

Bending and Compressive Properties of Finger-jointed Oil Palm Wood Products

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This work aimed to investigate the effects of the length of finger-contacted surfaces and oil palm wood densities on bending and compressive properties in the case of finger-jointed oil palm wood products (FJOP). The FJOP were manufactured from oil palm wood raw materials of three different density ranges ($303 \text{ kg/m}^3 \pm 14 \text{ kg/m}^3$, $381 \text{ kg/m}^3 \pm 24 \text{ kg/m}^3$, and $476 \text{ kg/m}^3 \pm 21 \text{ kg/m}^3$) using the same finger profile. Polyvinyl acetate was used for bonding. For each density range, FJOP were produced with three different lengths of the finger-contacted surfaces (6 mm, 8 mm, or 10 mm). The length of finger-contacted surfaces did not significantly affect the bending and compressive properties of FJOP for each density range. All examined properties of FJOP increased with oil palm wood density. However, most of the examined properties of FJOP were slightly lower compared with that of solid oil palm wood without the finger joint of the same density. In view of strength, FJOP especially at high density could be used for further processing of cross laminated timber as its original solid wood was used.

Keywords: Finger joint; Oil palm wood; Bending and compressive properties

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INTRODUCTION

In Southeast Asia, oil palm trunk can be considered an alternative potential raw material for wood-based products because there is a large area of plantations of oil palm trees in this region (Musikavong and Gheewala 2017; FAO 2018). The oil palm trunk is comprised of soft parenchyma ground tissue reinforced with vascular bundles (Erwinsyah 2008). Moreover, multiple vascular bundles in the periphery region of the cross-section are higher than in the central region (Erwinsyah 2008; Fathi 2014). Generally, physical and mechanical properties of oil palm wood within a trunk, which are mostly determined through the vascular bundle, are not uniform. However, a precise grading of the properties of oil palm wood for a whole trunk has been achieved for practical use (Erwinsyah 2008; Fathi 2014; Srivaro *et al.* 2018a,b). In order to achieve more effective use of oil palm wood material, exploration of the oil palm wood jointing process, which is generally needed to produce wood-based products, is still required.

Generally, wood jointing can be made either along the width or the length of the lumber, and adhesive is generally used as bonding for this process (Jokerst 1981; Kretschmann 2010). It is widely known that the end jointing of wood requires difficult processes because the glue bonding ability of wood in the longitudinal direction is poor

(Kamke and Lee 2007; Kretschmann 2010). For this reason, many types of end jointing patterns of wood have been developed with the objective of enhancing the joint strength and ideally to achieve a final product of equivalent mechanical properties to the original solid wood (Jokerst 1981; Bustos *et al.* 2003; Rao *et al.* 2012). According to the literature, the finger joint is the most widely used end-jointing pattern of wood products for both nonstructural and structural applications (Jokerst 1981; Follrich *et al.* 2007; Ozcifci and Yapici 2008; Kretschmann 2010).

Properties of finger-jointed wood products depend on many factors that involve the manufacturing processes, *i.e.*, adhesive types, application methods, curing time of adhesives, end pressures, *etc.*; material characteristics such as annual ring orientation, finger profile, wood species, density, *etc.*; and the parameters of the finger-jointing machine such as cutting speed, feed speed, chip load, *etc.* (Jokerst 1981; Dagenais and Salenikovich 2008; Kretschmann 2010). The impacts of these parameters on the properties of finger-jointed wood products made of various typical wood species have been widely investigated (Ozcifci and Yapici 2008; Dagenais and Salenikovich 2008; Rao *et al.* 2012; St-Pierre *et al.* 2012; Rao *et al.* 2014). However, such a study has not yet been conducted for oil palm wood.

The aim of this study was to investigate the bending and compression in parallel direction to the fiber properties of finger-jointed oil palm wood products. The effects of some potential parameters, including the length of the finger-contacted surface and the oil palm wood densities, on the examined properties of finger-jointed oil palm wood products that were produced using the same finger profile was explored. The obtained results were also compared with that of solid oil palm wood without a finger joint.

EXPERIMENTAL

Materials

Preparation of raw materials for finger-jointing process

The oil palm wood specimens were dried to approximately 12% moisture content using the kiln at The Research Center of Excellence on Wood Science and Engineering, School of Engineering and Technology, Walailak University, and the dried specimens with the dimensions of 16 mm (radial) × 50 mm (tangential) × 190 mm (longitudinal) were then prepared for the experiment. Prior to the finger-jointing process, these specimens were kept in conditioning rooms (temperature = 20 °C, relative humidity = 65%) for approximately 3 months to achieve the targeted moisture content of 12%. At this moisture content, a constant weight of wood sample was attained. The oil palm wood samples were then classified into three density ranges, namely low-density ($303 \text{ kg/m}^3 \pm 14 \text{ kg/m}^3$), medium-density ($381 \text{ kg/m}^3 \pm 24 \text{ kg/m}^3$), and high-density ($476 \text{ kg/m}^3 \pm 21 \text{ kg/m}^3$). Each value was averaged from 30 specimens. Afterwards, all oil palm wood specimens were machined along the thickness to produce a vertical finger joint profile (Fig. 1) using the finger-jointing machine (model: YNF-16L; Yung Nien Fa Machine Industry Co., Ltd., Taichung, Taiwan).

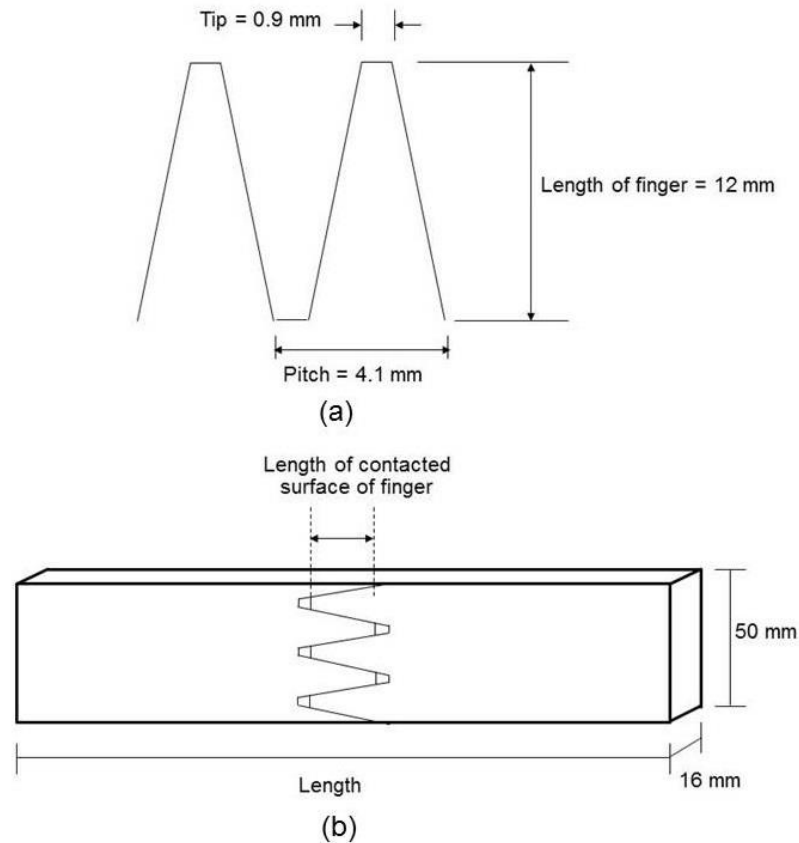


Fig. 1. (a) Finger profile and (b) vertical finger-jointed oil palm wood

Finger-jointing Process

The finger portion of the two pieces of machined oil palm wood specimens of the same density range was dipped into polyvinyl acetate adhesive (Aica Bangkok Co., Ltd., Samut Prakan Province, Thailand) for 10 s. The adhesive used in this work had a polyvinyl acetate content of 35%, a pH value of approximately 4.0 to 6.0, and a viscosity of approximately 9,000 to 13,000 cPs at 30 °C. The glued specimens were then assembled and transferred into a finger-jointing assembly machine (Yung Nien Fa Machine Industry Co., Ltd., Taichung, Taiwan) to produce finger-jointed oil palm wood products (FJOP) with three different lengths of finger-contacted surface (6 mm, 8 mm, and 10 mm) for each density range. Because the pilot study revealed that oil palm wood specimens were easily fractured during the finger-jointing process due to exceeding a critical compressive force, a relatively low-end pressure (Gage pressure = 0.5 MPa) was therefore used to produce FJOP in this study. To achieve the targeted length of the finger-contacted surface without damaging the assembly, the adjustable end stopper was set to a position so that the targeted final length of FJOP with the desired length of finger-contacted surface (TL-FJOP) was achieved when the piston reached its maximum working distance position; to avoid damaging of the assembly, the assembly was not further compressed (Fig. 2). It should be noted that TL-FJOP was equal to the total lengths of two pieces of oil palm wood materials minus the desired length of finger-contacted surface. In this experiment, end pressure and stationary pressure were kept constant at 0.5 MPa during the finger-jointing process. A total of 45 FJOP were produced in this study; 27 FJOP samples for the bending test and 18 FJOP samples for the compression test.

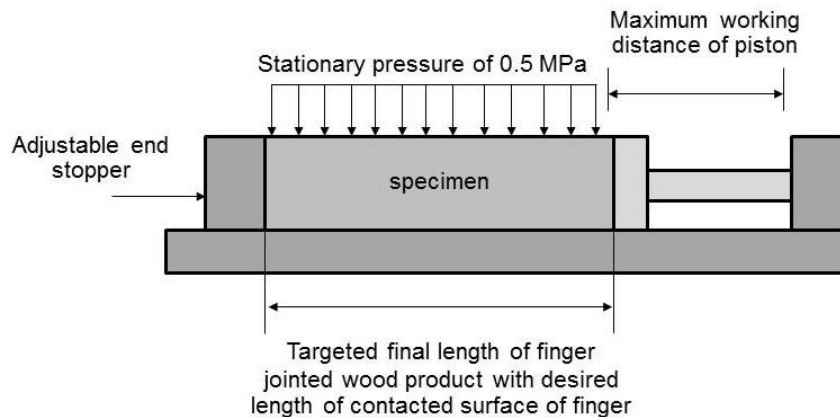


Fig. 2. Manufacturing of finger-jointed oil palm wood products

Methods

Three point static bending test

The three-point static bending test was conducted with some modifications to ASTM D143-09 (2009). The finger-jointed specimens with the dimensions of 16 mm (radial) \times 47 mm (tangential) \times 280 mm (longitudinal) were prepared from the produced FJOP for the three-point static bending test. The specimen was loaded on the flat plane side at the finger-joint position (Fig. 3a) using a universal testing machine (model: H100KU; Tinius Olsen, Horsham, PA, USA). The span length to thickness ratio (L/t) of 14 and crosshead speed of 2 mm/min were kept constant for the entire test. The modulus of rupture (MOR) and modulus of elasticity (MOE) were then calculated. After the bending test, the undamaged zone of the test specimen was cut to prepare the specimen with the dimensions of 8 mm (radial) \times 47 mm (tangential) \times 130 mm (longitudinal). These specimens were used to determine the MOR and MOE of the solid oil palm wood (without the finger joint). The bending test was also conducted using the L/t ratio of 14 as the FJOP specimen was tested. The obtained values were used to compare with that of the FJOP.

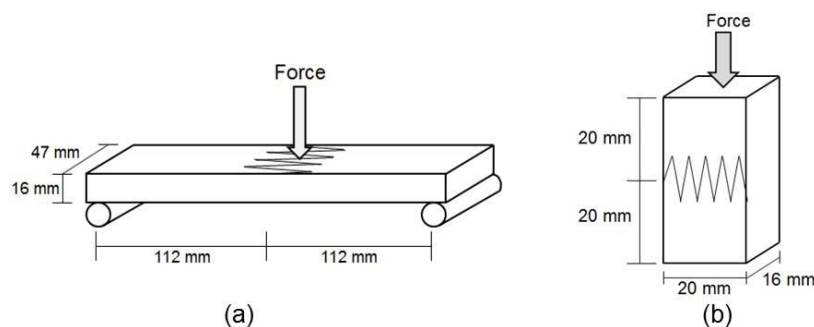


Fig. 3. (a) Three point bending test and (b) compression in parallel direction to the fiber test, of finger-jointed oil palm wood specimens

Compression in parallel direction to the fiber test

Compression in the parallel direction to the fiber test was conducted with some modification to ASTM D143-09 (2009). The test specimens of finger-jointed oil palm wood and oil palm wood without the finger joint with the same dimensions of 16 mm (radial) \times 20 mm (tangential) \times 40 mm (longitudinal) were prepared from the produced

FJOP for compression tests carried out in the parallel direction to the fiber (Fig. 3b). The test specimen was loaded using the universal testing machine until fracture, and the crosshead speed of 2 mm/min was used for the entire test.

The differences between the mean values were statistically evaluated by one way ANOVA analysis at 0.01 level of significant.

RESULTS AND DISCUSSION

Bending Test

The modulus of rupture (MOR_F) and modulus of elasticity (MOE_F) of the produced FJOP are shown in Fig. 4. The results showed that the difference of the lengths of finger-contacted surface did not notably affect the MOR_F and MOE_F of the produced FJOP made of low-density wood, but it seemed to slightly affect the MOR_F and MOE_F of FJOP made of medium- and high-density wood. However, the statistical analysis revealed that the difference of the length of finger-contacted surface had no significant effect on bending properties of FJOP for all examined density ranges. In addition, it was noticed that most of MOR_F and MOE_F of FJOP were not significantly different compared with that of solid oil palm wood without finger joint of the same density range. Only MOR_F of FJOP made of high density wood with the lengths of finger-contacted surface of 6 mm and 8 mm were found to be significantly lower compared with that of solid oil palm wood without finger joint.

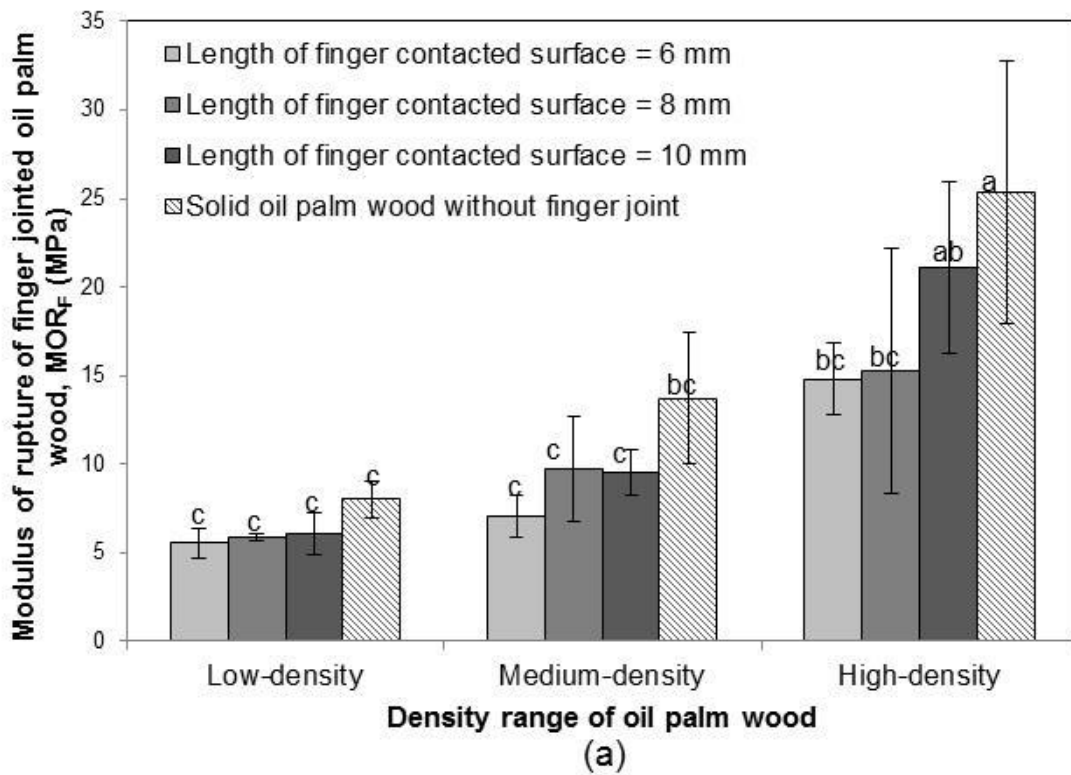


Fig. 4. (a). Modulus of rupture of finger-jointed oil palm wood products at various oil palm wood densities and lengths of finger-contacted surface

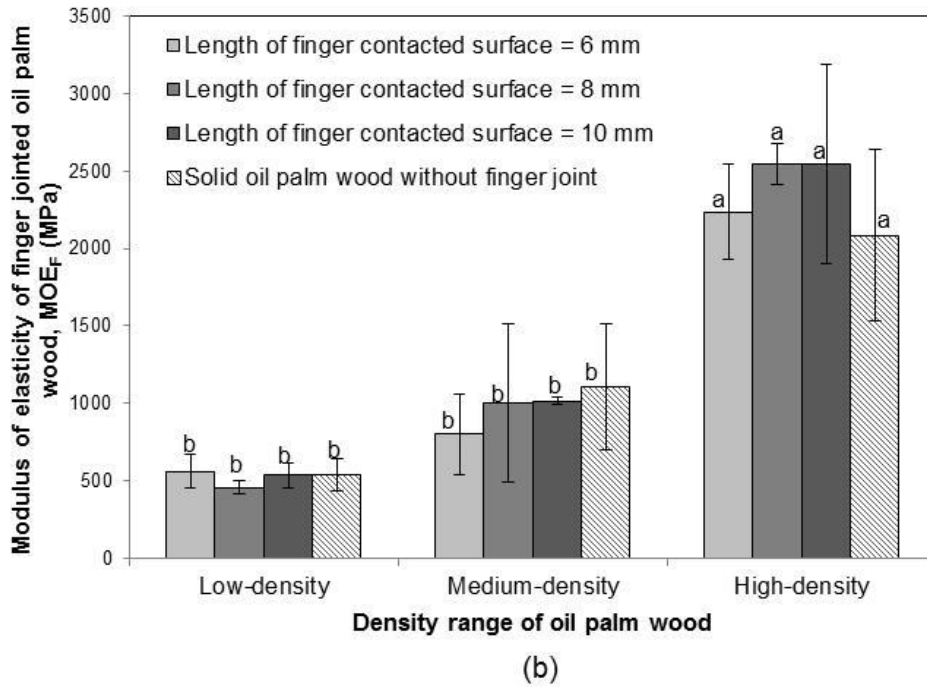


Fig. 4. (b). Modulus of elasticity of finger-jointed oil palm wood products at various oil palm wood densities and lengths of finger-contacted surface

Furthermore, it was noticed that the MOR_F and MOE_F of FJOP made of high-density oil palm wood seemed to be higher (Fig. 4). It is therefore useful to plot both values of FJOP in relationship with density to facilitate the practical design of this product (Fig. 5). MOR_s and MOE_s of the solid oil palm wood specimens without a finger joint were also plotted in the same graph for comparison, as shown in Fig. 5.

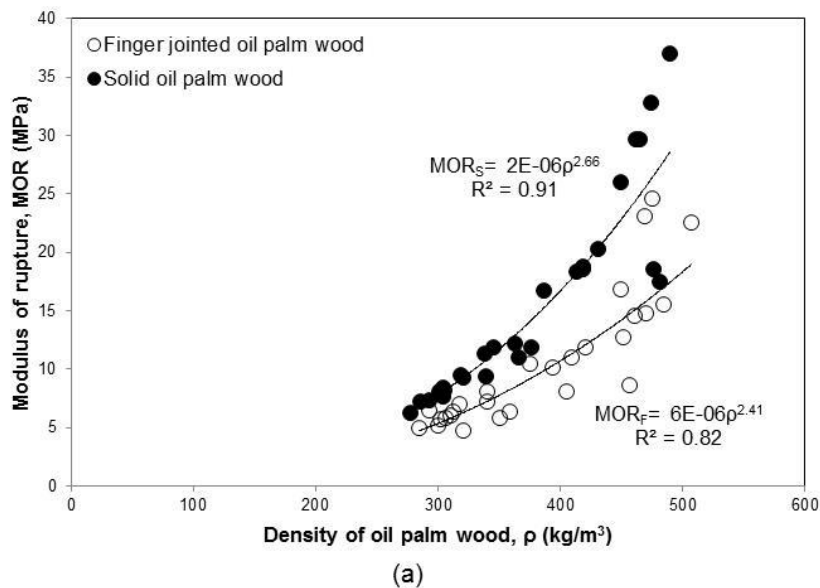


Fig. 5. (a). Modulus of rupture of finger-jointed oil palm wood in comparison to that of solid oil palm wood without finger joint at various densities

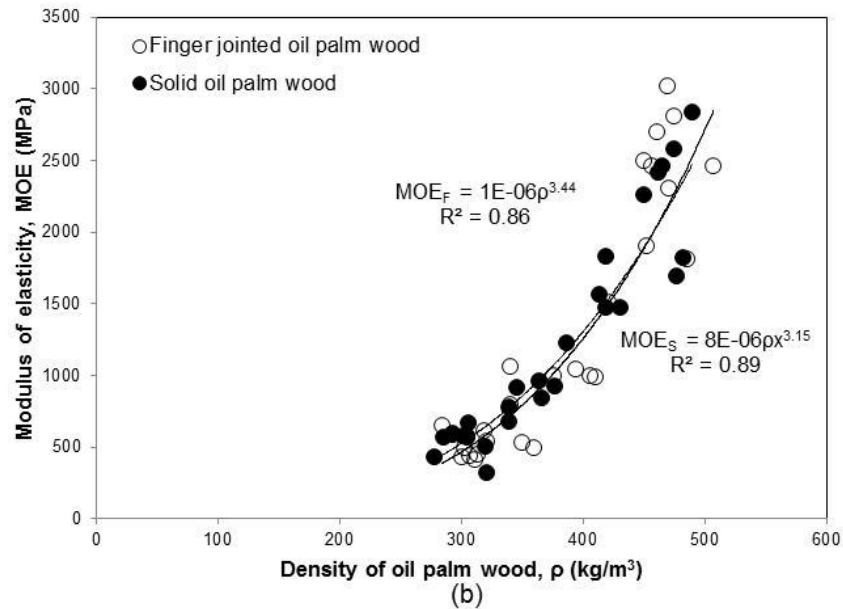


Fig. 5. (b). Modulus of elasticity of finger-jointed oil palm wood in comparison to that of solid oil palm wood without finger joint at various densities

As expected, the modulus of rupture (MOR_S) and modulus of elasticity (MOE_S) of solid oil palm wood without the finger joint increased with increasing density, as it has been reported elsewhere (Srivaro *et al.* 2018a). Interestingly, both values of FJOP also increased with density as a power law relationship (Fig. 5). Notably, MOR_F was slightly lower but MOE_F was roughly similar in comparison to that of solid oil palm wood of the same density range. Moreover, it was also noticed that the difference between MOR_F and MOR_S appeared to increase with increasing oil palm wood density. The MOR_F was approximately 64% to 73% of MOR_S for all examined density ranges. Visual observation of the test specimens revealed that all specimens failed by mixed modes of shearing around the bonded surface areas of the finger and fracturing of wood cells around the finger root (Fig. 6).

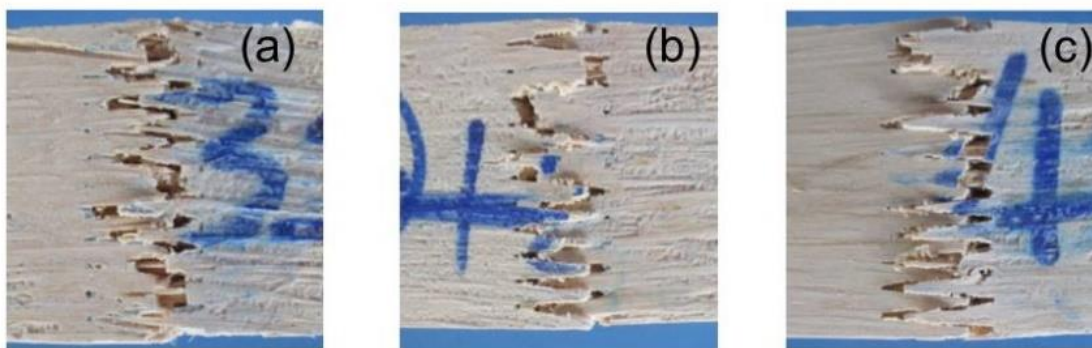


Fig. 6. Failure of finger-jointed oil palm wood specimens after bending test: (a) low-density oil palm wood, (b) medium-density oil palm wood, and (c) high-density oil palm wood

For the first case, it was observed that most parenchyma cells around the bonded surface area of the finger were torn away due to shear force. This implied that the bonding strength of the adhesive used was enough to withstand shear force during a bending test. For the latter case, the primary cause of failure was due to the maximum tensile stress that developed in oil palm wood finger root that reached to the maximum tensile strength of the oil palm wood itself. The failure of parenchyma cells along the bonded surface area of the finger should contribute to lowering the modulus of rupture of finger-jointed oil palm wood because the shearing strength of solid oil palm wood is relatively low compared with its modulus of rupture (Srivaró *et al.* 2018a).

The finger joint efficiency (FE) of oil palm wood (percentage of finger-jointed wood product to solid wood property ratio) obtained from this study was found to be very similar compared with that of rubberwood (FE was approximately 68.3%, MOR = 58.5 MPa), which was produced using the similar finger profile and adhesive type (Nadir and Praveen 2013). However, the MOR_F of FJOP was relatively low. In view of strength, FJOP especially at high density could be used for further processing of cross laminated timber as its original solid wood was used (Srivaró *et al.* 2019).

Compression in Parallel Direction to the Fiber Test

Compressive strength ($\sigma_{//F}$) and modulus ($E_{//F}$) in the parallel direction to the fiber of the produced FJOP are shown in Fig. 7. The results showed that the difference of the lengths of finger-contacted surfaces did not significantly affect the ($\sigma_{//F}$) and ($E_{//F}$) of FJOP for each density range. As shown in Fig. 7, both values of FJOP produced from oil palm wood of the same density range were roughly similar for all of the examined lengths of the finger-contacted surfaces. In comparison to solid oil palm wood at the same density range, it was found that ($\sigma_{//F}$) of FJOP made of high density oil palm wood was significantly lower while the others were not significantly different. In addition, it was also noticed that both values of FJOP appeared to increase with increasing density (Fig. 7).

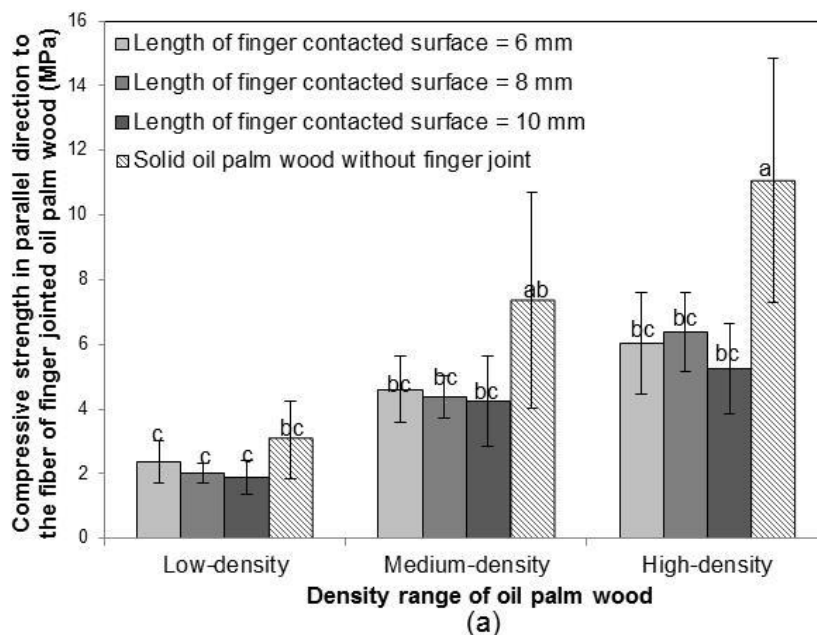


Fig. 7. (a). Compressive strength in the parallel direction to the fiber of finger-jointed oil palm wood products at various oil palm wood densities and lengths of finger-contacted surface

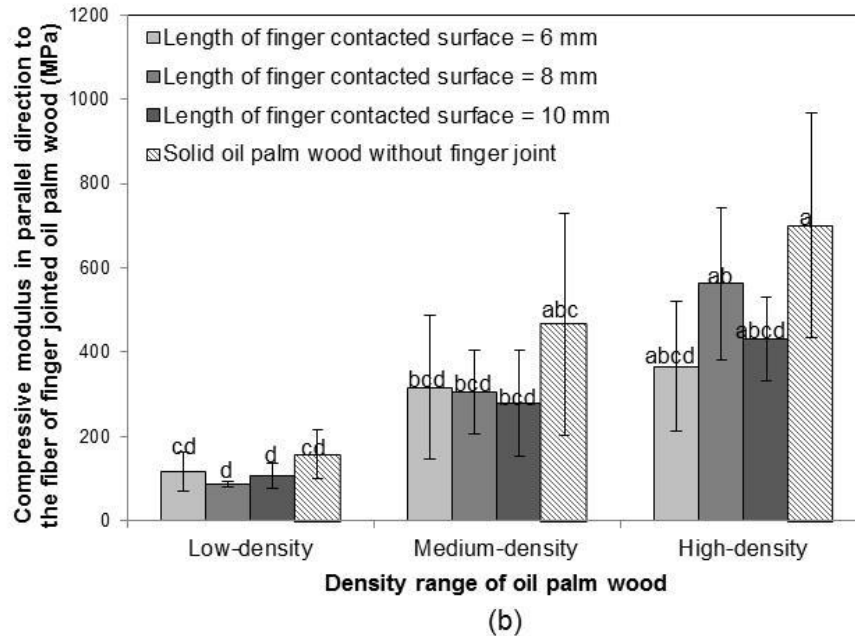


Fig. 7. (b). Compressive modulus in the parallel direction to the fiber of finger-jointed oil palm wood products at various oil palm wood densities and lengths of finger-contacted surface

By plotting both values of FJOP and solid oil palm wood in relationship with density (Fig. 8), it was found that $(\sigma_{//})_F$ and $(E_{//})_F$ of FJOP increased with density as a power law relationship. As expected, that of solid oil palm wood also varied with density as a power law relationship, as it has been reported elsewhere (Srivaro *et al.* 2018a). However, it was noticed that both values of FJOP were slightly lower compared with that of solid oil palm wood without the finger joint of the same density range (Fig. 8).

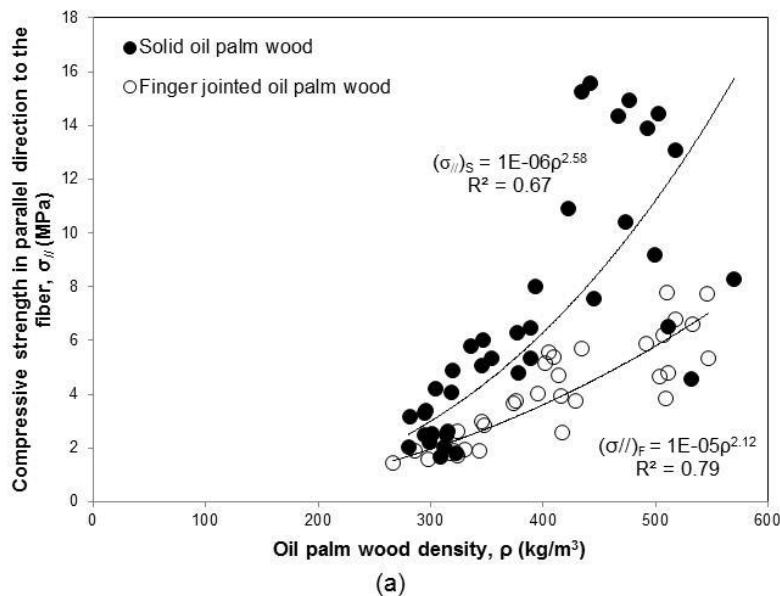


Fig. 8. (a). Compressive strength in the parallel direction of the fiber of finger-jointed oil palm wood in comparison to that of solid oil palm wood without the finger joint at various densities

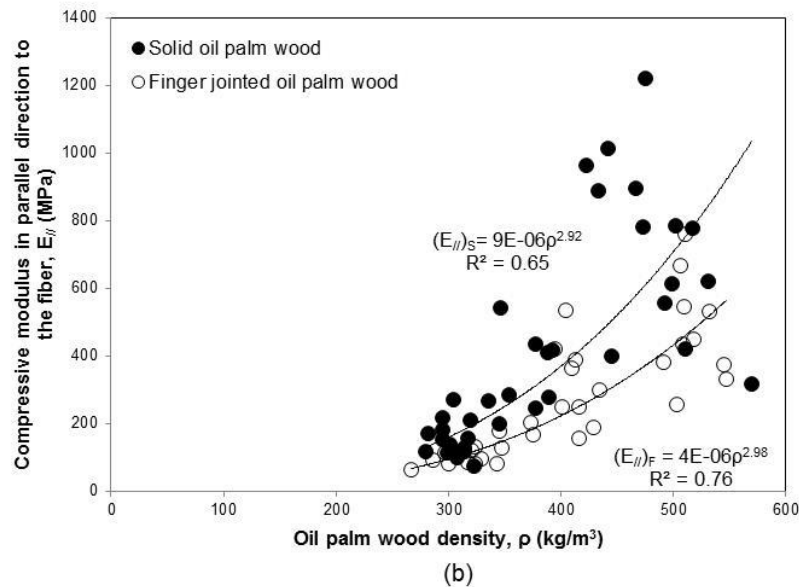


Fig. 8. (b). Compressive modulus in the parallel direction of the fiber of finger-jointed oil palm wood in comparison to that of solid oil palm wood without the finger joint at various densities

Moreover, it was also found that the difference of both values of FJOP and solid oil palm wood appeared to increase with increasing oil palm wood density. The $(\sigma_{//})_F$ and $(E_{//})_F$ of FJOP were approximately 54% to 69% and 59% to 66%, respectively, with respect to those of solid oil palm wood without finger joints for all the examined density ranges. It was visually observed that all test specimens failed around the finger, which might have been a result of a concentration of stress around the finger as shown in Fig. 9.

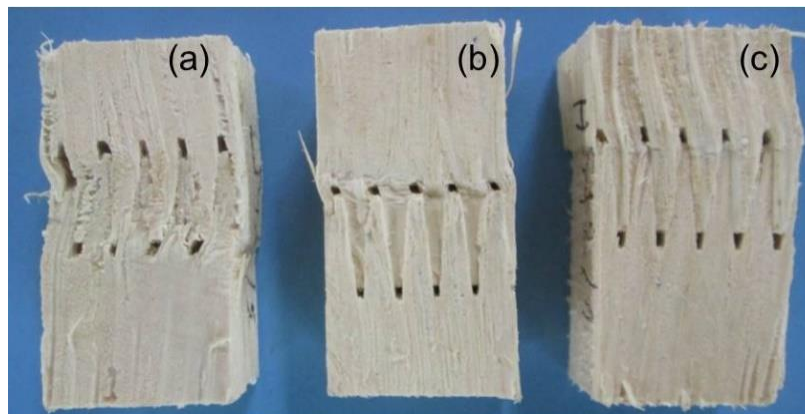


Fig. 9. Failure of finger-jointed oil palm wood specimens after compression in the parallel direction to the fiber test: (a) low-density oil palm wood, (b) medium-density oil palm wood, and (c) high-density oil palm wood

In comparison to other finger-jointed wood products made of other wood species, it was found that the finger joint efficiency of FJOP obtained from this study was lower than that of the finger-jointed rubberwood product that was produced using the same finger profile and adhesive type ($FE = 82.42\%$ for $\sigma_{//}$) (Nadir and Praveen 2013).

CONCLUSIONS

1. The length of the finger-contacted surface did not significantly affect the bending and compressive properties of the finger-jointed oil palm wood products for all examined density range.
2. In comparison to solid oil palm wood without finger joint at the same density range, the compressive strength of finger-jointed oil palm wood made of high density wood for all lengths of finger-contacted surface and the modulus of rupture of finger-jointed oil palm wood made of high density wood with the lengths of finger-contacted surface of 6 mm and 8 mm were significantly lower, while the others were not significantly different.
3. All examined mechanical properties of finger-jointed oil palm wood products were strongly dependent on the oil palm wood density, as a power law relationship.

ACKNOWLEDGMENTS

This work was conducted as part of the Sustainable Raw Material Management Thematic Network - RING 2017 project, which was supported by the European Union, and co-financed by the European Social Fund (Grant No. EFOP-3.6.2-16-2017-00010). This research was also partially supported by the new strategic research (P2P) project, Walailak University, Thailand. The Research Center of Excellence on Wood Science and Engineering, School of Engineering and Technology, Walailak University and the Department of Wood Technology, Faculty of Science and Industrial Technology, Prince of Songkla University (Surat Thani Campus), Thailand were also acknowledged for providing the facilities for experimental work. Special thanks also go to Aica Bangkok Co., Ltd., Samut Prakan Province, Thailand for providing adhesive for the experiment.

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Article submitted: March 14, 2019; Peer review completed: June 3, 2019; Revised version received: June 11, 2019; Accepted: June 14, 2019; Published: June 20, 2019; DOI: 10.15376/biores.14.3.6341-6352