Journal of Oil Palm Research Vol. 23 December 2011 p. 1166-1171

PRODUCTION OF OIL PALM TRUNK CORE BOARD WITH WOOD VENEER LAMINATION

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ABSTRACT

Malaysia has abundant oil palm trunks (OPT) from the replanting cycle of oil palm plantations, and these are convertible into value-added products. The most impending and immediate application is for wood composite products. Unlike softwood or hardwood, OPT has a unique physicochemical structure but is inefficient for use in its natural condition in woody application. In this study, the properties of OPT were upgraded via the formation of a core board and lamination process. OPT, as the core layer, was laminated with rubberwood veneers of two thicknesses using urea formaldehyde resin as a binder at three different levels of glue spread rate, and further hot pressed under three different levels of pressures. Tests for density, static bending, shear and water absorption were carried out in accordance with ASTM Standard. The results show that the board using higher glue spread rate and pressing pressure ended up with higher resistance to water absorption and to dimensional changes. The mechanical properties of the OPT core board laminated with 1.0 mm veneer thickness using 200 g m^{-2} glue spread rate and 80 bar pressing pressure were better than the boards produced by other processing variables.

Keywords: oil palm trunk, core layer, veneer thickness, glue spread rate, pressing pressure.

Date received: 20 August 2010; **Sent for revision:** 6 September 2010; **Received in final form:** 6 January 2011; **Accepted:** 25 July 2011.

INTRODUCTION

Oil palm has the largest planting in Malaysia with a total of 4.69 million hectares, and this amounts to about half the land utilised for agriculture in the country (MPOB, 2010). The productive life cycle for an oil palm is between 25 and 30 years. On reaching the replanting stage, the non-productive oil palms will be removed for replanting activities. The Malaysian government has implemented a zero burning policy during the replanting activities, and this has resulted in a huge quantity of felled oil palm trunks (OPT) that need to be disposed off by the oil palm plantation developers every year.

Several research studies have been carried out on the potential use of these by-products of replanting, and the results indicate that OPT possesses the potential for exploitation and conversion into various value-added products such as panels, particle and fibre products as well as chemical derivatives (Badri and Amin, 2006; Wahab *et al.*, 2008; Khalil *et al.*, 2009). However, the successful utilisation of OPT in composite panel products is still limited. This may be due to the fact that OPT poses complex problems that are entirely different from those of commercial timbers. The oil palm, being a monocotyledon, achieves its height without secondary thickening. Such an anatomical structure imparts variable density which increases towards the outer periphery and with the height of OPT (Killmann and Lim, 1985). These variations in the characteristic value reflect the variations in mechanical properties both along the length of an individual fibre and between the fibres. In this connection, preliminary research by the Malaysian Palm Oil Board (MPOB) has demonstrated that the production of OPT as sawn timber is laborious due to the poor processing and working characteristics of this material (Lim and Gan, 2005; Mokhtar *et al.*, 2008).

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In order to make use of OPT and expand its utilisation as a raw material in the processing industry of various types of panels, the panel processing method has to be intricately tailored. Upgrading the properties of OPT can be done in many ways, and one of these methods is via the compaction process of OPT core board which is laminated on both surfaces. OPT core lamination appears to be a feasible solution for the production of value-added products. The core material is normally a material of low strength, however in the case OPT, the overall thickness of OPT used provides the board with high bending stiffness and overall low density. This lamination technology enables a reduction in the varying properties of OPT through lumber production and forms a more dimensionally stable product. Therefore, the main aim of this work was to develop OPT core board with wood veneer lamination on both surfaces. The layers are glued together with adhesive under heat and pressure so that the grain direction of the laminated oil palm lumber and wood veneers run parallel to the longitudinal axis of the panel. The effects of different wood veneer thickness, glue spread rate and pressing pressure during hot press on the properties of the OPT core board with wood lamination are discussed.

MATERIALS AND METHODS

Board Fabrication

The trunks of two 30-year-old oil palms were obtained from an oil palm plantation during replanting activities. These OPT were transported to the Faculty of Forestry, Universiti Putra Malaysia, and were sawn into lumber 150 mm wide, 300 mm thick and 1200 mm long. The lumber were later kiln-dried to between 10% and 12% moisture content (MC) prior to the panel-making process. OPT lumber without drying defects were split and cut into 1000 mm length and 120 mm width, and planed to obtain planks with a thickness of 180 mm. After planing, the density of the planks was determined. In this study, OPT planks with a density above 400 kg m^{-3} were selected for further processing into OPT panels. The selected planks were laminated edge to edge into 480 mm wide panels using polyvinyl acetate (PVAc) glue. The assembled panels were clamped at room temperature for 24 hr for the purpose of glue curing. All the panels were conditioned under a relative humidity of 65 ± 5% and a temperature of 20 ± 2°C for three days. These panels were cut lengthwise to form two panels with dimensions of 18 mm thickness, 450 mm width and 500 mm length for further processing into OPT core boards. Rubberwood (*Hevea brasiliensis*) veneer was laminated onto the OPT panels, using 50% solid content urea formaldehyde (UF) type E1 supplied by the Malayan Adhesives and Chemicals Sdn Bhd.

Experimental Design

OPT core boards were formed by laminating OPT panels with rubberwood veneers at three different glue spread rates, *viz*. 160 g m^{-2}, 180 g m^{-2} and 200 g m^{-2}. Two thicknesses, 0.5 mm and 1.0 mm, of veneer were tested. After application of resin, each board was cold-pressed for 10 minutes to allow for the even distribution of the resin onto the board. The board was then hot-pressed at a temperature of 110°C for 4 min at three different levels of pressing pressure: 60 bar, 70 bar and 80 bar. In total, 18 types of boards with the different processing parameters were produced in this study.

Evaluation

Density and moisture content. Board density was measured on each sample according to the volume over weight method. Volume and weight of the test samples were measured one day prior to physical or mechanical testing. MC of the test samples was determined by the oven-drying method specified in ASTM D4442.

Compaction ratio. The volume of the OPT core boards before hot-pressing and after conditioning was measured. Compaction ratio was calculated according to the following formula (Eq. 1):

$$\text{Compaction ratio} = \frac{\text{Volume}_{\text{before hot-pressing}}}{\text{Volume}_{\text{after hot-pressing}}} \qquad \text{Eq. 1}$$

Physical properties. Tests on the physical properties were carried out according to the ASTM D 1037-99 standard. Results on water absorption (WA), width expansion (WE), linear expansion (LE) and thickness swelling (TS) after 2 hr and 24 hr of soaking are reported in this study.

Mechanical properties. Static bending and the block shear test were carried out according to ASTM D 1037-99. For static bending, test samples of a size of 50 mm width were prepared with the long dimension parallel to the longitudinal axis of the board. The span of the test sample was 16 times the nominal thickness of the samples. The load was applied at the centre of the span at a uniform rate of 9 mm per minute. The test was carried out until the samples showed clear rupture. Two properties were calculated in this study: modulus of rupture (MOR) and modulus of elasticity (MOE).

The block shear test was made on a 20 mm cube of each test sample using a pivoted arm shear apparatus. This test was conducted using an INSTRON Universal Testing Machine. The cube

TABLE 1. MEAN DENSITY, MOISTURE CONTENT AND COMPACT RATIO FROM DIFFERENT PROCESSING PARAMETERS IN THE PRODUCTION OF OIL PALM TRUNK CORE BOARDS

Pressure (bar)	Glue spread rate ($g\ m^{-2}$)	Veneer thickness (mm)	Board density ($kg\ m^{-3}$)	Moisture content (%)	Compaction ratio (%)
60	160	0.5	664	11.49	14.97
60	180	0.5	614	11.28	11.87
60	200	0.5	672	11.03	13.03
60	160	1.0	697	11.24	10.57
60	180	1.0	549	11.49	15.45
60	200	1.0	643	11.31	13.74
70	160	0.5	604	9.98	13.18
70	180	0.5	562	10.14	12.93
70	200	0.5	635	10.33	15.64
70	160	1.0	681	12.01	14.24
70	180	1.0	589	11.36	7.99
70	200	1.0	671	11.44	10.72
80	160	0.5	710	10.25	13.35
80	180	0.5	624	10.64	13.14
80	200	0.5	707	10.61	15.59
80	160	1.0	681	12.25	19.74
80	180	1.0	625	11.57	14.61
80	200	1.0	702	11.40	11.86

Note: values of density, moisture content and compaction ratio are the means of 10 replicates.

was loaded through a ball seating, thus, resulting in a relatively small movement of the long pivoted arm giving an approximately vertical shear. The crosshead speed used was 0.61 mm per minute.

RESULTS AND DISCUSSION

Density and Moisture Content

Table 1 shows the density, MC and compaction ratio of the OPT core boards. Board density varied from 549 kg m^{-3} to 710 kg m^{-3}. The board produced with 80 bar pressing pressure, 160 g m^{-2} glue spread rate and a veneer thickness of 0.5 mm had the highest board density. It was also revealed that generally boards using 80 bar pressing pressure produced a higher board density. Younesi and Bahrololoom (2009) stated that composite density increased gradually with an increase in the pressure of hot-pressing. They found that this effect was related to a decrease in the number of voids and porosities in the composites. MC for all the boards, ranging from 9.98% to 12.25%, was close to the targeted MC (which is 12%) after one week of conditioning.

Compaction Ratio

The compaction ratios of the core boards ranged from 1.09 to 1.25. The OPT core board with processing parameters of 80 bar pressing pressure, 160 g m^{-2} glue spread rate and a veneer thickness of 1.0 mm showed the highest compaction ratio of 1.25%.

Physical Properties

Analysis of variance (ANOVA) (*Tables 2* and *3*) revealed significant interactions at $p \leq 0.05$ among the processing parameters in the OPT core board production for WA, WE and TS after both soaking periods of 2 hr and 24 hr. No significant interaction was observed among these parameters for LE for either of the soaking periods. However, significant differences were observed for two independent parameters (glue spread rate and veneer thickness) for LE after 2 hr soaking, and for all the three independent parameters for LE in the 24-hr soaking period.

Generally, boards produced using a pressing pressure of 80 bar and a glue spread rate of 200 g m^{-2}, regardless of veneer thickness, showed the lowest dimensional changes and water absorption. This may be due to the fact that the pressing pressure of 80 bar provided a higher compaction ratio than the lower pressing pressure during hot press. It has been observed that compaction ratio for OPT core board increased with increasing pressing pressure. Vital *et al.* (1974) reported that boards with a higher compaction ratio absorbed a lower amount of water than those with a lower compaction ratio during

TABLE 2. LEVEL OF SIGNIFICANT DIFFERENCE FOR ALL THE PROCESSING PARAMETERS (at a 2-hr soaking period)

Parameter	df	Pr > F			
		WA	WE	LE	TS
Pressure	2	0.0348	0.0001	0.0704	0.5275
Glue spread rate	2	0.0001	0.0001	0.0532	0.0001
Veneer thickness	1	0.234	0.2345	0.0154	0.0699
Interaction	4	0.0001	0.0001	0.2167	0.0001

Note: WA – water absorption. LE – linear expansion.
WE – width expansion. TS – thickness swelling.

TABLE 3. LEVEL OF SIGNIFICANT DIFFERENCE FOR ALL THE PROCESSING PARAMETERS (at a 24-hr soaking period)

Parameter	df	Pr > F			
		WA	WE	LE	TS
Pressure	2	0.0022	0.8937	0.0271	0.0015
Glue spread rate	2	0.2041	0.0001	0.0153	0.0001
Veneer thickness	1	0.7907	0.4586	0.0293	0.0519
Interaction	4	0.0019	0.0149	0.4029	0.0001

Note: WA – water absorption. LE – linear expansion.
WE – width expansion. TS – thickness swelling.

the water dimensional stability test. Water entered into a board with a higher compaction ratio at a slower rate due to the decreased board porosity. In addition, the 200 kg m^{-3} glue spread rate applied to consolidate the wood veneers with OPT ensured intimate contact between the two materials. The veneer and glueline could have acted as a partially water-resistant layer which decelerated the water intake of the more porous material, *i.e.* OPT. An experiment carried out by Zhang *et al*. (1994) revealed that insufficient glue spread rate and pressing pressure failed to develop a proper glue bond between the two materials in a board due to poor contact of the resin. Khalil *et al.* (2010) reported that panels using a higher adhesive spread level had lower water absorption than panels using a lower adhesive spread level. They explained that this may be due to the higher compatibility between the hydrophilic fibre and adhesives in panels using a higher adhesive spread level. Greater intimate contact occurred with an increase in pressing pressure and a higher glue spread rate, resulting in a panel with better dimensional stability when subjected to the soaking test. Sreekala *et al.* (2002) mentioned that weak compatibility between the fibre surface and the adhesive could lead to the formation of void structures within the composites which facilitated water absorption.

Mechanical Properties

The properties of wood composite are influenced by the final board density (Yano *et al.*, 1997; 2000; Yano, 2001). Therefore, in order to consider the impact of density on the mechanical properties of OPT core boards, the obtained values were adjusted based on formulae used by Garcia *et al.* (2005) and Xing *et al.* (2007). Thus, the static bending properties in this study were adjusted to the same density level to remove the impact of board density. For MOR and MOE of each sample, the adjusted values of specific MOR (Eq. 2) and elasticity to density ratio (Eq. 3) were calculated from the formulae given below:

$$\text{Specific MOR} = \frac{\text{MOR}}{\text{Board density}} \qquad \text{Eq. 2}$$

$$\text{Elasticity to density ratio} = \frac{\text{MOE}}{\text{Board density}} \qquad \text{Eq. 3}$$

The specific MOE and the specific MOR were calculated to provide the data to perform the statistical analyses in this study. The following discussion on board static bending properties (MOR and MOE) is based on the adjusted mean values after eliminating the effect of board density. As shown in *Table 4*, ANOVA revealed no significant interaction at $p>0.05$ among the parameters for specific MOR, elasticity to density ratio and shear strength.

As shown in *Tables 5* to *7*, the least significant difference (LSD) test showed that OPT core boards with a 1.0 mm thick veneer at 160 g m^{-2} and 200 g m^{-2} glue spread rates under a pressing pressure of 80 bar resulted in better performance in their static bending properties. Higher pressure with a thicker veneer provided higher mechanical properties to the OPT core boards. Sellers (1985) reported that a higher pressing pressure during the hot press process is needed for better contact

TABLE 4. LEVEL OF SIGNIFICANT DIFFERENCE FOR ALL THE PROCESSING PARAMETERS

Treatment	df	Pr > F		
		Specific MOR	Elasticity to density ratio	Shear
Pressure	2	0.7991	0.3141	0.0001
Glue spread rate	2	0.0064	0.0440	0.3685
Veneer thickness	2	0.0004	0.0002	0.0001
Interaction	8	0.4330	0.6252	0.8935

Note: MOR – modulus of rupture.

TABLE 5. EFFECT OF PRESSURE ON MECHANICAL PROPERTIES OF THREE-LAYER ENGINEERED BOARDS

Pressure (bar)	Specific MOR*	Elasticity to density ratio*	Shear *
60	0.083[a]	11.78[a]	1.72[b]
70	0.083[a]	11.19[a]	1.69[b]
80	0.082[a]	11.11[a]	5.32[a]

Note: *means with the same letter in the same column are not significantly different at p≤0.05 according to the least significant difference test. MOR – modulus of rupture.

TABLE 6. EFFECT OF GLUE SPREAD RATE ON MECHANICAL PROPERTIES OF THREE-LAYER ENGINEERED BOARDS

Glue spread rate (g m^{-2})	Specific MOR*	Elasticity to density ratio*	Shear*
160	0.086[a]	11.81[a]	2.84[a]
180	0.078[b]	10.67[b]	2.80[a]
200	0.084[a]	11.61[ab]	3.09[a]

Note: *means with the same letter in the same column are not significantly different at p≤0.05 according to the least significant difference test. MOR – modulus of rupture.

TABLE 7. EFFECT OF VENEER THICKNESS ON MECHANICAL PROPERTIES OF THREE-LAYER ENGINEERED BOARDS

Veneer thickness (mm)	Specific MOR*	Elasticity to density ratio*	Shear*
0.5	0.078[b]	10.61[b]	3.26[a]
1.0	0.087[a]	12.12[a]	2.55[b]

Note: * means with the same letter in the same column are not significantly different at p≤0.05 according to the least significant difference test. MOR – modulus of rupture.

and to generate good bonding. Pressing pressure is normally used to enhance wetting by bringing the liquid resin into molecular contact with the wood surfaces and also to force the resin to penetrate into the wood structure for more effective mechanical interlocking that would eventually generate good bonding between the two wood substrates (Vick, 1999). During our pressing process, the mechanical interlocking between the OPT fibre and UF resin could have improved the mechanical strength of the OPT core boards. The combination of high pressing pressure and high glue spread rate caused the resin to more efficiently penetrate porous material such as OPT. Thus, this caused more loading of the resin into OPT and the formation of covalent bonding between the resin and OPT which improved the mechanical strength of the boards. Curry (1957) also stated that increased board strength may be expected with an increase in pressing pressure which results in a higher compaction ratio. Vital *et al*. (1974) found that particleboards had higher MOR values as the compaction ratio increased from 1.2 to 1.6.

Depending on veneer thickness, the strength of a veneer panel laminated in the hot press can increase compared to the strength of the un-laminated substrate. As observed in this study, the thicker veneer used to produce OPT core board performed better in its mechanical properties. Král (2006) stated that a thicker veneer has higher compactibility compared to a thinner veneer. Thus, the effects of thickness loss (compactibility) do not only change density and strength but also other properties related indirectly to the change in density. Compactibility is made possible by free cell spaces which are filled with air. Due to the effect of pressure, the cell walls will recede into these spaces, resulting in higher density and strength.

CONCLUSION

The pressure of hot pressing and glue spread rate during the manufacture of OPT core boards are the dominant parameters in determining their physical and mechanical properties. Veneer thickness used for laminating the OPT core, on the other hand, has a smaller effect on the physical and mechanical properties of the boards. Higher hot pressing pressure and a higher glue spread rate during the manufacture of the oil palm core plywood give better dimensional stability with lower water absorption. Generally, the optimum processing parameters in producing OPT core boards with rubberwood veneer lamination are 1.0 mm veneer thickness, 80 bar hot pressing pressure and 200 g m^{-2} of glue spread rate.

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