Finger Joint Performance of Green-Glued Rubberwood (*Hevea brasiliensis*) Lumber

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The feasibility of performing finger jointing of green rubberwood was considered with typical adhesives used for gluing kiln-dried wood. The effect of initial moisture content of rubberwood (12 ± 1.1%, 37.6 ± 3.2%, and 61.2 ± 6.1%), hot air oven-drying temperatures (60 °C, 80 °C, and 100 °C), and types of adhesives (polyurethane (PU) and emulsion polymeric isocyanate (EPI)) on bending and compressive properties of finger jointed rubberwood products were investigated. The controls were manufactured from 12 ± 1.1% moisture content rubberwood. The type of adhesives had no significant effect on the examined properties of the finger-jointed specimens. The initial moisture content had a slight effect on the modulus of rupture (MOR) and modulus of elasticity (MOE) of specimens bonded with EPI adhesive. The MOR of all types of specimens bonded with EPI adhesive were slightly lower, but their MOE tended to be slightly higher than the control. The drying temperature slightly improved the MOE of specimens bonded with EPI adhesive. The result suggests that the finger jointing process of green rubberwood using typical adhesives could be performed without notably reducing the strength of the final products compared with the control.

Keywords: Finger jointing; Green rubberwood; Bending and compressive properties

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INTRODUCTION

Generally, finger jointing is performed on kiln-dried lumber with a moisture content of approximately 12% (Frihart and Hunt 2010; Sterley 2012). To save the energy used for drying undesired parts of wood such as knots, finger jointing of green wood has been investigated (Troughton and Chow 1980; Sterley 2004; Na *et al.* 2005; Karastergiou *et al.* 2009; Mantanis *et al.* 2011; Na *et al.* 2013). This allows the manufacturer to remove the undesired parts from wood pieces before the drying process. However, one obstacle of finger jointing of green wood is that its moisture content is relatively high, which could result in poor bonding quality (Jokerst 1981; Sterley 2004, 2012). To solve this problem, heat has been used to accelerate the curing rate of the adhesive around finger joints of green wood before kiln drying (Throughton and Chow 1980), which could be cost-intensive. Adhesives with rapid curing rates such as tannin-based cold setting adhesives, one component polyurethane and two component phenol resorcinol formaldehyde adhesive system have been developed for gluing green wood (Kreibich and Hemingway 1987; Pommier and Elbez 2007; Sterley 2012; Na *et al.* 2013). However, the bonding performance of these adhesives varies with wood species (Sterley *et al.* 2004; Zhou *et al.* 2017; Proller *et al.* 2018).

This study investigated the feasibility of performing finger jointing of green rubberwood lumber using polyurethane and emulsion polymeric isocyanate adhesives, which are commonly used for gluing wood with the initial moisture content of approximately 12% in wood industries in Thailand. The effects of adhesive types, initial moisture content of wood, and drying temperature on the bending and compressive properties of finger jointed rubberwood were explored.

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EXPERIMENTAL

Material Preparation and Finger Jointing Process

The kiln-dried and green rubberwood (*Hevea brasiliensis* Muell. Arg) lumber specimens with the dimensions of 85 mm (tangential) × 30 mm (radial) × 1000 mm (longitudinal) were taken from local rubberwood factory in Nakhon Si Thammarat province, Thailand, for finger jointing. The average moisture content of kiln-dried and green rubberwood lumbers at the time of finger jointing process were 12 ± 1.1% and 61.2 ± 6.1%, respectively. In practice, the lumber pieces are stacked under ambient environment before further processing, which could decrease the initial moisture content of lumber. To examine this effect on finger joint performance, a separated set of green lumber was stacked under ambient environment for about 5 days before finger jointing. The final moisture content of this lumber was 37.6 ± 3.2%. All prepared lumbers with three different initial moisture contents were cut into specimens with the dimensions of 85 mm (tangential)× 25 mm (radial) × 200 mm (longitudinal). These samples were machined to produce finger profiles with finger length of 12 mm, tip of 0.9 mm, and pitch of 4.1 mm. Two machined samples from the same lumber piece were selected for finger jointing. Two types of adhesives including polyurethane (PU) and emulsion polymeric isocyanate (EPI) were selected for this experiment because they are commonly used for gluing wood with initial moisture content of approximately 12%. The machined samples were dipped into these adhesives and transferred onto the finger jointing machine (Yung Nien Fa Machine Industry Co., Ltd., Taichung, Taiwan). Both end sides of the assembly were pressed at a constant end gage pressure of 1 MPa during the entire process. The finger jointed specimens made of wood raw material with an initial moisture content of 61.2 ± 6.1% were transferred into hot air oven to dry at three different temperatures of 60 °C (Specimen type A), 80 °C (Specimen type B), and 100 °C (specimen type C), to the final moisture content of 12%. The finger jointed wood specimens made of wood raw material with the initial moisture content of 37.6 ± 3.2% were dried only at 60 °C (Specimen type D). These specimens were used to explore the effect of seasoning of lumber on the properties of the final products regardless of drying temperature. The values of this set of specimens were compared with ones made of rubberwood raw material with initial moisture content of 61.2 ± 6.1% at the same drying temperature (Specimen type A). Prior to mechanical testing, all specimens were conditioned at 20 °C and 65% humidity for 2 months.

Mechanical Property Testing

Three point bending and compression parallel to the grain tests were conducted on the specimens with the dimensions of 20 mm (width) × 20 mm (thick) × 300 mm (length) and 20 mm (width) × 20 mm (thick) × 60 mm (length), respectively (modified from ASTM D 143 2009). The position of the glued finger was at the mid length of the specimen (Fig. 1). For bending test, span length to thickness ratio was kept constant at 14, and the finger orientation of the specimen during bending test was in vertical direction (Fig. 1). The specimen was loaded using universal testing machine (Lloy, UK) with the cross head speed of 10 mm/min for bending test and 2 mm/min for compression tests. Solid wood specimens without finger joints were used as controls. Six replicates were used for compression tests, and five replicates were used for bending tests.

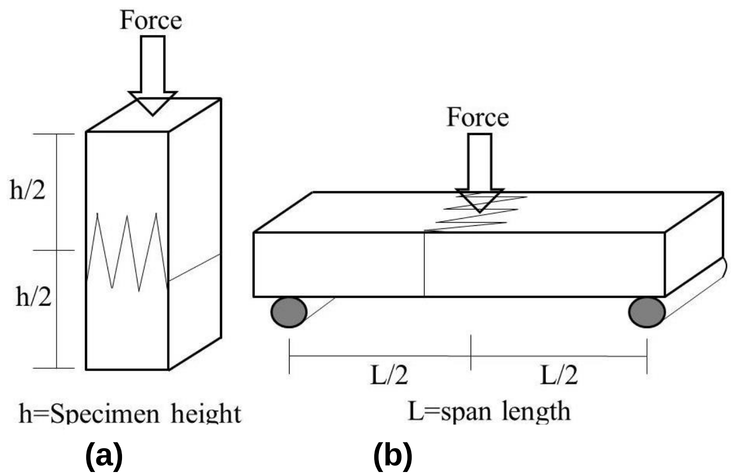

Fig. 1. (a) Compression parallel to the grain test and (b) three point bending test of finger jointed wood products

RESULTS AND DISCUSSION

Table 1 shows the modulus of rupture (MOR), modulus of elasticity (MOE), and compressive strength ($\sigma_{//}$) parallel to the grain of the produced finger jointed rubberwood specimens and solid rubberwood. The difference of the mean value for each property among each type of specimens was determined by using one-way ANOVA analysis at the 0.05 level of significance.

For bending properties, the type of adhesive had no significant effect on MOR and MOE of finger jointed wood products. As shown in Table 1, for each type of specimen, finger jointed wood products bonded using the PU and EPI adhesives had similar MOR and MOE values. Initial moisture content and drying temperature did not significantly affect MOR and MOE of specimens boned with PU adhesive. However, initial moisture content appeared to slightly affect MOR of finger jointed wood products bonded with EPI adhesive. The MOR of finger jointed specimens made of green rubberwood with the initial moisture content of 61.2 ± 6.1% (specimen types A, B, and C) were slightly lower but that of specimen made of wood with initial moisture content of 37.6 ± 3.2% (specimen type D) was similar compared with the control. Additionally, the MOR values of specimens type A, B, and C were similar, indicating that the drying temperature had no significant effect on MOR of this type of specimens but its corresponding MOE had slightly improved compared with the control.

Figure 2 shows typical failure modes of the specimens after bending test. Specimens made of wood raw material with an initial moisture content of 61.2 ± 6.1%

failed entirely along the glued line, indicating that interfacial bonding of the finger was poor due to lack of adhesive. This might because that high moisture content in wood created starved bond, resulting a good penetration of adhesive into the inside of wood tissue (Sterley 2012). Jokert (1981), St-Pierre *et al.* (2005) and Amoah *et al.* 2014 also reported that high moisture content of wood materials negatively affects the strength of finger jointed products. The test specimens type D and the control failed by mixed failure modes of shearing along glued line and fracturing of finger. In comparison to solid rubberwood, the obtained MOR and MOE of all types of finger jointed specimens were found lower.

Table 1. Modulus of Rupture (MOR), Modulus of Elasticity (MOE) and Compressive Strength ($\sigma_{//}$) Parallel to the Grain of Finger Jointed Rubberwood and Solid Rubberwood

Adhesive	Specimen	MOR (MPa)	MOE (MPa)	σ// (MPa)
PU	Control	59.6^{bc} (6.4)	8,235^{de} (947)	45.0^{a} (6.3)
	Type A	50.6^{cd} (8.8)	8,441^{cde} (1090)	41.1^{a} (3.5)
	Type B	53.4^{cd} (8.7)	8,868^{bcd} (1,116)	40.1^{a} (4.9)
	Type C	55.8^{bcd} (5.2)	8,656^{bcd} (912)	45.6^{a} (8.2)
	Type D	65.0^{b} (8.6)	9,597^{bcd} (989)	44.3^{a} (2.3)
EPI	Control	59.6^{bc} (7.8)	7,220^{e} (1,326)	41.3^{a} (2.2)
	Type A	48.3^{cd} (7.5)	8,395^{de} (671)	38.7^{a} (5.8)
	Type B	46.3^{d} (3.3)	9,905^{ab} (840)	41.9^{a} (4.5)
	Type C	47.0^{d} (2.4)	9,550^{bcd} (489)	42.8^{a} (5.9)
	Type D	59.4^{bc} (11.5)	9,842^{abc} (1,263)	45.7^{a} (9.3)
Solid rubberwood (without finger joint)		104.0^{a} (11.5)	10,984^{a} (970)	45.6^{a} (2.4)

The superscript letters refer to a statistical comparison of the mean values within a column determined by one-way ANOVA analysis at the 0.05 level of significance. The same letters indicate that there is no significant difference at the 0.05 level of probability.

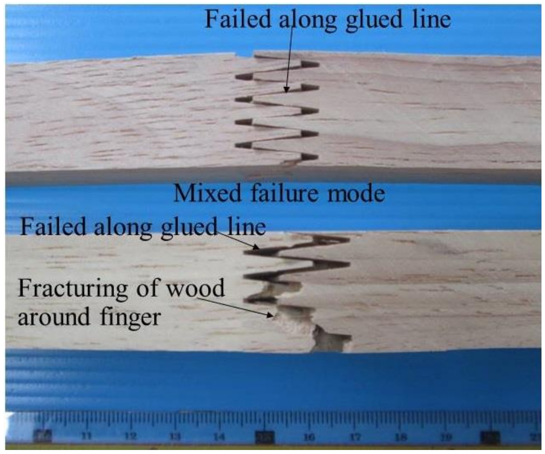

Fig. 2. Typical failure modes of finger jointed specimens after bending test

For compression tests, the types of adhesive, initial moisture content, and drying temperature had no significant effect on compressive strength parallel to the grain of all produced finger jointed rubberwood (Table 1). Figure 3 shows typical failure modes of specimens after compression tests. Some specimens failed by fracturing of wood along the grain, and some failed around the fingers due to high stress concentration. Moreover, the values were similar to those of solid rubberwood without finger joints.

Fig. 3. Typical failure modes of finger jointed specimens after compression parallel to the grain test

CONCLUSIONS

1. The type of adhesive had no significant effect on the examined properties.
2. The initial moisture content slightly affected the modulus of rupture (MOR) and modulus of elasticity (MOE) of specimens bonded with emulsion polymeric isocyanate (EPI) adhesive. The MOR of all types of specimens bonded with EPI adhesive were slightly lower, but their MOE tended to be slightly higher than the

control. However, compressive strength parallel to the grain was not affected by this parameter.

3. Drying temperature slightly improved MOE of specimen bonded with EPI adhesive.

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