Physico-mechanical properties and fracture characteristics of composite lumber from bamboo strips and oil palm trunk veneers

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Introduction

Wood-based veneer has been widely used in structural applications. Nowadays, wood supply has become shortage since it is highly sought for the wood-based products. Fortunately, Malaysia has a lot of forest resources such as bamboo and oil palm as alternative materials for lumber and panel products. Previously, Kamarulzaman et al [2], Razak et al [3] and Abdul Hamid et al [4] had also studied the properties and potential of oil palm veneers for wood-based industry. According to Kamarulzaman et al [2], the performance of oil palm trunk (OPT) veneer lumber was improved by combining OPT with several layers of rubberwood veneers. The combinations have resulted in the improvement of bending and compression strength of laminated veneer lumber from OPT. Apart from rubberwood veneers, bamboo strips also have a great potential to be utilized as laminated lumber in Malaysia. A study on composite lumber from bamboo strips and oil palm trunk veneers was conducted with the following objectives: (1) to determine the mechanical and physical properties of composite lumber at different pressing times and layer orientations, and (2) to observe the fracture characteristics of composite lumber at different pressing times and layer orientations.

Experimental

Raw Material Preparation

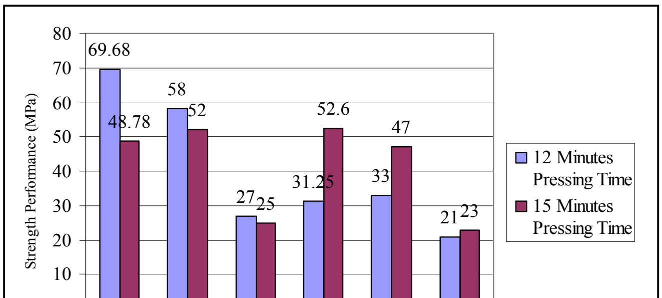
The dried oil palm trunk veneers with an average thickness of 6 mm, were supplied by local wood-based supplier. They were stacked in laboratory to allow air-drying process. Semantan bamboo, or its scientific name *Gigantochloa scortechinii*, was selected for the production of bamboo strips. The bamboo was harvested from bamboo plantation in Felda Mempaga, Bentong, Malaysia. The round bamboo were cut into 60 cm in length, and air-dried for several weeks prior to production process of composite lumber.

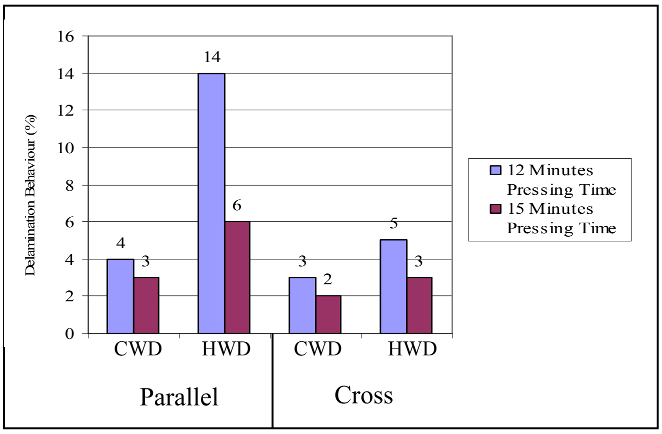
Production Process and Performance Tests of Composite Lumber

The bamboos were split using bamboo splitter machine to produce bamboo strips with 2 cm width. The strips were planed using planer machine to get the thickness of approximately 6 mm. The adhesive used was phenol formaldehyde (PF). PF was spread on bamboo strips and oil palm trunk veneers using glue roller machine with a spreading rate of 212.8 g/m^2. The bamboo strips and oil palm trunk veneers were laid-up together alternately with two different types of layer orientation, such as parallel and cross orientation to each other. The total number of layers was seven (7). The composite was pressed using hydraulic hot pressing machine at two different pressing times such as 12 and 15 minutes. The targeted thickness of composite after pressing was 18 mm. The composite was cooled, trimmed and finally sanded. The composite was cut for mechanical test, such as flexural and compression, and physical test, such as cold water delamination (CWD) and hot water delamination (HWD). The tests were conducted based on Japanese Agricultural Standard for LVL JAS: SE-10 [1]. The thickness, width and length of flexural sample was 18 x 90 x 550 mm, respectively, while compression was 18 x 25 x 50.8 mm, respectively. The thickness, width and length of both CWD and HWD samples were 18 x 75 x 75 mm, respectively. Prior to testing stage, all samples were conditioned in conditioning chamber at 65 ± 5 % relative humidity and 20 ± 2 °C temperature. Modulus of elasticity (MOE) and modulus of rupture (MOR) in flexural were calculated. Compression perpendicular to the grain test was conducted and maximum compressive stress (MCS) was calculated. The CWD was conducted by submerging the samples in cold water for 24 hours, and then dried at temperature of 60 ± 3 °C for 24 hours. The HWD was conducted by submerging the samples for five hours in boiling water, followed by 1 hour in cold water, and finally oven-dried at 60 ± 3 °C for 24 hours. The delamination was measured in term of percentage (%) and the ratio of delamination was not more than 10 % of total glue lines. Fracture characteristics of composite lumber under mechanical and physical performance tests were investigated by observing the pattern of failure by naked eyes and low magnification microscope for each sample tested. Failure modes were identified according to the appearance of fractured surface and manner in which the failure develops.

Results and Discussion

Figure 1 shows the mean mechanical and physical properties of composite lumber (CL) at different pressing times and layer orientations, while Table 1 shows the significant difference of those values. From Figure 1 (a) and Table 1 (a), MOE and MOR of parallel orientation at 12 minutes pressing time (MOE = 6968MPa, MOR = 58MPa) was significantly higher than 15 minutes (MOE = 4878MPa, MOR = 52MPa). MCS of parallel orientation at 12 minutes (27MPa) was insignificantly higher than 15 minutes (25MPa). On the other hand, MOE and MOR of cross orientation at 12 minutes pressing time (MOE = 3125MPa, MOR = 33MPa) was significantly lower than 15 minutes (MOE = 5260MPa, MOR = 47MPa). MCS of cross orientation at 12 minutes (21MPa) was insignificantly lower than 15 minutes (23MPa). Longer pressing time has only influenced the increment of strength for cross orientation. This was due to the cross laminates orientation that influenced the strong bonding behaviour between bamboo strips and oil palm trunk veneers under longer pressing time. At 12 minutes pressing time, strength performance of parallel orientation (MOE = 6968MPa, MOR = 58MPa, MCS = 27MPa) was significantly higher than cross orientation (MOE = 3125MPa, MOR = 33MPa, MCS = 21MPa). At 15 minutes pressing time, MOR of parallel orientation (52MPa) was significantly higher than cross orientation (47MPa). MCS of parallel orientation (25MPa) was insignificantly higher than cross orientation (23MPa). However, MOE of cross orientation (5260MPa) was higher than parallel (4878MPa), although the difference was not significant. The results showed that cross orientation of bamboo strips and oil palm trunk veneers has good influence only on MOE. Poor adhesion between bamboo strips and oil palm trunk veneers was believed to influence poor strength performance of cross orientation. Additionally, the density of oil palm stem is generally low with considerable density variability over the stem [5], thus reduced the strength. From Figure 1 (b) and Table 1 (b), CWD of parallel orientation at 12 minutes pressing time (4%) was insignificantly higher than 15 minutes (3%). However, HWD of parallel orientation at 12 minutes (14%) was significantly higher than 15 minutes (6%). On the other hand, CWD and HWD of cross orientation at 12 minutes pressing time (CWD = 3%, HWD = 5%) were insignificantly higher than 15 minutes. At 12 minutes pressing time, CWD of parallel orientation (4%) was insignificantly higher than cross orientation. In contrast, HWD of parallel orientation (14%) was significantly higher than cross orientation (5%). At 15 minutes pressing time, delamination of parallel orientation (CWD = 3%, HWD = 6%) was insignificantly higher than cross orientation (CWD = 2%, HWD = 3%). Low delamination values were due to the cross orientation of bamboo strips and oil palm trunk veneers that influenced good bonding behaviour, thus reduced the potential of delamination.





(b)

Figure 1. The Mean Mechanical and Physical Properties of CL at Different Hot Pressing Times (12 and 15 minutes) and Layer Orientations (Parallel and Cross Orientations): (a) The Mean MOE, MOR and MCS Values, (b) The Mean CWD and HWD Values

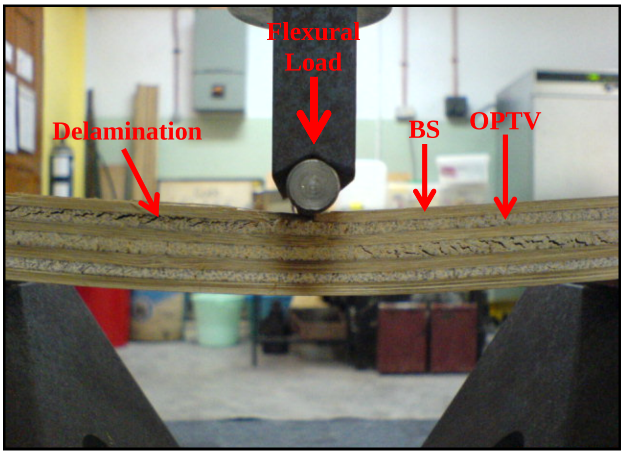
Table 1. The Significant Difference of Mechanical and Physical Properties of CL at Different Hot Pressing Times and Layer Orientations: (a) The Significant Difference of MOE, MOR and MCS Mean Values, (b) The Significant Difference of CWD and HWD Mean Values (Notes: Means with the same letter are for comparison between two variables, different numbers indicate the variables are significantly different at α = 0.05)

CL	Pressing Time (min.)	Mechanical Properties (MPa)		
		MOE	MOR	MCS
Parallel	12	$6968^{A1, G1}$	$58^{C1, I1}$	$27^{E1, K1}$
	15	$4878^{A2, H1}$	$52^{C2, J1}$	$25^{E1, L1}$
Cross	12	$3125^{B1, G2}$	$33^{D1, I2}$	$21^{F1, K2}$
	15	$5260^{B2, H1}$	$47^{D2, J2}$	$23^{F1, L1}$

(b)

CL	Pressing Time (min.)	Physical Properties (%)	
		CWD	HWD
Parallel	12	$4^{M1, Q1}$	$14^{O1, S1}$
	15	$3^{M1, R1}$	$6^{O2, T1}$
Cross	12	$3^{N1, Q1}$	$5^{P1, S2}$
	15	$2^{N1, R1}$	$3^{P1, T1}$

Figure 2 shows the fracture characteristic of CL after the flexural test. Delamination occurred between bamboo strips and oil palm trunk veneers, especially at the compression zone due to vertical flexural load.



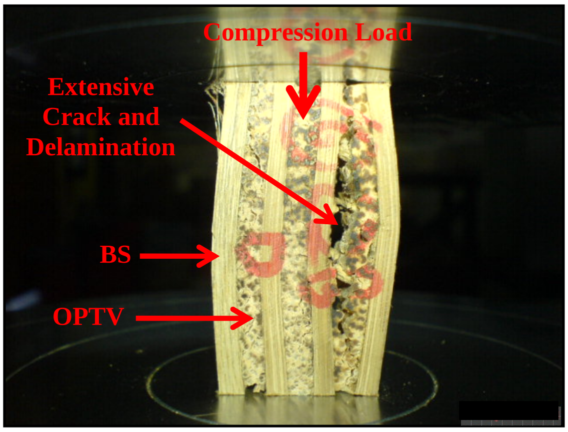
Note: OPTV = Oil Palm Trunk Veneer, BS = Bamboo Strip

Figure 2. Fracture Characteristic of CL after flexural test

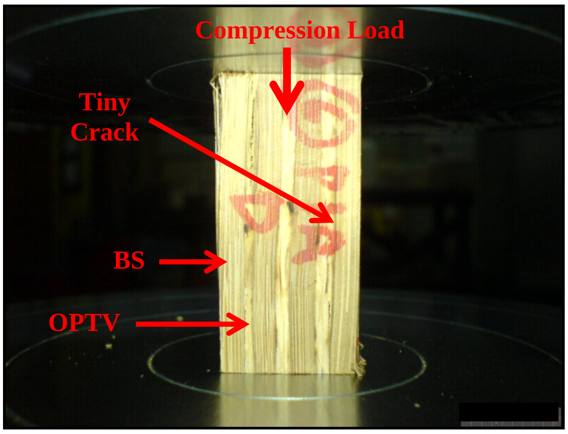
Figure 3 shows the fracture characteristic of CL after the compression test. From Figure 3 (a), cross orientation samples from 12 and 15 minutes pressing times showed the extensive

(a)

crack and delamination between bamboo strips and oil palm trunk veneers, caused by vertical compression loading direction. Cross-oriented lamination of CL has influenced the extensive failure modes and at the same time reduced the MCS value compared to parallel-oriented lamination. From Figure 3 (b), parallel orientation samples from both pressing times showed only tiny crack between bamboo strips and oil palm trunk veneers. The parallel-oriented direction of laminate has increased the vertical compressive resistance of CL.



(a)

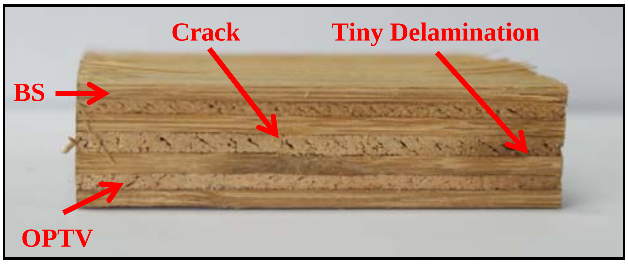


(b)

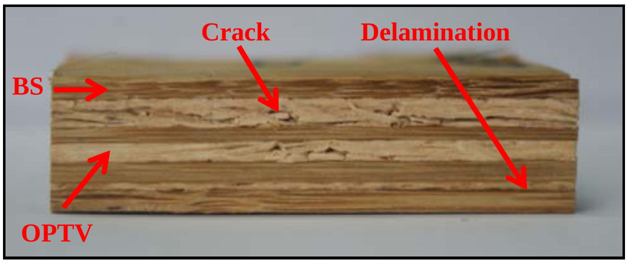
Note: OPTV = Oil Palm Trunk Veneer, BS = Bamboo Strip

Figure 3. Fracture Characteristic of CL after compression test: (a) Cross Orientation, (b) Parallel Orientation

Figure 4 shows the fracture characteristic of CL after the CWD test. From Figure 4 (a), cross orientation samples from 12 and 15 minutes pressing times showed only tiny delamination between bamboo strips and oil palm trunk veneers, and crack within oil palm trunk veneers caused by water absorption. From Figure 4 (b), parallel orientation samples from both pressing times showed delamination between bamboo strips oil palm trunk veneers, and crack within oil palm trunk veneers. It is believed that the cracks occurred within oil palm trunk veneers was influenced by the low density of oil palm stem with density variability within oil palm veneer [5].



(a)

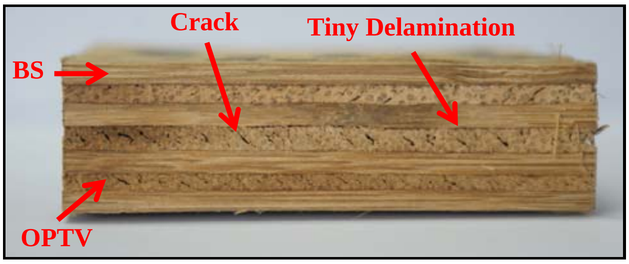


(b)

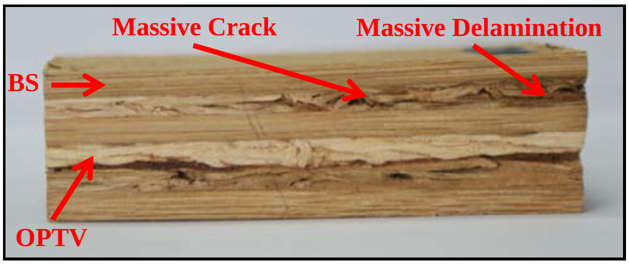
Note: OPTV = Oil Palm Trunk Veneer, BS = Bamboo Strip

Figure 4. Fracture Characteristic of CL after CWD test: (a) Cross Orientation, (b) Parallel Orientation

Figure 5 shows the fracture characteristic of CL after the HWD test. From Figure 5 (a), similar to CWD, the cross orientation samples from both pressing times showed only tiny delamination between bamboo strips and oil palm trunk veneers, and crack within oil palm trunk veneers. However, from Figure 5 (b), parallel orientation samples from both pressing times showed massive delamination between bamboo strips and oil palm trunk veneers, as well as massive crack within oil palm trunk veneers due to hot water absorption during HWD test and low veneer density. This massive failure mode has influenced the high percentage of delamination for parallel lamination compared to cross lamination.



(a)



(b)

Note: OPTV = Oil Palm Trunk Veneer, BS = Bamboo Strip

Figure 5. Fracture Characteristic of CL after HWD test: (a) Cross Orientation, (b) Parallel Orientation

Conclusion

This study showed that the longer pressing time has increased the mechanical and physical performance, except for mechanical performance of parallel orientation board. Cross orientation has increased the bonding strength behaviour between bamboo strips and oil palm trunk veneers, thus influenced the good modulus of elasticity value and low delamination percentage. From fracture characteristic, it is observed that the different failure behaviour was influenced by different types of layer orientation, especially in compression, CWD and HWD tests. Different pressing times had not influenced any difference of failure modes.

References

[1] Anonymous. Japanese Agricultural Standard (JAS) for Structural Laminated Veneer Lumber Japan, Ministry of Agriculture, Forestry and Fisheries. (1993).

[2] Kamarulzaman Nordin, Mohd Ariff Jamaludin, Mansur Ahmad, Hashim W. Samsi, Abdul Hamid Salleh and Zaihan Jalaludin. Minimizing the Environmental Burden of Oil Palm Trunk Residues Through the Development of Laminated Veneer Lumber Products. Management of Environmental Quality: An International Journal Vol. 15 No. 5, 2004. Pp. 484-490 Emerald Group Publishing Limited. (2004).

[3] Razak Wahab, Hashim W. Samsi, Aminuddin Mohamad, Othman Sulaiman and Rafidah Salim. Properties of Laminated Veneer Lumbers from Oil Palm Trunks. Journal of Plant Sciences, 3 (3): 255-259. (2008).

[4] Abdul Hamid, S., H.P.S. Abdul Khalil, A. Khairul, W. A. Wan Tarmezi and M.S. Shakri. Recovery and Physical Properties of Oil Palm Veneers and its Effects on the Density of LOPVL Boards. International Conference on Environmental Research and Technology (ICERT 2008). Pp. 163 – 166. (2008).

[5] S. C. Lim and K. S. Gan. Characteristics and Utilization of Oil Palm Stem. Timber Technology Bulletin No. 35. Forest Institute of Malaysia. (2005).