The Effect of Jabon Veneer Quality on Laminated Veneer Lumber Glue Bond and Bending Strength

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Abstract

Jabon (*Anthocephalus cadamba*) is a fast growing wood species widely planted by community in Indonesia. Jabon has large percentage of juvenile wood which affect its veneer quality. This research objective were to determine the effects of wood juvenility and pretreatment on lathe checks, surface roughness and contact angle of the 3.00 mm rotary-cut jabon veneer and to analyze the impact of lathe checks frequency on the LVL glue bond and bending strength. Jabon logs were subjected to boiling in 75 °C water for 4 h. Then they were peeled to produce 3.00 mm veneers in thickness. Frequency, length and depth of lathe checks were measured per 10 cm veneer length by using optical microscope. Laminated veneer lumber (20x20x500) mm^3 were made from 7-ply of jabon veneers by using Poly Vinyl Acetate (PVAc) as adhesive. Glue bond strength and bending strength were measured by UTM Instron. The results showed lathe check (frequency, length and depth), surface roughness and contact angle were influenced by juvenility. Glue bond strength, Modulus of Elasticity (MOE) and Modulus of Rupture (MOR) of jabon LVL decreased as frequency of lathe check increased.

Keywords: *Anthocephalus cadamba*, juvenile wood, laminated veneer lumber, lathe check, surface roughness, wettability

Abstrak

Jabon (*Anthocephalus cadamba*) adalah salah satu kayu cepat tumbuh yang banyak di tanam di Indonesia. Jabon memiliki persentase kayu juvenile yang besar yang dapat mempengaruhi kualitas finirnya. Tujuan penelitian ini adalah untuk menentukan pengaruh kayu juvenile dan perebusan terhadap retak kupas, kekasaran permukaan dan sudut kontak serta untuk menganalisa pengaruh frekuensi retak kupas terhadap keteguhan rekat dan lentur Laminated Veneer Lumber (LVL) jabon. Sebelum dikupas, log jabon direbus dalam air yang bertemperatur 75 °C selama 4 jam. Kemudian log dikupas untuk menghasilkan finir setebal 3.00 mm. Frekuensi, panjang dan kedalaman retak kupas diukur pada 10 cm panjang finir, menggunakan mikroskop optik. Laminated veneer lumber berukuran (20x20x500) mm^3 dibuat dari 7 lapis finir yang direkat menggunakan *Poly Vinyl Acetate* (PVAc). Keteguhan rekat dan keteguhan lentur diukur menggunakan UTM Instron. Hasil penelitian menunjukkan frekuensi, panjang, dan kedalaman retak kupas, kekasaran permukaan serta sudut kontak dipengaruhi oleh kayu juvenile. Keteguhan rekat, *modulus of elasticity* (MOE) dan *modulus of rupture* (MOR) LVL jabon menurun seiring dengan meningkatnya frekuensi retak kupas.

Kata kunci: *Anthocephalus cadamba*, kayu *juvenile*, kekasaran permukaan, keterbasahan, *laminated veneer lumber*, retak kupas

Introduction

Jabon (*Anthocephalus cadamba*) is a fast growing wood species widely planted by community in Indonesia. The jabon trees in the age of 5 years can reach breast height diameter up to 28 cm. Though all part of the trees in the age of 5 years are juvenile (Rahayu *et al.* 2014). Recently the jabon wood has been rotary cut for laminated wood products. However, as the jabon logs are being peeled and much more juvenile woods are being utilized, severe lathe check veneer would undoubtedly be produced and manufactured. Therefore, it considerably needs to study lathe checks of veneer peeled from the jabon logs, and their effect on the glue bond and bending strength.

The quality of veneer, such as moisture content, density, lathe checks, and surface roughness would influence the bonding strength of the veneers (Dundar *et al.* 2008). Among these factors, lathe check and surface roughness are the important factors on the bonding strength. The risk of this checking can be reduced by using a nosebar (Kollmann *et al*. 1975). However, recent spindle less rotary lathes, which are widely used to peel small log diameter of fast growing wood species, have not been completed with an adjustable nosebar. A boiling treatment of bolts would be considered to reduce the lathe check. Jabon logs boiled in water at 75 °C for 4 h, could reduce the lathe check frequency of jabon veneers (Kabe *et al*. 2013). The measurement of lathe check methods and devices for lathe check detection are not so common. Palubicki *et al*. (2010) develop lathe check method by using pulley to arch the veneer. The success of measurement is strongly influenced by the choice of pulley diameter. He investigate that when diameter of the pulley is too small, the measurement process will lead to cracking and increase the depth of lathe check thus the measure is not reliable. Otherwise, if diameter of pulley is too large, veneer cracks would not open so it is difficult to be detected by the camera. Therefore, in this study, we adopted other method that develops by Jung and Day (1981). Before measuring, the ink is stained on the loose side of veneer to obtain better observation on the lathe check, without increasing the depth and length of lathe check.

Wetting is a term to describe what happens when a liquid comes into contact with a solid surface. To obtain proper interfacial bonding and a strong adhesive joint, good adhesive wetting, proper solidification (curing) of the adhesive and sufficient deformability of the cured adhesive (to reduce stresses that occur in the formation of the join) is important (Shi & Gardner 2001). The wettability of wood was usually evaluated by contact angle measurement. Dropping some fluids (water or adhesive) on to the loose side or tight side of veneers are common method to measure contact angle (Shi & Gardner 2001, Sulaeman *et al*. 2009).

One of the most significant technical advantages of laminated veneer lumber (LVL) is that specific performance characteristics can be considered in its design. By strategically placing selected veneer sheets within the composite, it is possible to manufacture a wood-based product that has well-controlled physical and mechanical properties (Wang *et al*. 2003). Daoui *et al*. (2011) recommend carefully selecting the veneers to be used in composing LVL.

The effect of lathe checks on glue-bond quality, modulus of elasticity (MOE) and modulus of rupture (MOR) during laminated veneer lumber (LVL) production should be also important by considering that the increasing of lathe check on the veneer would lead to lower glue bond quality and bending strength (MOE and MOR). Veneer with more frequent lathe checks may result in a higher incidence of delamination. To avoid delamination, the LVL may be typically produced by increasing the adhesive spread rate. Although increasing the adhesive spread rate is a common practice, however a question on how lathe checks affect the LVL glue-bond and bending strength would exist.

Investigation of lathe check characteristics of veneer from fast growing jabon and its LVL glue-bond and bending strength, gets less concern. Therefore it requires such study. The objectives of this study were 1) To determine the effects of wood juvenility and pretreatment on lathe checks, surface roughness and contact angle of the 3.00 mm rotary-cut jabon (*A. cadamba*) veneer; and 2) To analyze the impact of lathe checks frequency on the LVL glue-bond and bending strength.

Materials and Methods

Wood sample

Tree sample used in this study was jabon (*Anthocephalus cadamba*). Wood samples were taken from 28 cm diameter of 5 years old stem which growth at Sukabumi, West Java, Indonesia.

Veneer quality

Logs preparation for rotary cutting

Jabon log sections (bolts) in length of 60 cm were taken from each tree. Four bolts of about 28 cm in diameter were selected. The first two bolts were soaked in water at room temperature as control, and the other two bolts were subjected to boiling process in hot water at 75 °C for 4 h. Subsequently, the bolts were peeled off to obtain veneers in the thickness of 3.00 mm. The other factors such as knife angle, peeling angle, nose bar pressure, log temperature, peeling speed were kept constant in the study. A specified 1 cm width of radial increment was made from pith to bark on the cross section of logs and numbered consecutively (No. 1 - 7) as shown in Figure 1. The logs were peeled using a spindle less rotary lathe. The bolts were peeled up to core diameter of 10 cm. Veneer in each radial increment was measured for characterizing the thickness variation, lathe checks frequency and surface roughness.

Measurements of thickness variation

Veneer sheets produced from each radial increment were collected and clipped to (10x60) cm^2 veneer specimens. Three test specimens were used for the measurements of thickness variation. Six points of thickness measurements were marked on the side of each test specimen.

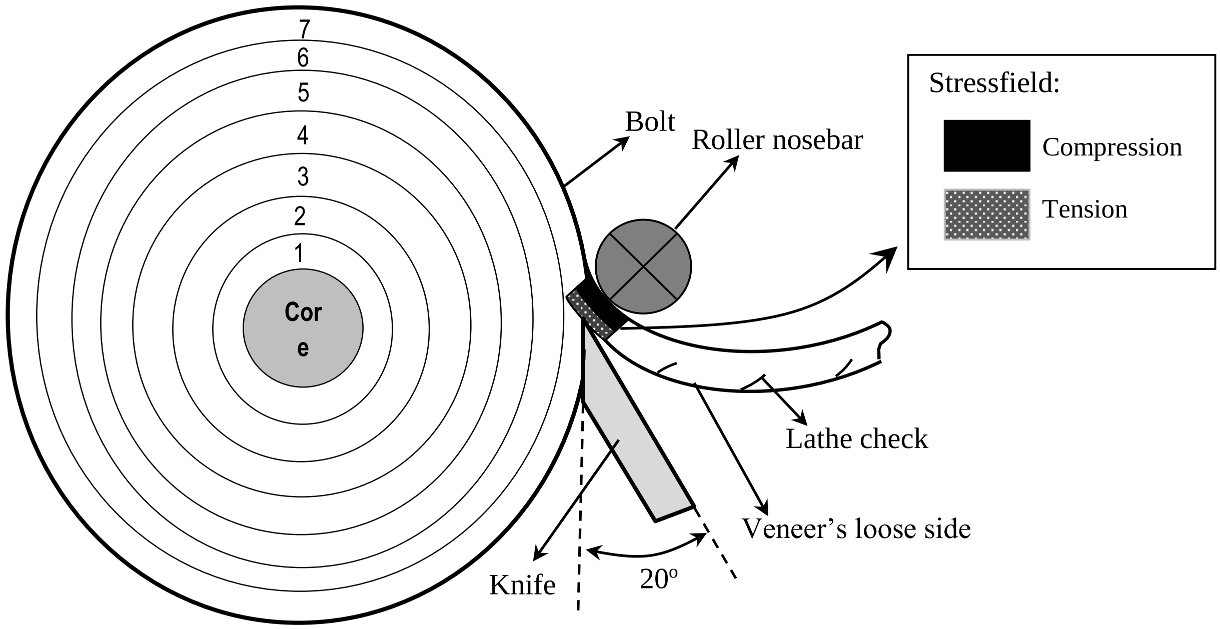

Figure 1 Peeling diagram on the cross section of logs to produce veneers from segmented rings number 1 to 7, and stress (tension and compression) occurring during the peeling (Darmawan *et al*. 2015).

Measurements of lathe check frequency

The test specimen was kept in the green condition. In order to be able to observe lathe checks clearly (improve contrast), red ink was stained on loose side of veneer samples. Then an optical video microscope was used to capture images from the surface of veneer's loose side. The images then were analyzed using motic image software to count the lathe checks frequency, length (l) and depth (d) (Figure 2). Frequency of lathe check was presented as the number of lathe check per 10 cm length of veneer.

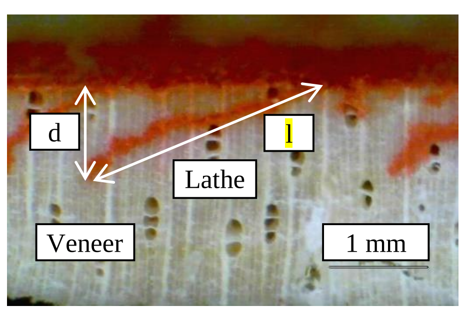

Figure 2 Veneer presenting the lathe checks.

Surface roughness measurement

A portable surface roughness tester TR200 was used for roughness evaluation of the samples. A total of 10 roughness measurements were conducted according to JIS standard 2001 by using the roughness tester. Measurements were performed on each surface roughness test specimen across the grain orientation of the veneer. Measurements were repeated whenever the stylus tip fell into the pores. The calibration of the instruments was checked in every 100 measurements by using a standard reference plate with Ra values of 7 µm. Average roughness (Ra) values were recorded to evaluate surface roughness.

Measurements of contact angle

Liquid wettability of wood usually evaluated by contact angle measurement. Water and PVAc were dropped by using pipette on loose side of veneer (Figure 3). Pictures were taken during three minutes period (started from 10 seconds after initial drop, until 180 second after initial drop). Those images were analyzed by motic image software to measure their contact angles. Then, equilibrium contact angle was determined by PROC NLIN from SAS.

LVL production, glue bond and bending strength measurements

LVL production

The veneer specimens were conditioned at relative humidity (RH) of 85% and temperature of 25 °C to an air-dry moisture content of 12%. Water based polymer PVAc resin adhesive was used for producing 20 mm thick of LVL panels. The PVAC resin had a viscosity of 90-110 poise at 23 °C, pH 4-5, solid material 50±1% and a density of 1.23 g cm^{-3}. LVL panels with dimension of (20x20x500) mm^3 were manufactured by 3mm veneer thick (7-ply) at each segmented rings. The spread volume of the PVAc resin was 260 g m^{-2} on single bonding surface of the veneers as recommended by the manufacture. The glue was uniformly spread on the surface of veneers by hand brushing. Assembled samples were pressed in a cold press at a pressure of 2.5 kg cm^{-2} for 45 min. The resulting LVL panels were allowed to a stable condition for 72 h before cutting into test specimens.

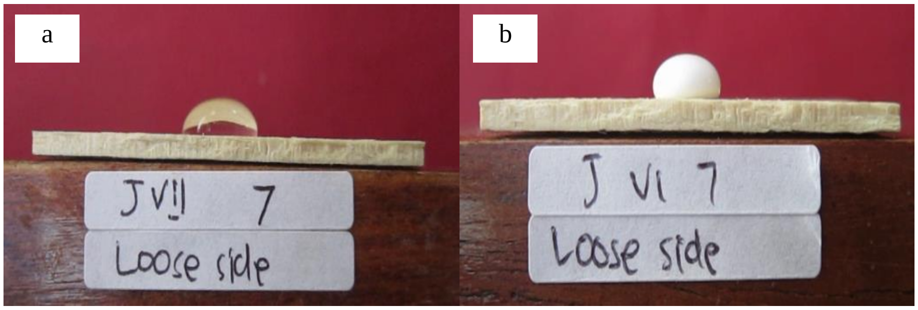

Figure 3 Contact angle of water (a) and PVAc as adhesive (b).

Glue bond and bending strength test

The glue bond and bending strength test were conducted for the LVL specimen. Prior to the testing, the specimens were conditioned for 2 weeks at 25 °C and 85% relative humidity to air dry moisture content (±12%). The glue bond and bending tests were carried out on an INSTRON universal testing machine. Perpendicular to the fiber and glue line (flatwise) and two point bending test for modulus of rupture (MOR) and modulus of elasticity (MOE) tests were carried out according to EN standard (EN 789). Specimen size for the bending tests was 400 mm long by 20 mm wide by 20 mm thick of LVL. Glue-bond tests were also carried out according to JAS SE 11. The dimension of test samples was 50 mm length by 20 mm width by 20 mm thick. A loading rate of 10 mm min^{-1} was used in all tests according to the JAS SE 11. Loading on the glue bond test was continued until separation between the surfaces of the specimens occurred.

Results and Discussion

Veneer quality

Variation of veneer thickness

Uniformity of veneer thickness is a very important factor affecting the quality of glue bond strength in LVL or plywood. The result in Figure 4 shows that thickness variations of rotary cut jabon veneers are occurred. The thickness of jabon veneer peeled from some bolts, which was intended to be 3.00 mm, ranged from a minimum of 2.50 mm to a maximum of 3.38 mm. Due to our spindle less rotary lathe was not able to peel 3.00 mm veneer, so that the targeted 3.00 mm veneer thickness was not accomplished. However, the uniformity of veneer thickness variation from pith to bark was reached. Coefficient of variations of the veneer thickness from pith to bark calculated was 1.02% for the veneers from control log and 2.17% for the veneers from boiled veneers. By considering the coefficient of variations was less than 6%, the bolts of jabon were correctly peeled to maintain the thickness regularity.

Lathe check frequency, depth and length

Figure 5 shows average values of frequency of lathe check per 10 cm of veneer length taken from the loose side of the veneer. The average frequency of lathe check tended to decrease from pith to bark of the veneers. The veneers near the pits showed larger frequency of lathe check. Several researchers also observe the same trend on 2.00 mm jabon and sengon veneers (Kabe *et al*. 2013, Darmawan *et al*. 2015).

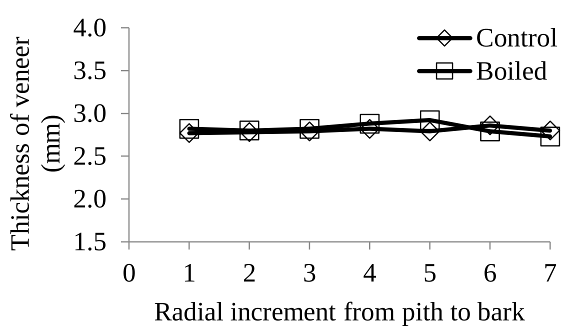

Figure 4 Variation of veneer thickness from pith to bark.

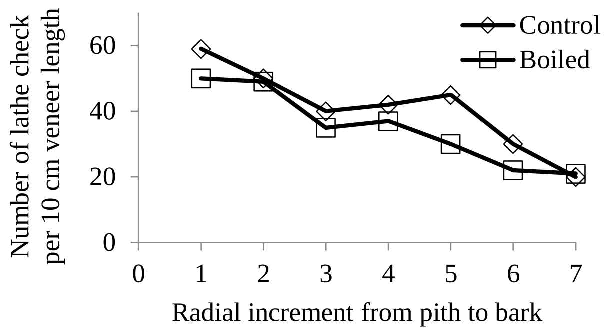

Figure 5 Variation of lathe check frequency from pith to bark for the 3mm jabon veneer.

Higher lignin content of the wood near the pith could be responsible for high frequency of lathe check of the veneers taken from the inner parts of the jabon logs. Juvenile wood is an important wood quality attribute because it have lower density, larger fibril angle, and higher lignin content and slightly lower cellulose content than mature wood (Bao *et al*. (2001). Higher frequency of lathe check near the pith could be also caused by smaller radius of its natural curvature in the bolt, which imposed greater tension during the flattening.

The results in Figure 4 also reveal that veneers with lower average frequency of lathe checks are produced by bolts boiled for 4 h at temperature of 75 °C, when compare to control bolts. This result gave an indication that boiling at a higher temperature resulted in better surface properties of the veneers. It could be announced that jabon bolts boiled for 4 h at 75 °C could be proposed before manufacturing veneers from the jabon wood. The boiling of jabon bolts at the temperatures and periods is considered to soften the jabon bolts during the peeling process. A softening process does temporarily alter the microstructure of the wood, making it more plastic due to thermal expansion of cellulose, and softening of lignin in the cell wall (Jorgensen 1968).

According to Darmawan *et al*. (2015), the thicker veneer peel from the logs tends to produce larger frequency of lathe check compare to thinner veneer. The frequency of lathe check per 10 cm veneer length near pith was 59 and 50 for jabon control and boiled logs, subsequently. While, at near bark were 20 (for control log) and 21 (for boiled log). Kabe *et al*. (2013) finds the frequency of lathe check for 2.0 mm jabon veneers were 26 (for control logs) and 14 (for boiled logs)

The second variable that is important in determining the veneer quality is deep or shallow lathe check. The depth of lathe check in percent of veneer thickness increased from pith to bark (Figure 6). The lathe check frequency of veneers near pith was approximately twice larger than near the bark. It can be considered that lathe check on the loose side of veneer was generated due to tensile stress in bending at the rake face of the knife (Figure 1). Then, further unbending process during for flattening the veneer from its natural curvature caused the increase of lathe check. Surface tension generated by unbending process would increase with veneer thickness, and much more cutting splits occurred during peeling and so it would generate deeper and longer lathe check (Figure 6 and 7).

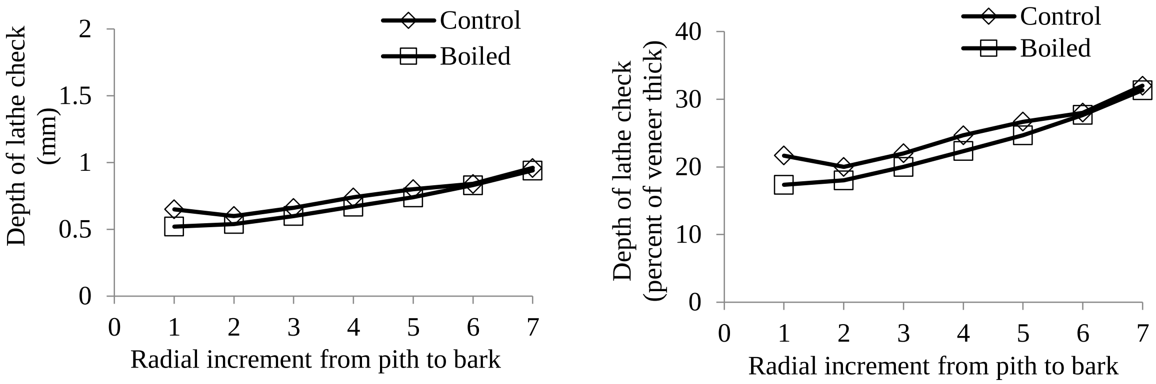

Figure 6 The progress of depth of lathe check from pith to bark.

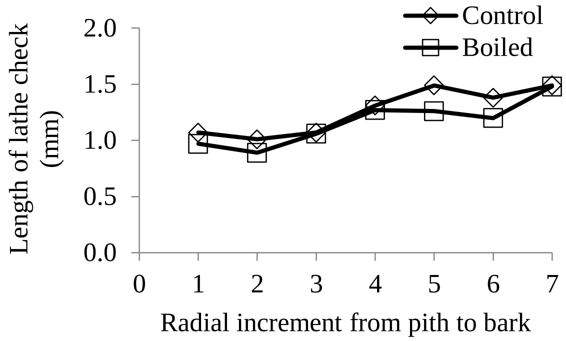

Figure 7 The progress of length of lathe check from pith to bark.

The thicker the veneer peeled, the deeper the lathe check will be. The depth of lathe check near pith were 0.65 mm (control log) and 0.52 mm (boiled log), while near bark were 0.96 mm (control log) and 0.94 mm (boiled logs). Kabe *et al*. (2013) states that the depth of 2.00 mm jabon veneer is 0.58 mm. The other lathe check measured in determining veneer quality was length of lathe check. The length of lathe check tended to slightly fluctuate from pith to bark. The length of lathe check followed the behaviors of the depth of lathe check. The average lathe check length for control and boiled veneers were 1.21 and 1.11 mm, respectively.

Surface roughness

The average Ra values tended to decrease from pith to bark of the veneers. The veneers near pits showed larger Ra values. Further Tanritanir *et al*. (2006) investigate the effect of steaming time on surface roughness of beech veneer and they also found that the roughness of veneer sheets taken from heartwood (near pith) had higher values than those of sapwood (near bark). Average Ra values of the samples manufactured from the logs with a temperature of 75 °C from pith to bark were 13.5 µm. These values were significantly lower than those of the samples soaked in cold water (control). Findings in this study suggest that surface roughness of the veneer improved with increasing log temperature. This result corresponded with Aydin *et al*. (2005), who discovered the same trend on spruce veneer. Hecker (1995) reported that heating time and log temperature influenced significantly surface characteristics of veneer samples. It seems that higher temperature resulted in better surface properties of the samples based on the results of the tests. This finding would also contribute to reduced resin consumption during the gluing and making veneer more plastic during the peeling so that veneer with enhanced surface quality can be produced without any defects.

Wettability – contact angle

We could conclude that jabon veneers had lower wettability when PVAc was dropped into veneer loose side when compare to water (Figure 8). It was due to PVAc had higher viscosity than water so that adhesive was slower and more difficult penetrating jabon veneers. Surface wettability decrease as fluid viscosity increase (Gavrilovic-Grmusa *et al.* 2012). The correlation between equilibrium contact angle and lathe check frequency and surface roughness were made. The results were shown on Table 1. On jabon boiled, surface roughness did not show negative effect on equilibrium contact angle. We suspected that there were alteration in jabon wood microstructure caused by boiling pretreatment. So that, equilibrium contact angle was not only influenced by lathe check frequency and surface roughness, but also wood structure. In line with Shi and Gardner (2001) who state that liquid penetration in the phase of wetting is mainly related to the wood structure.Though in general, from those linear regressions, we could conclude that veneers from boiled logs had better wettability than veneers from control logs. This characteristic would contribute to LVL glue bond and bending strength.

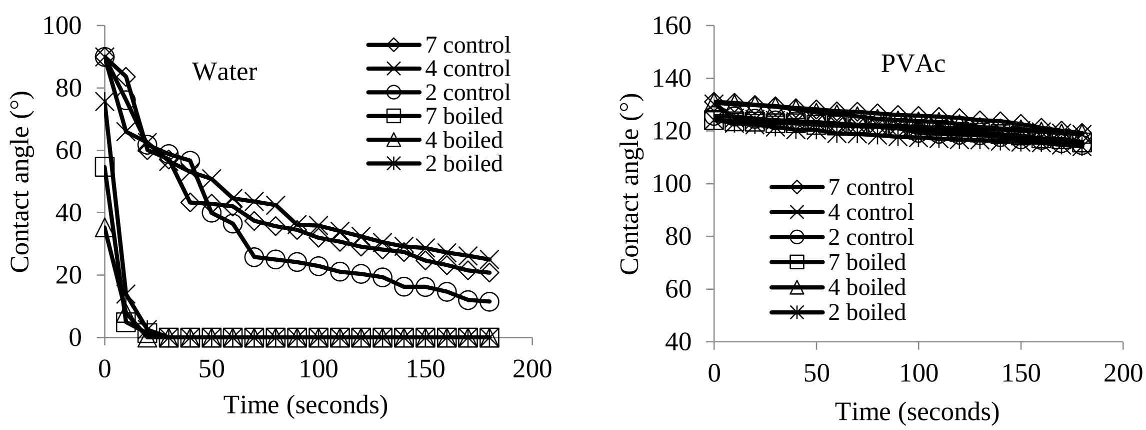

Figure 8 Average contact angle on veneer loose side from pith to bark when being dropped by water and PVAc as adhesive.

Table 1 Multiple linear regression equation and correlation coefficients (Y = contact angle, X_1 = frequency of lathe check, X_2 = surface roughness, R^2 = determination coefficient)

	Linear regression	R^2
Control	$Y = 114.20 - 0.088X_1 - 0.19\ X_2$	98%
Boiled	$Y = 25.38 - 1.65\ X_1 + 10.21\ X_2$	90%

Effect of lathe check on glue bond and bending strength

The glue bond strengths of veneer glue-line on the LVL increased from pith to bark for LVL from control and boiled veneers (Figure 9a). The results suggest that increasing proportion of veneer near the pith would decrease the glue-line's capacity to withstand concentrated shear stresses, thus resulting in higher amounts of glue-line failure and a reduction in percent wood failure. However, as the proportion of veneer near bark at the tight-side glue-line increased, percent glue-line failure decreased. This was attributed to an interaction between the juvenility (Figure 9a) and the frequency of lathe check (Figure 9b). The glue bond strength had a statistically significant, negative correlation to lathe check frequency, and its correlation coefficients according to the lines in Figure 9b are summarized in Table 2.

Lathe check frequency was the first variable analyzed to explain the glue bond strength. As lathe check frequency of veneers in between the glue line increased, the amount of bridging wood material between each lathe check decreases. This decrease would reduce contact between the layers resulting in a weak glue line and low glue bond strength of the LVL. This result was in agreement with DeVallance *et al*. (2007), who reported that a high frequency of lathe checks results in lower strength. The LVL failures after glue bond test were observed and evaluated visually. The specimens failed mainly along a line delineated by the propagation of fracture of lathe checks within the veneer itself. This failure confirmed to the results of Rohumaa *et al.* (2013).

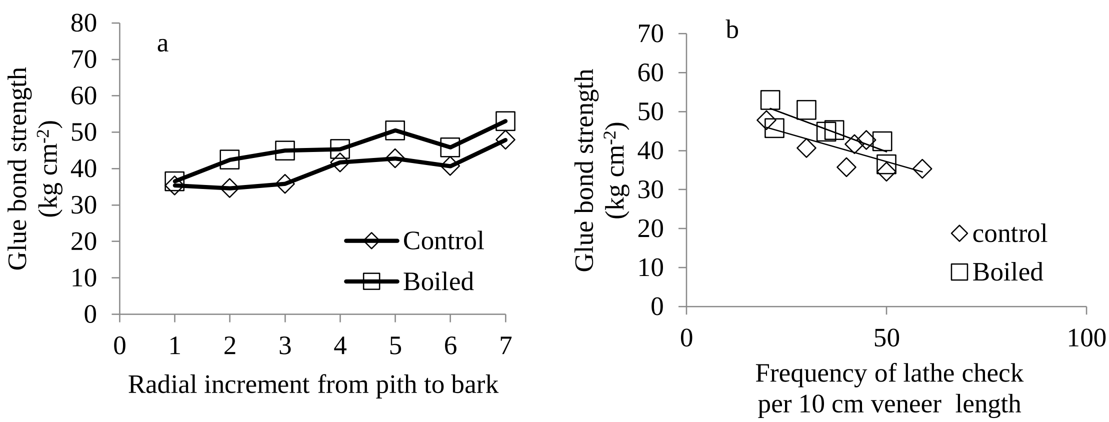

Figure 9 The effect of juvenility (a) and lathe check (b) on the LVL glue bond strength.

Table 2 Linear regression equation and correlation coefficients according to figure 9b (Y = glue bond strength, X = frequency of lathe check, R^2 = determination coefficient)

	Linear regression	R^2
Control	y = 51.77 - 0.29X	60%
Boiled	y = 58.85 - 0.38X	70%

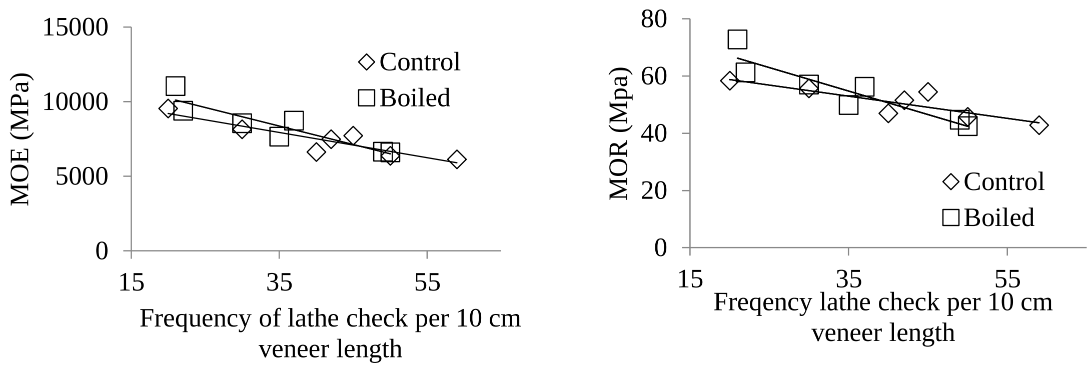

Figure 10 The effect of lathe check on the LVL bending strength.

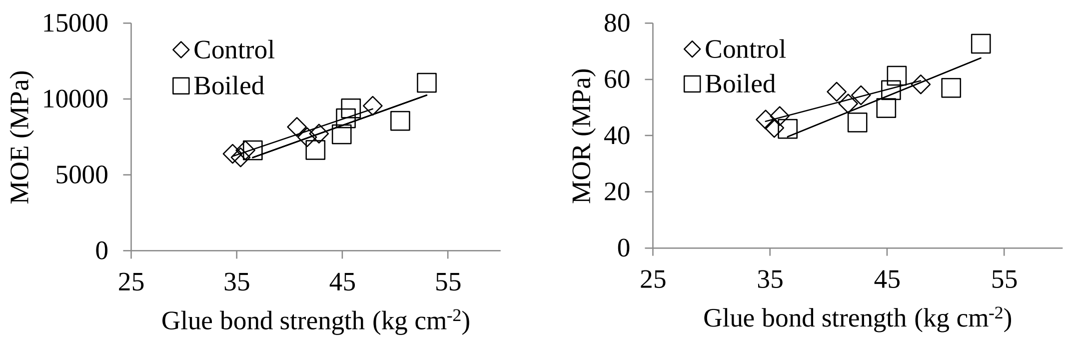

Figure 11 Relation between glue bond strength with LVL MOE and MOR.

Both the MOR and MOE seem to be influenced by the lathe check (Figure 10). This suggests the lathe checks may cause a great deal of local stresses on tensile side of the bending specimen, and determine the bending failure of LVL when the lathe checks are situated under the maximum bending moment. The lack of proper connection among the fiber elements is the reason of the frequent rupture on the tensile side.

The results in Figure 11 show that both MOE and MOR increased with an increase in glue bond strength. The MOE and MOR of jabon LVL from the bending test decreased with increasing in the lathe check frequency of the veneers. Higher glue bond strengths were also obtained for jabon LVL manufactured from veneers having lower frequency of lathe checks.

Conclusion

In general, 3.00 mm jabon veneers from 5-years-old boiled jabon logs had better veneer quality (lower lathe check frequency, better surface roughness and better wettability) than control logs. The frequency, depth and length of lathe check, surface roughness and contact angle were influenced by juvenility. The frequency of lathe check, surface roughness and contact angle decreased from pith to bark, whilst for length and depth of lathe check, the values increased. The glue bond strength, MOE and MOR of jabon LVL were decreased as the frequency of lathe check increased.

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