of BS EN 300 (2006) for general strandboards. It indicated good adhesion, as well as efficient resin spreading and fine atomization. The IB value of all panels ranged from 0.38 MPa to 0.43 MPa. There was a tendency toward increasingly large proportions of falcata, resulting in smaller densities, due to the influence of raw material spring back (Table 1).

Wood density is an important factor in determining final panel properties, while the basic requirement of raw materials for making strandboard panels with acceptable properties is a relatively low wood density (Woodson 1976; Maloney 1993; Hsu 1997). When the relationship between IB and density was compared, it was found that the higher falcata ratio resulted in better IB properties. This is presumably because the compaction ratio of falcata was higher than rubber and the low density of falcata was easier to consolidate into the target thickness. However, the target density of 600 kg/m<sup>3</sup> is nearly equal to the density of rubber wood, so the adhesive penetration is relatively low, which resulted in smaller IB values.

Maloney (1993) and Hsu (1997) reported that compaction ratio is important, as well-bonded panels are primarily associated with high compaction ratios. The loss of bonding strength is largely attributed to the premature debonding of low-density regions,

and the subsequent load concentration and failure acceleration of the higher-density regions (Dai *et al* 2008). The high variation was affected by resin distribution and density variation. However, there is potential to produce strandboards made from waste of falcata and rubber veneer. Further studies are needed to provide strong bond quality with high density and lower adhesive contents. In general, the low basic density of falcata requires the use of high compaction levels, which increases the bending properties and internal bond strength

### Thickness Swelling and Water Absorption

Thickness swelling (TS) of strandboard is related to moisture content (MC) change during panel manufacture. When OSB panels are submitted to water submersion, internal forces are released, which results in panel swelling. This phenomenon is called springback, and it is stronger when high densification occurs during the pressing process, which in turn, is related to low basic density-woods or higher board density (Hiziroglu 2009). After 2 h of water immersion the thickness swelling ranged from 28% to 31% and increased to 43% to 59%, after 24 h of water immersion (Fig. 3). The effect of proportion ratio of rubber and falcata was found to not be significant for 2 h water immersion, and slightly affected swelling at 24 h of treatment. The difference in TS values between 2 h and 24 h of immersion showed that there was a tendency for TS to increase with increasing proportions of falcata strand. Water uptake occurred in two-step patterns. During the first 2 h, more than half of the absorption of water occurred. This was followed by a period of very slow and consistent water uptake as reported by Khazaei 2008.

The WA panel was made of a mixture of rubber wood and falcata (WA 2 h = 39%-47%; WA 24 h = 50%-62%, Fig. 3) and was smaller than the strandboard, which was made from a mixture of woods *Pinus oocarpa*, *Eucalyptus grandis*, and *Toona ciliata* as reported by Bufalino (2015). Those values ranged from 32% to 66% for WA 2 h and from 55% to 85% for WA 24 h. Considering the high proportion of rubber in the panel, this result could be possibly attributed to the decreased number of voids in the mat microstructure. The high proportion of rubber acted as a barrier to water entrance, resulting in lower WA. Therefore, higher resistance was found in the panel with all rubber proportions, however, panels made solely from falcata had high WA. This indicated that lower densities of falcata caused high spring back in panel properties until 55% at 24 h water immersion.

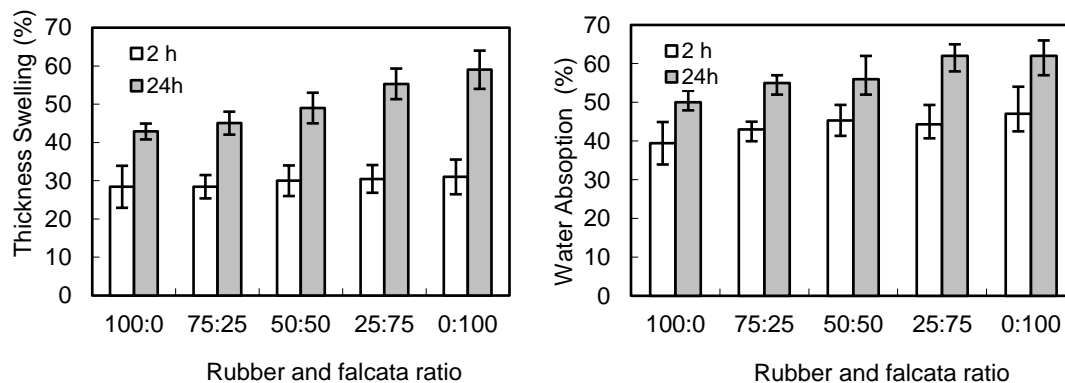


Fig. 3. Effect of rubber and falcata ratio to the panel swelling

The proportion of falcata had the most effect on the value of TS, most likely because the CR of falcata was greater than rubber. This was consistent with the study performed by

Pelit *et al.* (2014), which suggested that the occurrence of springback will be greater in high density panels or on a high compaction ratio. Figure 3 indicated that mixtures of falcata and rubber tended to be better than only using falcata. This was because the density of the target was only 600 kg/m<sup>3</sup>, so the compaction ratio was more common in falcata. This indicated that the most optimal ratio of composition was 75% falcata and 25% rubber, based on the value of bending and IB. Even though TS was classified as high at 24 h, it still met the standards for commercial panels.

## CONCLUSIONS

1. The panels met the IB requirements of EN 300 (2006) but must be improved for TS and MOR/MOE. The other OSB compositions did not fully achieve the standard's requirements.
2. When considering commercial feasibility of the compositions proposed, the ratio of 25% rubber and 75% falcata strand was found to be the best composition for the manufacture of boards.
3. The physical and mechanical properties of strandboard made from materials of different densities materials was found to be better than homogeneous materials.

## ACKNOWLEDGMENTS

The authors thank Institut Teknologi Bandung for funding this research through the Research and Community Service and Innovation Program (P3MI).

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Article submitted: July 26, 2018; Peer review completed: September 9, 2018; Revised version received and accepted: September 18, 2018; Published: September 25, 2018.  
DOI: 10.15376/biores.13.4.8385-8393