Research and Innovations in Products Quality Improvement of Short Rotation Woods for Industry 4.0

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Abstract

Juvenile portion of tree stem surrounding the pith is characterized by a progressive change in cell features and wood properties (Panshin and de Zeeuw 1980). In comparison with mature wood, juvenile wood is made of smaller and shorter fibers with thinner walls and larger microfibril angles, lower density, and lower strength properties (Clark et al. 2006; Gryc et al. 2011; Koubaa et al. 2005: Adamopoulus et al. 2007; Evans et al. 2000). It is well known that characteristics of juvenile wood contribute to undesirable solid wood properties. Juvenile wood is not substandard for products such as newsprint and quality printing paper (Zobel 1984). However, it may cause serious problems for quality products, especially veneer or solid wood products. This is due to its low bending strength and dimensional instability upon drying. Juvenile wood of black locust had on average significantly lower static bending strength (MOR, and MOE), dynamic strength, and toughness strength than the mature wood (Adamopoulus et al. 2007). One of the most serious problems in drying and utilization of young plantation grown conifers was warp in the form of twist, crook and bow (Kliger 2001; Johansson and Kliger 2002). One possible means to reduce the negative impact of juvenile wood is to select for an earlier transition age from juvenile to mature wood.

Introduction

Timber as an important forest resource in the tropics has been processed to wood products in large quantity to fulfill an increasing need of both local and international consumers. To satisfy the increasing demand for the wood products, much of the future wood supply will be from fast-growing tree species grown on managed plantations (community forest, industrial plantation forest). This fast-growing wood species will tend to be harvested in short age rotations and will contain higher portions of juvenile wood.

Criterias for identifying a juvenile core are needed that are more appropriate for veneer for plywood or laminated veneer lumber (LVL), and solid wood products. Pith-to-bark variation in wood traits such as density, fiber length, microfibril angle, longitudinal shrinkage, ring width and latewood proportion is frequently described in terms of juvenile and mature wood zones and is used to estimate the transition age. Several methods have been proposed to estimate transition age from juvenile to mature wood. The simplest method is the so-called threshold method where a value is selected from graphs to define where a property has reached that of mature wood (Clark et al. 2006). Other methods are to use segmented regression models (Abdel-Gadir and Krahmer 1993; Sauter et al. 1999; Tasissa and Burkhart 1998) or nonlinear mixed-effects models (Mutz et al. 2004; Adamopoulos et al. 2011; Mora et al. 2007). Other methods used mathematical and numerical approaches that produce a unique polynomial functions from each pith-to-bark profile (Koubaa et al. 2005).

Tropical trees are increasingly seen as a valuable renewable natural resource. Fast growing trees in the tropics grow in a similar way all year round that are a continuous response to favorable environmental conditions (available sun, soil moisture and nutrients). They maintain and improve soil fertility, and provide protection from sun, wind and heavy raindrops. Among the fast growing tropical trees, sengon (*Paraserianthes falcataria*) and jabon (*Anthocephalus cadamba*) are widely planted across Java Island (Indonesia) by the communities. The sengon and jabon trees have inherently adapted to take advantage of the continuous growing season and suitable growing site of the Java regions in which they grow well. In Java, important artificial regeneration programs and tree improvement research activities have been devoted to these species in recent years. Large-scale reforestation with fast-growing sengon and jabon are likely to shorten rotations in the near future. The favorable combinations contribute not only to rapid juvenile growth but also to the many vagaries in quality of sengon and jabon wood associated with such growth.

The Indonesian wood industries are now about to utilize the fast growing wood species of jabon and sengon not only for pulpwood but also for light construction, furniture, and wood composite for constructions (plywood and laminated veneer lumber (LVL)). Sengon and jabon trees are valuable as both lumber, core veneer for plywood, and pulpwood. These species are therefore of vital economic importance. However, these species were inevitably cut by the community at the age of 5 to 7 years. This may lead to a high percentage of juvenile portions in the tree stems. In addition, sengon and jabon do not experience the winter and summer extremes seen in temperate forests. Their growth rings are not apparent. In this case, entire growth rings of the stem consist of wood portion formed during the rainy and dry seasons. Detailed information on growth rates, and maturation ages of sengon and jabon is important to obtain a better understanding of their functioning.

The characteristics in Table 1.1 describe that mean of breast height diameter were 34 cm for sengon and 36 cm for jabon at the age of 7 years. The mean of braches-free height of the two species was between 8 to 11 m at the age of 7 years. Therefore, it could be considered that the mean diameter growth for the two species was about 5 cm/year. Differences in diameter and height among tress in this study reflect the two wood's sensitivity to environmental conditions.

Table 1.1. Characteristics of sample trees

Tree species	Characteristics		
	Trees age	Height of branch-free stem	Diameter of breast height
Sengon	7 year	8	34 cm
	7 year	8	34 cm
	7 year	9	35 cm
Jabon	7 year	11	37 cm
	7 year	10	36 cm
	7 year	10	36 cm

The ring at which the transition from juvenile to mature wood occurs for fast growing wood species in the tropics is important issue affecting wood quality and product value. However, to estimate this ring with sufficient reliability is very difficult. One reason for this difficulty is that fast growing wood species as sengon or jabon show unclear annual or growth rings and indistinct juvenile-mature transition zone. Another reason is that, there are no specific traits and missing appropriate statistical methods to obtain consistent, efficient and reliable estimates of the transition ring parameter.

Previous studies on determination or modeling of transition age from juvenile to mature wood have considered several traits as indicators of juvenile-mature wood transition. These include ring density, latewood density, specific gravity, microfibril angle, fiber length, and strength properties (Clark et al. 2006; Gryc et al. 2011; Koubaa et al. 2005: Adamopoulus et al. 2007; Evans et al. 2000). These characteristics are closely related to fiber or tracheid differentiation, which changes with cambial age. While the transition age for each of these characteristics is of scientific interest, in this study the transition age is more focused with density, fiber length and microfibril angle (MFA).

1.2 Density

The results in Fig. 1.1 show a typical density patterns for sengon and jabon. Although density variations occurred in all segmented rings from near the pith to close the bark, however the same pattern of changes in density from pith to bark was mentioned for sengon and jabon. Development of ring density on the radial section showed low variations from pith to bark, making it unclear as to where the demarcation between juvenile and mature wood could be drawn. The density trends from pith to bark showed that density was not suitable for a clear differentiation between juvenile and mature wood. When the segmented regression models were applied, it was deduced that the use of ring density was not appropriate, because of low coefficients of determination and large range of ages for transition from juvenile to mature wood. Such a trend was unexpected as other studies on fast growing conifers were able to use ring density to estimate transition age (Koubaa et al. 2002; Koubaa et al. 2005; Gryc at al. 2011).

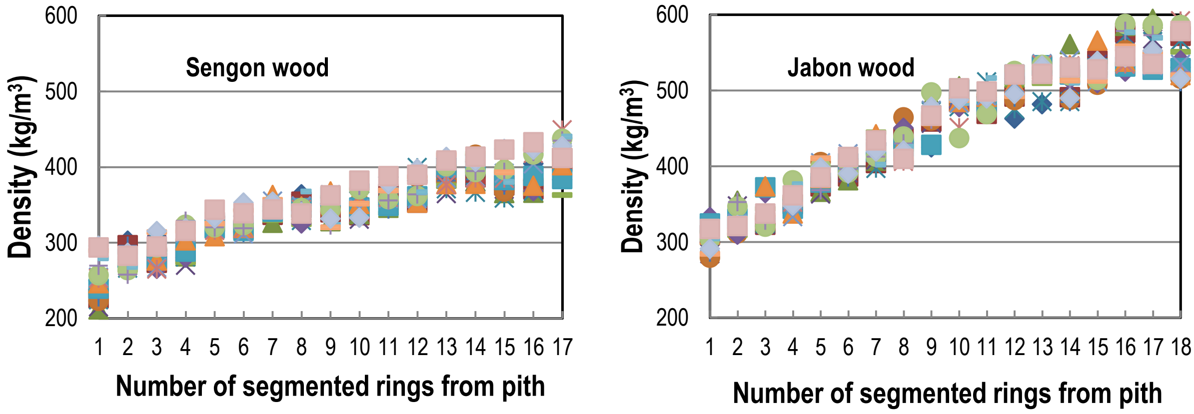
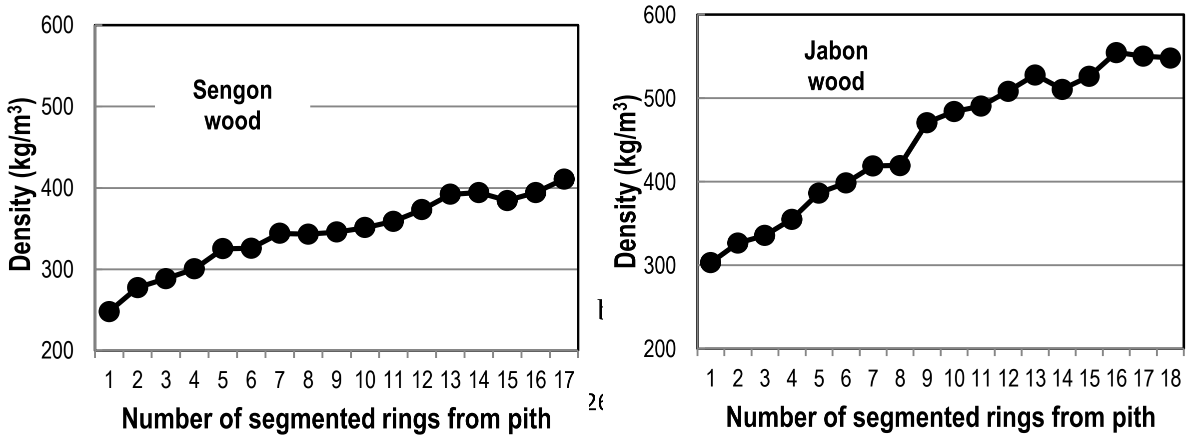


Fig. 1.1 Profiles of density from pith to bark for sengon and jabon

The average values of density at each segmented ring in Fig. 1.1 are calculated and the results are presented in Fig. 1.2. The results in Fig. 1.2 indicate that density increased proportionally from pith to bark. The results also indicate that jabon had larger density compared to sengon. The wood density of most species of sengon and jabon depends also on the location. The density of sengon wood close to the pith was 250 kg/m^3, and of jabon close to the pith was 280 kg/m^3. The density of woods immediately below the bark was 450 kg/m^3 and 580 kg/m^3 for sengon and jabon respectively. Martawijaya et al. (2005) found out the density of sengon wood range from 0.24 – 0.49 g/cm^3 in the average of 0.33 g/cm^3, and density of jabon wood range from 0.29 – 0.56 g/cm^3 in the average of 0.42 g/cm^3. It follows from this data that the results in this work are within the range reported in that literature. In all logs of sengon and jabon, the density near the pith is lower than the density near the bark. The differences are 200 kg/m^3 for sengon, and 300 kg/m^3 for jabon. This large difference gives an indication that sengon and jabon woods are inhomogeneous material. The consequent careful attentions should be given for the use of these woods by some wood-processing technologies (e.g. production of sawn timber and drying, plywoods, LVL).



1.3 Fiber length

The profiles of fiber length at 1.3 m sampling height from pith to bark are presented in Fig. 1.3. At every segmented ring, the length of thirty individual fibers was measured. The results in Fig. 1.3 indicate that the fibers varied in length for each segmented ring both for sengon and jabon. However, jabon wood showed more uniform distributions of fiber length compared to sengon wood at all segmented rings. The difference between the shortest and longest fibers in every segmented ring was in the averere of 520 μm for sengon and about 380 μm for jabon. In the first segmented rings of the stems at 1.3 m height, all fibers less than one millimeter length were found. Fiber lengths at the 1.3 m height of the trees vary in a generally similar patter from pith to bark for sengon and jabon.

The average values of fiber length at each segmented ring in Fig. 1.3 are calculated and the results are presented in Fig. 1.4. The average fiber length values of the first up to third segmented rings began from less than one millimeter, while, in the fourth ring they exceeded one millimeter. The mean fiber length value of the sengon and jabon reached 1400 μm at segmented ring 15. The fiber length increased markedly up to the segmented ring12 for sengon and up to the segmented ring of about 13 cm for the jabon. From the segmented ring 12 and 13 to the bark the fiber lengths of sengon and jabon increased gradually and nearly to be constant. These profiles indicate an expected transition age at a glance.

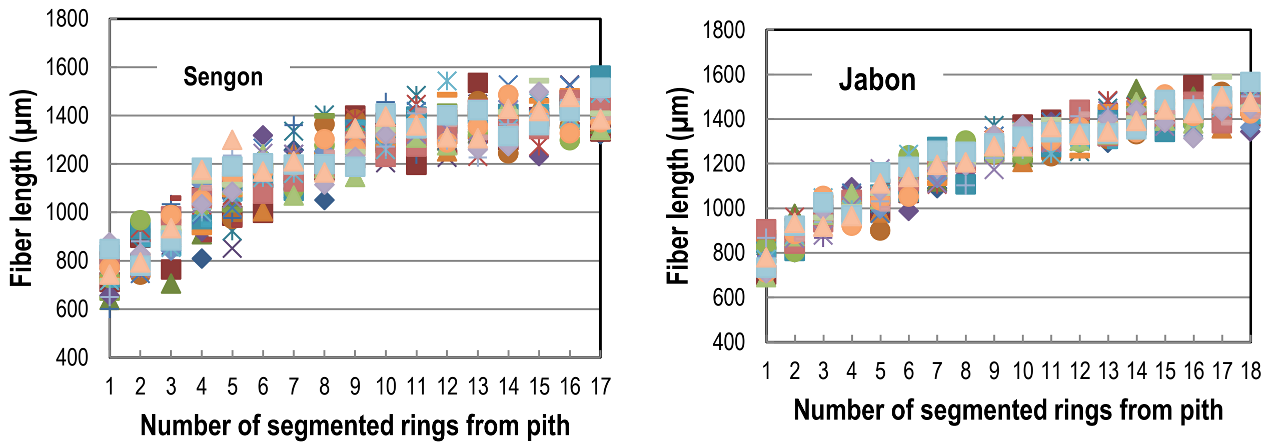


Fig. 1.3 Profiles of fiber length from pith to bark for sengon and jabon

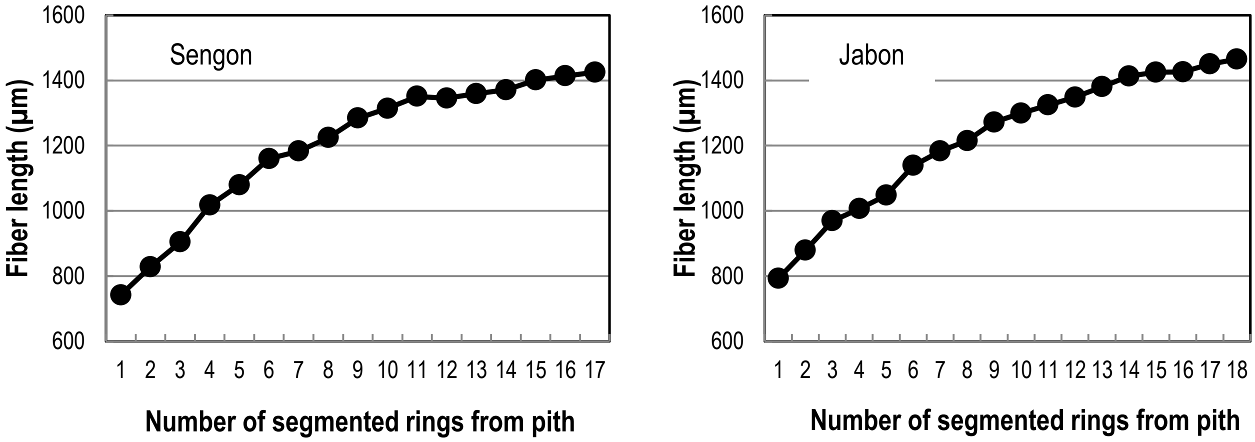


Fig. 1.4 Development of mean fiber length from pith to bark for sengon and jabon

Fiber from the 7 years old of the trees stem at the 1.3 m sampling height has showed little differences in length, in which jabon tended to produced fibers of slightly longer length compared to sengon as their segmented rings are the same. These little differences give an indication that the tree species in this study would have different impacts on their utilization. Further, average fiber length at the 1.3 m stem height from pith to bark at the age of 7 years was calculated to be 1233 µm for sengon and 1240 µm for jabon. These findings were close to the value 1.28 mm that Panshin and Zeeuw (1980) found for American beech wood *(Fagus grandifolia L)*.

Procedure non-linear (PROC NLIN) of SAS 9.1.3 was applied for the results in Fig. 1.4 to determine the transition ring from juvenile to mature wood. As a first consequence, the result of analysis suggests that fiber length is appropriate trait to determine the transition ring from juvenile to mature of sengon and jabon. The transition rings according to the fiber length values are presented in Table 1.2. Transition ring was estimated to occur at segmented ring 17 (Xo = 17) for sengon wood, and at segmented ring 18 (Xo = 18) for jabon wood. The results in Table 1.2 indicate that tree stems of sengon and jabon at the 7 years are dominated by juveniles. The stems of sengon and jabon had contain mature fibers at the segmented ring 18 (at diameter of 36 cm) and 19 (at diameter 38 cm), respectively. Therefore, the juvenile wood portions in the stem were found to be 100% for both sengon and jabon at the tree age of 7 years. With respect to the juvenile wood portion of the stems, the mean fiber lengths of juvenile wood for sengon and jabon were calculated to be 1207 µm and 1220 µm at the 1.3 m tree stem height. The porsions of juvenile wood in the stems of sengon and jabon play an important role in determining the exploitation age that is mainly dependent on the number of segmented rings of which the juvenile wood is comprised. Unfortunately, both sengon and jabon in all part of Indonesia were felled at the age between 5 to 7 years, by considering that their breast height diameters are up to 35 cm which are large enough for wood industry, and are important incomes for the communities.

Table 1.2. Transition ring from juvenile to mature wood for sengon and jabon based on fiber length and MFA as estimated using segmented regression approach

Tree species	Tree Age	Number of segmented ring based on	
		Fiber length	MFA
Sengon	7	17	18
Jabon	7	18	20

1.4 Microfibril angle

The transition age was also determined with MFA by the segmented regression model. The profiles of MFA at 1.3 m sampling height from pith to bark are presented in Fig. 1.5. Different from fiber length, the profiles of MFA decreased exponentially from pith to bark. The MFA decreased steeply from pith up to the segmented ring 14, then it decreasesd gradually toward the bark. Microfibril angles in the stem wood were large as far out as the 14^{th} segmented ring with values up to 65° near the pith. Beyond the 14^{th} segmented ring, microfibril angles decreased with angles of almost less than 30°. These results suggest that microfibril angles in the stems of sengon and jabon would stabilize at values lower than 30^{o}.

In Fig. 1.5, the plots of the MFA versus segmented ring (distance from the pith) of the wood species investigated are arranged side by side for comparison. It is obvious that the microfibril angles (MFA) decreased from pith to bark in the similar patters between sengon and jabon. Sengon and jabon woods also showed similar MFA distributions at all segmented rings. In sengon (Fig. 1.5-left), the microfibril angle (MFA) varied from about 60° to 68° (average of 65°) near the pith and from to 20° to 28° (average of 24°) near the bark. In jabon (Fig. 1.5-right), the microfibril angle (MFA) varied from about 56° to 67° (average of 62°) near the pith and from to 22° to 29° (average of 26°) near the bark.

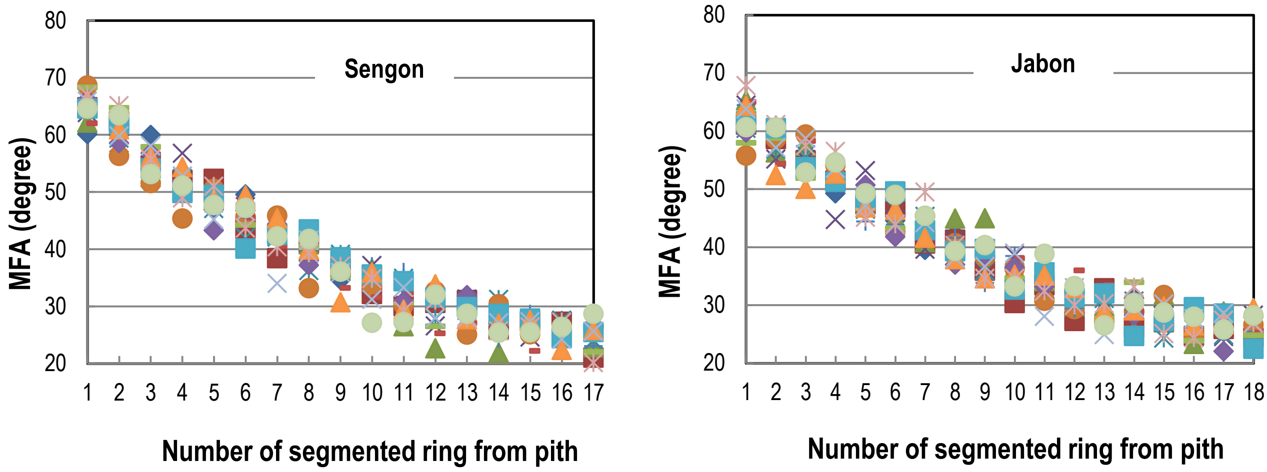


Fig. 1.5 Profiles of MFA from pith to bark for sengon and jabon

The average values of MFA in Fig. 1.5 were calculated and the results are presented in Fig. 1.6. Developments of MFA in Fig. 1.6 indicate that MFA is also an appropriate trait to find the juvenile and mature transition ring as in the fiber length. Procedure non-linear (PROC NLIN) was applied to analyze the results in Fig. 1.6 to determine the transition ring from juvenile to mature wood. The transition rings according to the MFA values are presented in Table 1.2. Transition rings were estimated to occur at about segmented ring 18 for sengon wood and segmented ring 20 for jabon wood. This results suggest that all parts of tree stems of both sengon and jabon at the 7 years were juveniles. The stems of sengon and jabon could be estimated to contain mature microfibril angles at segmented ring 19 (at diameter of 38 cm) and 21 (at diameter 42 cm), respectively. Therefore, the juvenile wood portions in the stem were found to be 100% for both sengon and jabon at the tree age of 7 years. With respect to the juvenile wood portion of the stems, the mean MFA of juvenile wood for sengon and jabon were calculated to be 39° at the 1.3m tree stem height.

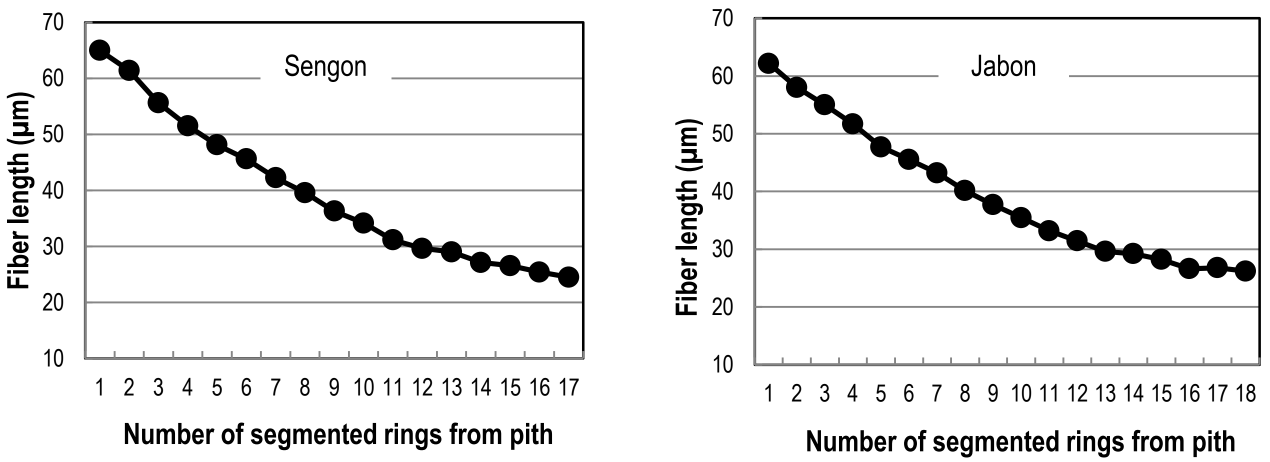


Fig. 1.6 Development of mean MFA from pith to bark for sengon and jabon

1.5 Variation of transition ring with traits

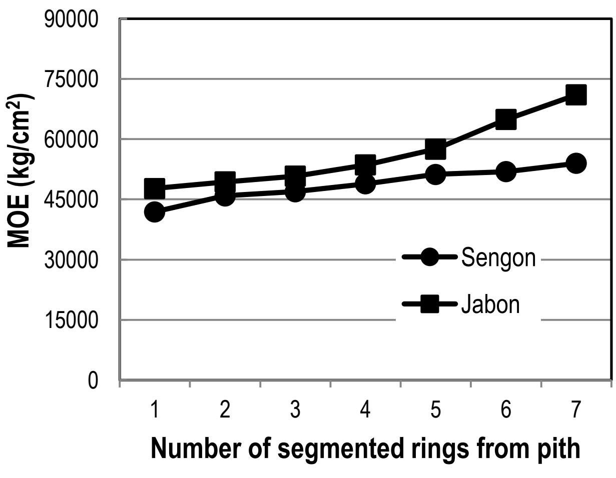
The transition ring for each tree was calculated from fiber length and MFA, using segmented regression model, as described above. The segmented regression model applied to the two traits (fiber length and MFA), led to four different results for transition ring at the 1.3 m sampling height (Table 1.2). The difference between the traits was not remarkable. The results showed that transition ring determined from MFA is 1 to 2 cm higher than transition age determined from fiber length. This analysis confirms that the determination of transition ring is dependent on the trait considered. Although fiber length and MFA have different radial patterns, the transition value found by the two traits is not significantly different.

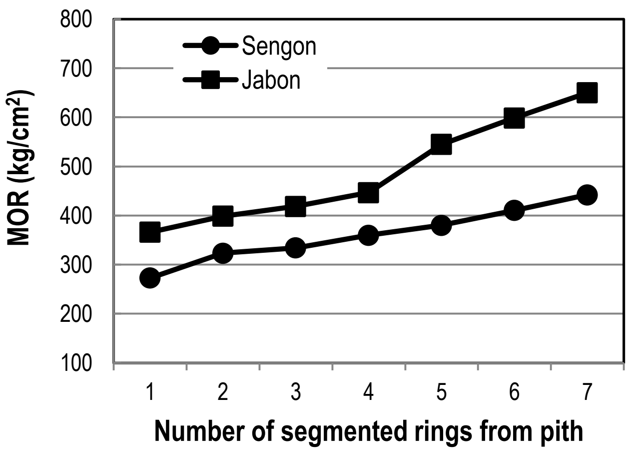
The variations in fiber length and MFA in temperate woods have been extensively characterized in many species, especially in pine. The commercial importance of fiber length and MFA, as it relates to wood quality, is well established for temperate woods, but is less clear for tropical woods. Relatively few tropical woods have been characterized, so there is a need to extend the range of species and ecotypes that have been investigated. Additionally, more well-designed studies relating fiber length and MFA and its interaction with other wood properties to timber quality are needed. Finally, the means through which trees control changes in fiber length and MFA in response to developmental and environmental influences are poorly understood, but the use of model plant systems, molecular biological and genetic techniques is already making a significant contribution to this aspect of plant cell biology.

1.6 Modulus of elasticity and modulus of rupture

The behaviors of MOE and MOR from pith to bark for sengon and jabon are presented in **Fig. 1.7**. The results indicate that juvenile woods of sengon and jabon near pith have on average a significantly lower modulus of elasticity (MOE) and modulus of rupture (MOR) than the juvenile wood near the bark. The lower MOE and MOR of juvenile wood near pith are due to larger microfibril angle, and lower density. However, the proportional increase of the MOE and MOR from pith to bark precludes the use of MOE and MOR as a reliable juvenile wood presence indicator.

Mean MOE values from pith to bark for sengon and jabon wood calculated in this study were 48675 kg/cm^2 and 56421 kg/cm^2, respectively, and their mean MOR values were 360 and 489 kg/cm^2, respectively. Martawijaya et al. (2005) found out that the MOE and MOR of sengon were 44500 kg/cm^2 and 316 kg/cm^2, respectively, and that of jabon were 55450 kg/cm^2 and 387 kg/cm^2, respectively. Though the average strength values in this reference was without giving information separately for juvenile and mature, however it could be considered that the studies were also carried out on juvenile wood from sengon and jabon trees aged below 7 years. Fortunately, the MOE and MOR results in this work are within the range reported in that literature. However, review of the strength properties of sengon and jabon woods was beyond the scope of this paper.





The behaviors of density, fiber length, MFA and strength values of juvenile sengon and jabon wood obtained in this study are expected to provide practical information for processors and silviculturists of sengon and jabon, leading to a more appropriate usage of these species. The presence of juvenile wood has to be taken into consideration with respect to the use of sengon and jabon for construction purposes particularly when bending and dynamic strength properties are critically important factors. Lower strength properties of juvenile wood imply that strength properties of sengon and jabon trees depend on their juvenile wood contents. Thus, timber with large percentages of juvenile wood, especially from fast-growing trees, will be less desirable for solid wood products. Several studies completed on solid-sawn lumber have provided a good understanding of how juvenile wood affects the mechanical properties of solid-sawn lumber (Biblis 1990, Kretschmann and Bendtsen 1992, MacPeak et al. 1990).
Considering efficiency in utilizing sengon and jabon timber, reducing the volume of juvenile wood is advantageous. This can be achieved through genetic improvement or management systems with a longer rotation age that lead to production of larger saw-logs with a lower juvenile wood content. In response to a need for increased strength, stiffness, and good dimensional stability, laminated veneer lumber (LVL) made of sengon and jabon have been being investigated. Utilization of sengon and jabon for LVL production can help to solve the problems linked to the shrinkage of raw material for construction and to the protection of native forest. At the same time, this LVL production would come up against a main problem related to veneer surface quality. Peeling parameters will carefully be optimized on such sengon and jabon having high portion of juveniles or important heterogeneity.

Both fiber length and MFA used to estimate the ring of demarcation show that sengon wood has shorter lengths of juvenility (ranging from 17 to 18 segmented ring) compared to jabon wood (ranging from 18 to 20 segmented ring). The projected figures for the portion of juvenile wood both in sengon and jabon at breast height at age of 7 year are 100%. Fiber length and microfibril angle appear to be the best anatomical indicators of age demarcation between juvenile and mature wood of sengon and jabon wood, although maturation age often varies among the traits. Lower density and static bending strength (MOE/MOR) of the juvenile wood at the age of 7 years suggest that both sengon and jabon plantation forest can be manipulated effectively through appropriate management practices (e.g. longer rotation age) to reduce juvenile wood content. Segmented regression analysis proves to be a practical and objective method to estimate transition ring from juvenile to mature wood in a study of sengon and jabon woods

II. Characteristics of Rotary Cutting Veneer

2.1 Introduction

Sengon (*Paraserianthes moluccana*) is a fast growing wood species widely planted by community in Indonesia. The sengon tress in the age of 7 years can reach breast height diameter up to 38 cm. Though all part of the tress in the age of 7 years are juvenile (**Darmawan et al., 2013**), however they have been felled in that age because demand of the sengon woods for wood industry is high, and are important incomes for the communities (**Krisnawati et al., 2011**). Sengon is the most common species used for packaging and pulp in Indonesia. Recently the sengon wood has been rotary cut for laminated-wood products. Since the sengon wood is being used in the laminated wood industry, high bonding properties are expected. However, as the sengon 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 sengon logs, and their effect on the glue bond and bending strength.

The bonding strength of the veneers depends upon a variety of factors. These factors are classified as veneers quality (moisture content, density, lathe checks, and surface roughness) and as adhesive quality (type of adhesive, mixture of adhesive, and its viscosity) and as bonding quality (glue spread, pressure time and temperature, relative humidity, and temperature of air) (**Dundar et al., 2008a**). Among these factors, lathe check is one of the important factors on the bonding strength. The bonding strength decreases, probably because of the presence of important lathe checks. Also, the veneers with lathe checks require much more glue spread because of the degradation of veneer surface topography (**Daoui et al., 2011**). Veneers with lathe checks can also cause excessive resin use and may result in resin-bleed through the inside of veneer.

In rotary-cut veneer manufacturing, when peeling starts, the wood tends to split along the grain. Lathe checks are formed at the veneer's loose side (**Fig. 1**) as tension force of the lathe's knife pulls the veneer away from the peeler block and flattens the veneer from its natural curvature (**DeVallance et al., 2007**). With respect to the cross section of the veneer, this advance splitting causes the formation of vertical cracks (known as lathe checks). The depth, length and frequency of lathe checks have been widely taken into account during veneer surface quality evaluation. 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.

There are many factors which contribute to the formation and severity of veneer lathe checks. It is usually very difficult to determine the exact cause of checking for any given incident. However, experience and research have taught us some of the most common and severe influences of veneer lathe checking. Veneer lathe check can be affected by wood log's characteristic (specific gravity, wood pores, juvenile and mature wood). In addition, pretreatment and manufacturing conditions such as steaming or boiling, knife bevel and nose bar pressure, peeling temperature, peeling thickness and peeling speed, may also affect lathe checks.

The pretreatment and manufacturing factors affecting lathe check can be controlled to achieve better veneer surface. Log temperature at the time of peeling veneer significantly affects the quality of veneer. Low temperatures produce veneers with deeper and more spaced checks than high temperatures log (**Suh and Kim, 1988**; **Dupleix et al., 2012**). Other studies indicated that higher peeling temperatures reduced the severity of lathe check depth (**Palka, 1974**). Most wood species are said to produce the best veneer quality when log temperatures are between 100 °F to 160 °F. **Dundar et al. (2008b)** found that when beech logs boiled in water at 60–70 ˚C for 20 h, 40 h, and 60 h, the veneers obtained from a 40 h boiling period could minimize the mean surface roughness values for all veneers obtained from inner (heartwood), center or outer (sapwood) portion of the logs. The magnitude of compression applied to veneer surface was considered as important factor that affects peeled veneer quality. Pressure can be applied ahead of the knife by use of nose bar pressure. In eucalyptus veneer, the lathe check was found to decrease when the veneer was peeled with nose bar pressure up to 5% (ratio of lead gap opening to thickness). Between 0.5 to 5% pressures, deformation is within the elastic zone of the eucalyptus (**Acevedo et al., 2012**). Another study indicated that settings the nose bar pressure up to a certain point by adjusting the lead and exit gap lathe (5% to 20%) reduced lathe check depth in redwood veneer (**Cumming and Collett, 1970**) and also showed a tendency to produce more frequent shallow lathe checks. In many instances, higher horizontal pressures are needed for thicker veneers and lower pressure for thinner veneers, and in general, the thinner the veneer, the better the resulting peeled veneer quality. Rotary cutting speed (meter of veneer produced per minute) is another variable that affects veneer lathe check. An increase in cutting speed results in weaker veneer with deeper lathe checks (**Lutz, 1974**). An increase in speed causes reductions in nose bar pressure and can result in more severe lathe check formation.

Differences in log's wood properties have shown significant relationships to lathe check formation when peeled into veneer. In particular, tree growth rate, specific gravity, juvenility (the pith-to-bark variation in wood traits such as density, fiber length, microfibril angle, longitudinal shrinkage, ring width, latewood proportion, and lignin-cellulose composition), and log conditioning have shown to affect veneer quality. A spindle-less rotary lathe allows manufacturers to peel smaller log’s diameter and to produce more veneer sheet up to the log's core. When fast-grown logs were peeled, deeper lathe checking resulted. In general, it has been found that peeled quality is reduced as peeling from the log's sapwood to core material, due to factors such as lower specific gravity, highest growth rate, cutting speed, and highest angle of attack at the core material (**Palka and Holmes, 1973**). It has been noted that the best veneer was produced when peeling logs with growth rings orientated at 0^o to the knife, while veneer quality decreased progressively as growth ring angle varied in either the plus or minus directions (**Cumming and Collett 1970**). Past research indicated that coarse grain, higher specific gravity veneer tends to check more significantly than does fine grain, lower specific gravity veneer. Lathe check depth was significantly less for fast growing trees (**Cumming et al. 1969**). Species of wood with fine pores check less than wood with large pores. This is because deep lathe checks and large pores create weak spots on the face veneer which provide less resistance to failure when the face veneer is under stress.

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.

2.2 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 **Fig. 2.1** shows that thickness variations of rotary-cut sengon veneers were slightly occurred. The thickness of sengon veneer peeled from some bolts, which was intended to be 1.0 mm, ranged from a minimum of 0.93 mm to a maximum of 1.08 mm, and the veneer thickness intended to be 2.0 mm ranged from a minimum of 1.95 mm to a maximum of 2.11 mm. Coefficient of variations of the veneer thickness from pith to bark calculated from the ranges was 5.3%, 5.8%, 5.9% for the intended veneer thickness of 1.0, 1.5, and 2.0 mm respectively. By considering the coefficient of variations less than 6%, the bolts of sengon were correctly peeled to maintain the thickness regularity.

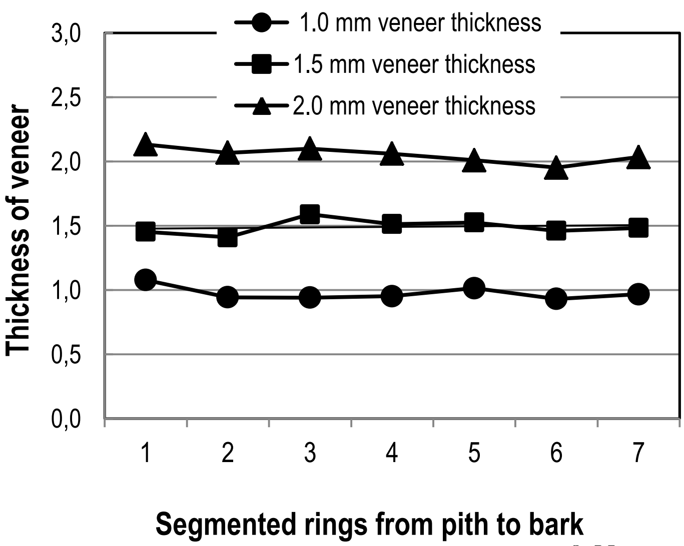


Fig. 2.1 - Variation of veneer thickness from pith to bark

2.3 Lathe check frequency, depth, and length

Fig. 2.2 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 to the pits showed larger frequency of lathe check. 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 sengon logs. **Bao et. al. (2001)** noted that juvenile wood is an important wood quality attribute because it can have lower density, larger fibril angle, and high (more than 10%) lignin content and slightly lower cellulose content than mature wood. 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. Further **Tanritanir et al. (2006)** investigated 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).

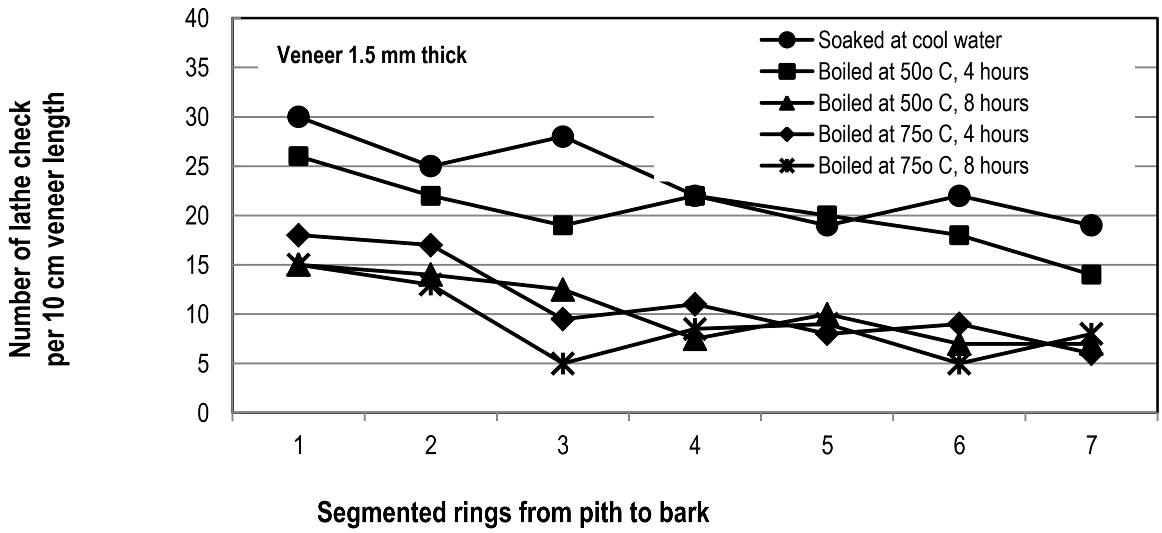


Fig. 2.2 - Variation of lathe check frequency from pith to bark for the 1.5 mm veneer thickness

The results in **Fig. 2.2** also reveal that veneers with lower frequency of lathe checks were produced by bolts boiled for 4h and 8h at temperature of 75 ^{o}C, and for 8h at temperature of 50 ^{o}C, when compare to unboiled bolts. However, the bolts boiled for 4h at 50 ^{o}C produced the same frequency of lathe checks as the unboiled bolts. This result gives an indication that boiling at a higher temperature resulted in better surface properties of the veneers. It could be announced that sengon bolts boiled for 8h at 50 ^{o}C or 4h at 75 ^{o}C could be proposed before manufacturing veneers from the sengon wood. The boiling of sengon bolts at the temperatures and periods is considered to soften the sengon 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 crystal lattice of cellulose, and softening of lignin in the cell wall **(Jorgensen, 1968)**. The softening by heat has produced a degree of plasticity roughly 10 times than that of wood at normal temperature, and subsequently rendering the wood more pliable. The temperatures applied in this work caused the sengon wood polymers to soften, and therefore the flattening of the veneer from its natural curvature is more easily accommodated with less formation of lathe checks.

Fig. 2.3 shows the values of lathe check from pith to bark for different veneer thickness. Lathe check frequency of the veneers decreased from pith to bark. The lathe check frequency of veneers near the pith was twice larger than near the bark. The results in **Fig. 2.3** indicated that the lathe check frequency tended to increase as the veneer thickness increased. It can be considered that lathe checks on the loose side of veneer were generated due to tensile stress in bending at the rake face of the knife **(Fig. 1)**. Then, further unbending process for flattening the veneer from its natural curvature caused the increase of lathe checks. Surface tension generated by the unbending process would increase with veneer thickness, and so it would cause small fracture (lathe check) more frequently. With respect to the cross section of the veneer, the greater surface tension caused the formation of more severe lathe checks.

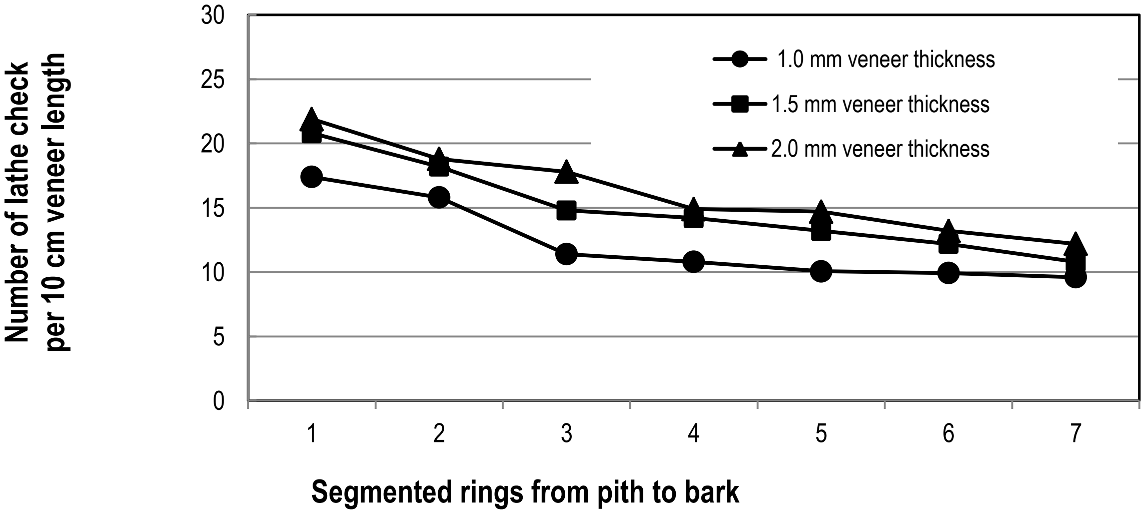


Fig. 2.3 - The effect of veneer thickness on the frequency of lathe checks

The second variable that is important in determining the veneer quality is deep lathe checks or shallow lathe checks. This study found that though the frequency of lathe checks decrease from pith to bark (**Fig. 2.3**), however the depths of lathe check in percent of veneer thickness are not significantly change from pith to bark (**Fig. 2.4b**), and did not differ prominently among the veneer thick. This result indicates that the thicker the veneer peeled, the deeper the lathe check will be (**Fig. 2.4a**). The average lathe check depths for the intended veneer thickness of 1.0 mm, 1.5 mm, and 2.0 mm were 0.28 mm, 0.41 mm, and 0.57 mm respectively (in the average depth of 28% of veneer thickness) .

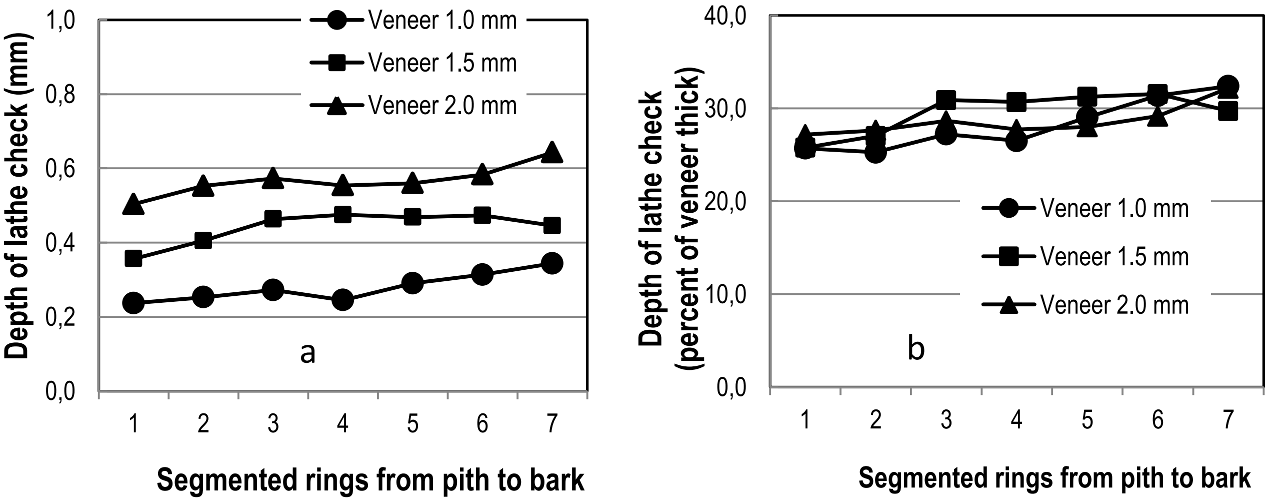


Fig. 2.4 - The progress of depth of lathe check from pith to bark

The other lathe check measured in determining veneer quality was length of lathe check. The lengths of lathe checks tended to slightly fluctuate from the pith to the bark. The length of lathe check follows the behavior of the depth of lathe check. The result in **Fig. 2.5** indicates that the thicker the veneer peeled, the longer the lathe check will be, however their depth and length ratio is almost the same. The average lathe check length for the intended veneer thickness of 1.0 mm, 1.5 mm, and 2.0 mm was 0.44 mm, 0.63 mm, and 0.88 mm respectively. The ratios between depth and length of the lathe check were 0.64, 0.65, and 0.65 for the veneer thickness of 1.0, 1.5, and 2.0 mm respectively.

In this study the lathe checks were propagated in the same radial direction at a roughly 45° angle to the annual ring for all veneer thickness, as shown **in Fig. 2**. It could be considered that the surface tension generated by the unbending process during flattening the veneer from its natural curvature would increase with veneer thickness and much more cutting splits occurred during the peeling, and so it would generate deeper and longer length of lathe check. During the rotary peeling of veneer for plywood or the laminated veneer lumber manufacture, lathe checks are formed in the veneer that are as deep as 20 – 30 % of the veneer thickness (**Rohumaa et al., 2013**). In this study the average lathe check depth was 28% of the veneer thickness, and the ratios between depth and length of the lathe check for all intended veneer thickness was 65%. Therefore, these results suggest that obtaining higher glue bond strength will need to reduce the lathe check frequency rather than the depth and the length of lathe checks.

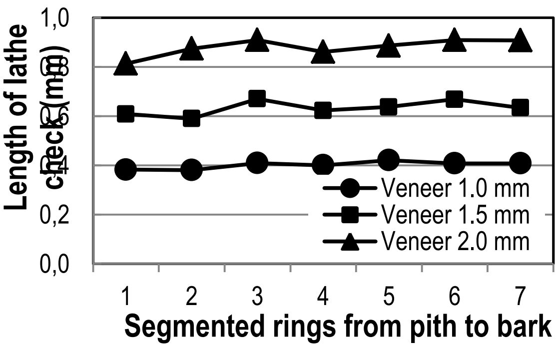


Fig. 2.5 - The progress of length of lathe check from pith to bark

2.4 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 (**Fig. 2.6**) for all veneer thickness. 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 (**Fig. 2.6a**) and the frequency of lathe check (**Fig. 2.6b**). The glue bond strength had a statistically significant, high, negative correlation to lathe check frequency, and its correlation coefficients according to the lines in **Fig. 2.6b** are summarized in **Table 2.1**. The results show that the regression coefficients for the glue bond strength linear equations depicted by the veneer thickness varied from -0.814 to -1.124. These variations indicate that the glue bond strength would decrease as the veneer thickness increase (**Table 2.1**).

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 results are in agreement with **DeVallance et al. (2007)**, who reported that a high frequency of lathe checks results in lower strength. Increasing veneer thickness generally goes to a reduction of glue bond strength. We attribute this relation mainly due to lathe checking that increases with veneer thickness, and due to higher impregnation rate of veneers and lathe checks with glue. 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 observation results of **Rohumaa et al. (2013)**, in which the failure when specimens pulled closed involved a predominantly mode II (shear) mechanism, which tends to drive wood failure toward the loose side of veneer.

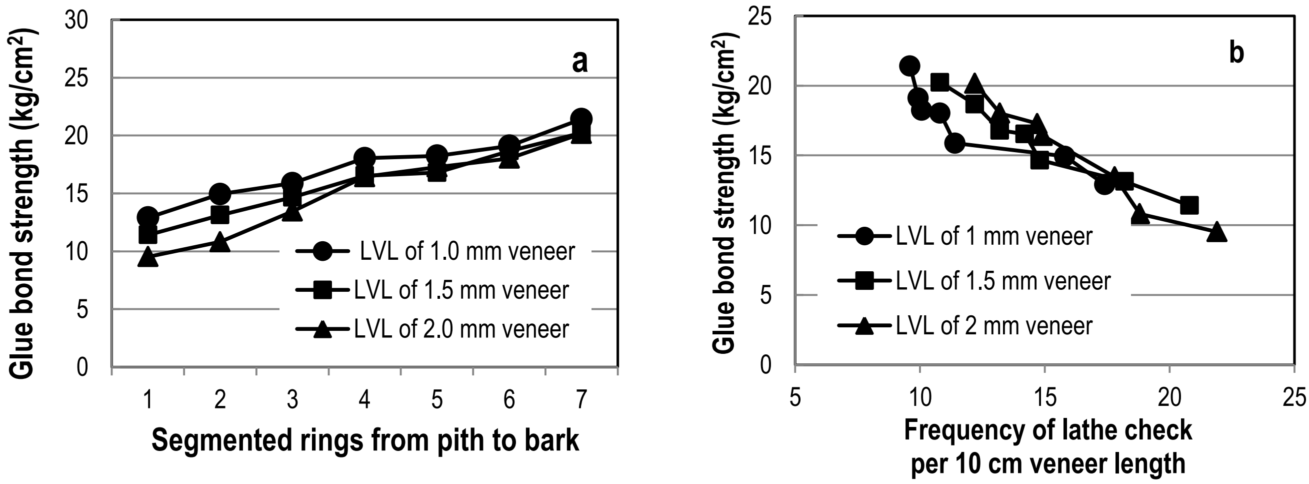


Fig. 2.6 – The effect of juvenility and lathe check on the glue bond strength for different veneer thickness

Table 2.1 - Linear regression equations and correlation coefficients according to Fig. 2.6b (**y = glue bond strength, x = frequency of lathe check, r = correlation coefficient)**

Veneer thickness	Linear equation	r
1.0 mm	y = -0,814x + 27,10	0.90
1.5 mm	y = -0,857x + 28,68	0.97
2.0 mm	y = -1,124x + 33,33	0.98

The behaviors of modulus of elasticity (MOE) and modulus of rupture (MOR) from pith to bark for sengon solid wood was published (**Darmawan et al. 2013**). It was noted in the article that juvenile woods of sengon near pith have a significantly lower MOE and MOR than the juvenile wood near the bark. The lower MOE and MOR of juvenile wood near pith are due to larger microfibril angle, and lower density. Mean MOE and MOR values from pith to bark for sengon wood reported in the study were 43651 kg/cm^2 and 302 kg/cm^2, respectively. **Martawijaya et al. (2005)** also found out that the MOE and MOR of sengon were 44500 kg/cm^2 and 316 kg/cm^2, respectively. It was found in this study that MOE and MOR values of sengon LVLs are slightly lower compared to those of sengon solid woods. The average MOE for the sengon LVL made of 1 mm veneer thick (24-ply), 1.5 mm veneer thick (14-ply), and 2 mm veneer thick (11-ply) was 42953, 40172, and 38907 kg/cm^2, respectively, and their average MOR was 269, 233, 216 kg/cm^2, respectively.

This research approved that the MOR and MOE of sengon LVLs were lower than those of corresponding solid sengon wood. The decrease could be due to the presence of lathe checks on the sengon veneer. **Fig. 2.7** shows that the MOE and MOR's of all three different thicknesses (number of plies) of LVL decrease when the frequency of lathe check in the veneer is increased. Both the MOR and MOE seem to be influenced by the lathe check. Lathe check had little effect on the MOE of sengon LVL, but had more adverse effect on the MOR of sengon LVL. The results in **Fig. 2.7** indicated that the MOE of 11, 14 and 24 ply LVL was reduced in the average of 20.6 percent and the MOR of 11, 14 and 24 ply LVL was reduced in the average of 26.9 percent when lathe check in the veneers of LVL was increased in the amount of 5 lathe check. 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.

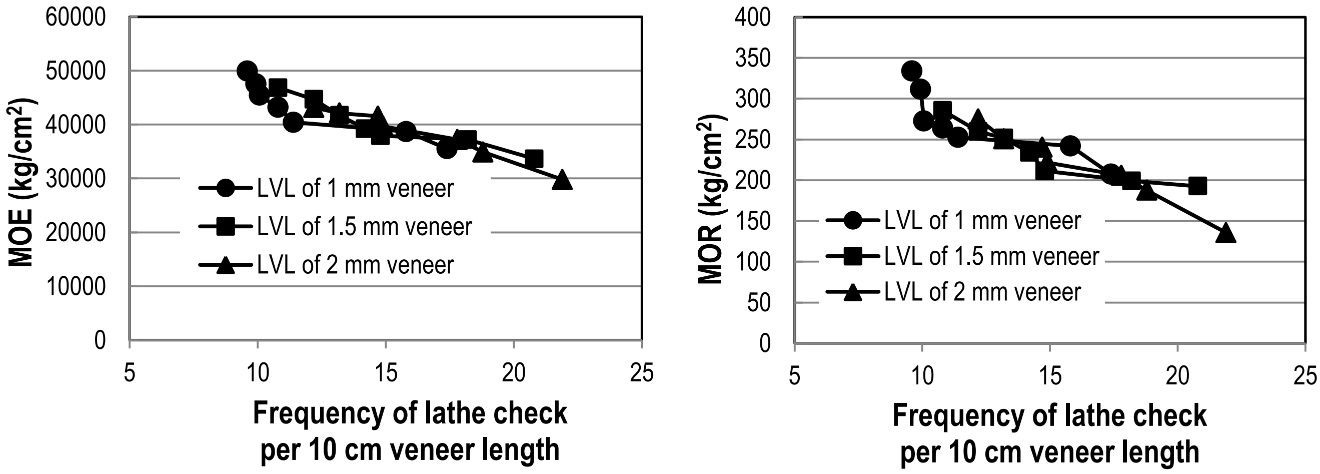


Fig. 2.7 – The effect of lathe check on the bending strength (MOE and MOR) for different veneer thickness

The results in **Fig. 2.8** show that both MOE and MOR increased with an increase in glue bond strength. Though MOE are almost the same among the veneer thickness, however MOR among veneer thickness is slightly different. As shown in **Fig. 2.8** the 22-ply LVL had higher MOR compared to those of 14 and 11-ply. This is mainly due to the higher glue bond strength produced in the glue-lines between the plies of the 22-ply which consisted of veneers of less lathe check frequency. The thinner the veneer the higher amounts of glue were needed in the manufacturing process resulting in better compaction of the wood during the pressing. This strongly suggest that by using thinner veneers (higher number of ply), the LVL will exhibit higher strength compare to those thicker veneers in production of LVL. This finding confirms with results published by **Kilic et al. (2006)**. It was reported in his article that the bending properties of LVL produced with thinner veneers were higher compared to those from thicker veneers.

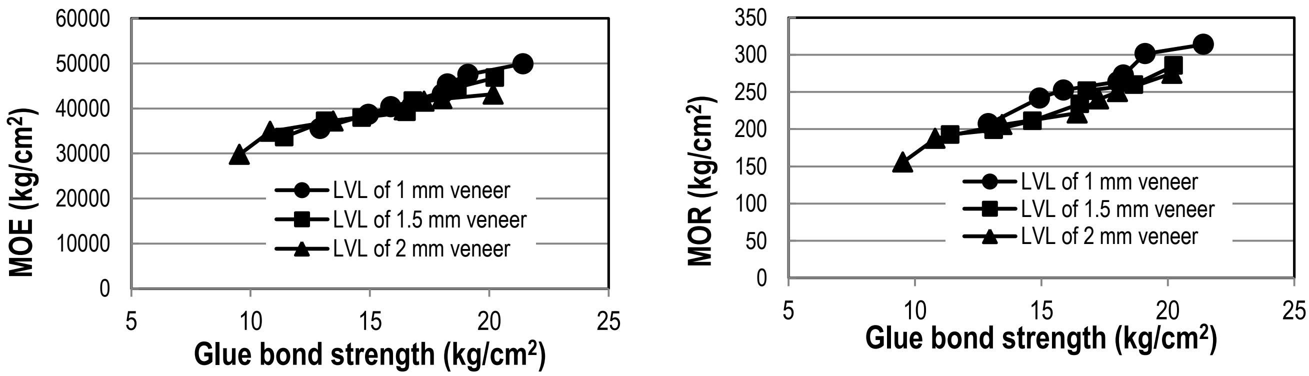


Fig. 2.8 - Relation between glue bond strength with MOE and MOR

The increases in boiling temperature significantly decreased the lathe check frequency of the veneers peeled from the pith to the bark. When the logs boiled in water for 8 h at 50 ^{o}C, and 4 – 8 h at 75 ^{o}C, the veneers obtained from the pith to the bark of the logs showed significantly less lathe check than those boiled for 4 h at 50 ^oC. The thicker veneer peeled from the logs tend to produce larger frequency of lathe check compared to thinner veneer. The MOE and MOR of sengon LVL from the bending test decreased with increasing in the lathe check frequency of the veneers. Higher glue bond strengths were also obtained for sengon LVL manufactured from veneers having lower frequency of lathe checks. The thin veneer provides better glue bond strength, MOE and MOR compared to thicker veneers. Using thinner veneers in LVL manufacture improved the strengths of the resulting panel.

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