DEMARCATION POINT BETWEEN JUVENILE AND MATURE WOOD IN SENGON (*FALCATARIA MOLUCCANA*) AND JABON (*ANTHOCEPHALUS CADAMBA*)

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RAHAYU I, DARMAWAN W, NUGROHO N, NANDIKA D & MARCHAL R. 2014. Demarcation point between juvenile and mature wood in sengon (*Falcataria moluccana*) and jabon (*Anthocephalus cadamba*). Declining natural forests in Indonesia has forced communities to search for alternative sources of wood. In order to meet the demand, wood is taken from fast-growing species grown in community forests. The species have short cutting cycle and contain a large proportion of juvenile woods. This article discusses the characteristics and demarcation point of juvenility in sengon (*Falcataria moluccana*) and jabon (*Anthocephalus cadamba*) at two different ages (5 and 6 years old) based on density, fibre length, microfibril angle and modulus of rupture. Segmented modelling approach was used to estimate juvenile and mature transition and the SAS non-linear procedure was applied to identify the juvenile to mature transition ring. To determine juvenile and mature transition ring for sengon and jabon, three trees of each species and age were sampled from a community forest in Sukabumi, Bogor, Indonesia. Discs of 2 cm thick were collected to determine density, modulus of rupture (MOR), fibre length and microfibril angle. Density was measured along the radial from pith to bark by X-ray densitometry. Fibre length and microfibril angle were measured on isolated segmented rings of 1-cm width from pith to bark. Results showed that fibre length and microfibril angle were better anatomical indicators of demarcation point between juvenile and mature wood than density and MOR. The segmented regression models for radial patterns of variation in fibre length and microfibril angle revealed that juvenility in sengon and jabon extended up to 6 years old.

Keywords: Fibre length, microfibril angle, density, community forest, juvenility

INTRODUCTION

Nowadays in Indonesia, it is difficult to get large diameter timber for lumber purposes in the market. In order to meet the demand and maintain natural forests, wood will have to be taken from fast-growing trees grown in community forests. These trees with short cutting cycle contain large proportion of juvenile wood. Juvenile wood is xylem which is created during the first few years of tree growth (Bowyer et al. 2007).

Wood near the pith of a tree, i.e. juvenile wood is different from wood near the bark, i.e. mature wood. The presence of juvenile wood can reduce mechanical properties as well as cause problems of warping, excessive shrinking and swelling, fuzzy grain, and general instability in the manufacture and use of the wood. These problems may show up in the wood when sawing, veneering, drying and machining (Maeglin 1987). Juvenile wood is characterised by lower density, shorter tracheids or fibres, lower percentage of latewood, thinner cell walls, smaller tangential cell dimensions, lower cellulose content, lower strength, higher longitudinal shrinkage, higher microfibril angle, larger cell lumen, more reaction wood, more spiral grain and higher degree of knottiness compared with mature wood (Panshin & de Zeeuw 1980). Mature wood in softwood is defined by relatively constant tracheid length whereas juvenile wood, by increasing tracheid length (Yang & Hazenberg 1994). Due to intensive silviculture, proportion of juvenile wood relative to mature wood has increased, resulting in warping problems during drying. This higher proportion of juvenile wood can have significant impact on wood quality, e.g. reduced lumber strength and reduced yields in pulp production.

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Therefore, determination of demarcation point between juvenile and mature wood is very important. Demarcation point between juvenile and mature wood is determined based on density value, fibre length, modulus of rupture (MOR) and microfibril angle from each growth ring. Juvenile area has increasing density and fibre length from pith to bark. Area with constant density value and fibre length is considered as mature wood. Turn point between these two areas is the transition area between juvenile and mature wood (Tsoumis 1991, Bowyer et al. 2007).

Demarcation point (transition ring) has been estimated from radial pattern of the average ring area, ring maximum density, ring width and ring basic density using quantitative determination based on regression analyses. Methods used include visual interpretation, polynomial regression, segmented linear regression, derivative function, studied features, sampling height, density and estimation of wood juvenile proportion. In this research, determination of demarcation point was based on anatomical properties, namely, fibre length and microfibril angle as well as physical (density) and mechanical (MOR) properties. These parameters were analysed from each segmented ring from pith to bark. For comparison, results of 7-year-old sengon and jabon transition rings which was performed by Darmawan et al. (2013) are also mentioned and discussed in this paper.

Indonesian wood industries are currently using sengon and jabon not only for pulpwood but also for light construction, furniture and wood composite for construction (plywood and laminated veneer lumber). However, these species have short cutting cycle (5 to 7 years) and, thus, have high percentage of juvenile portions in their stems. Moreover, both species do not have distinct growth rings. Therefore, investigating the juvenile and mature transition rings will lead to better utilisation of the sengon and jabon wood. The objective of this research was to analyse demarcation point between juvenile and mature wood of sengon and jabon based on density, fibre length, microfibril angle and MOR.

MATERIALS AND METHODS

Tree sample

We used three trees each of 5- and 6-year-old sengon which were planted in Cicantayan (6° 56' S, 106° 50' E, average elevation 507 m) and jabon which were planted in Jampang (6° 56' S, 106° 50' E), both in Sukabumi, West Java, Indonesia. The trees had diameter at breast height (dbh) between 28 and 32 cm (Table 1). After cutting, we took 2.5-m section in length from the bottom part of each tree stem. Sample logs were wrapped in plastic and maintained in green condition before they were transported to the workshop for testing.

Sample preparation

Discs of 2 cm thick (Figure 1; A1) were cross-cut from the middle part of the log using bandsaw. The rest of of the cut logs (Figure 1; B1) were kept as bending sample discs. From the A1 discs, flitches of 2 cm width were prepared from bark to bark through the pith using a bandsaw for measurements of density, fibre length and microfibril angle (Figure 1; A2). The flitches were cut in segments of 1 cm thick from pith to bark and numbered consecutively. Segments for determination of fibre length and microfibril angle were kept in green condition (Figure 1;

Table 1 Characteristics of sample trees

Tree species	Characteristic		
	Tree age (years)	Height of branch-free stem (cm)	Dbh (cm)
Sengon	5	8	32
	6	8	34
Jabon	5	11	34
	6	10	36

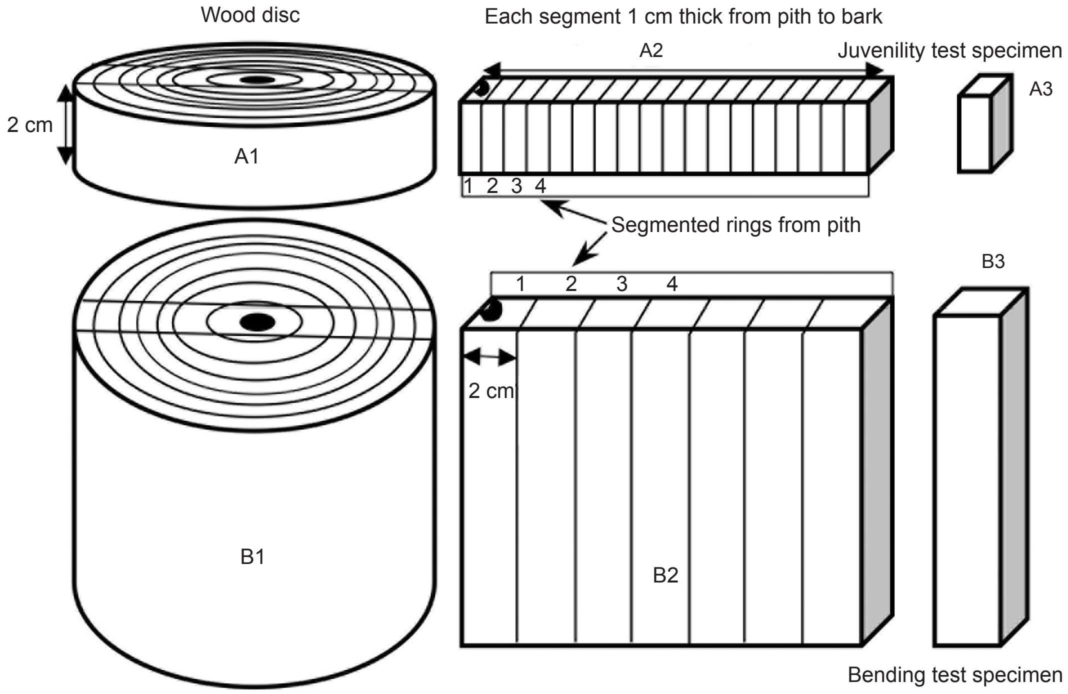

Figure 1 Schematic drawing of the preparation of the juvenility and bending test specimens (Darmawan et al. 2013)

A3). From the B1 discs, boards of 2.5 cm width were band sawn bark to bark through the pith for specimens of bending strength (MOR) tests (Figure 1; B2). The boards were also re-sawed in segments of 2 cm thick from pith to bark and numbered consecutively. Individual test specimens (Figure 1; B3) were carefully air dried to prevent warping.

Density

Density profiles from pith to bark were measured using X-ray densitometer at the Institut National de la Recherche Agronomique (INRA) in Champenoux, Nancy, France. The A2 fliches were air dried before being sawn into 2-mm thick (longitudinal) strips with a specially designed pneumatic-carriage twin-bladed circular saw. The strips were measured for air-dried moisture content. The strips were scanned to estimate the air-dried wood density for each segmented ring from pith to bark. Density of each 1-cm ring width (each segmented ring) was determined based on the intra-ring microdensitometric profiles. Density value (kg m^{-3}) from each segmented ring was obtained and the density profiles were recorded.

Modulus of rupture

Air-dried bending test specimens which were straight grained and free from any visible defects, 2 × 2 cm in cross-section, with true radial and tangential surfaces, were prepared. The bending test specimens were numbered consecutively from the pith to bark. MOR tests were conducted using Universal testing machine based on the ASTMD-143 (ASTM 2008).

Fibre length and microfibril angle

Specimens for juvenility test (Figure 1; A3) were used to determine fibre length and microfibril angle from the pith to bark. The specimens were macerated using a cutter based on Schulze's method (TAPPI 1991). The small pieces were treated with nitric acid and 0.03 g of potassium chlorate to dissolve the middle lamella and allow the fibres to become separated from one another. Using a needle dropper, the macerated fibre suspension was placed on a standard slide of 7.5 cm × 2.5 cm based on TAPPI T401 om-88 procedure (TAPPI 1991). Thirty slides of macerated fibres were prepared from each segmented ring (segment of 1 cm width). The slides were then dried and a cover glass of 22 mm × 30 mm was placed over the fibres. Fibre length was measured under an optical video microscope. Undamaged single fibre was selected from each slide and its image was taken. The captured images were analysed using Motic image software for measurement of the fibre length.

Using a microtome, thin sliced specimens were prepared for measurement of microfibril angle. Juvenility test specimens (Figure 1; A3) inserted into the microtome holder and sliced to produce undamaged thin slices of 30 µm thick. The undamaged thin slice was transferred onto a slide of 7.5 cm × 2.5 cm which had a few drops of distilled water using drawing brush. Fifteen slides were prepared from each segmented ring. The slides were then dried and a cover glass of 22 mm × 30 mm was placed over each thin slice specimen. The slides were analysed under a light microscope to find cells containing microfibrils. Images of the cells were captured and analysed using Motic image software for measurement of the microfibril angle.

Transition age

A segmented regression model was used to determine the ring of transition from juvenile to mature wood. It was assumed that development of fibre length and microfibril angle from pith to bark can be described by two functions in a curve. The first function was a steep slope of the curve over the first few years beginning at the pith (juvenile wood) and the second function was a constant slope for the later part of the curve (mature wood). The fitted regression model for the functions took the form of quadratic model with plateau (Figure 2). The change of slope in the radial fibre length, microfibril angel and density trends as a function of segmented ring number was modelled as follows:

$$Y_i = A + BX_i + CX_i^2 + E_i \qquad (1)$$

where Y_i = independent variable (fibre length, microfibril angle, density), X_i = segmented ring number, A = intercept of the line of the juvenile wood, B and C = regression coefficients and E_i = error.

From theoretical considerations, it can be hypothesised that:

$y = a + bx + cx^2$ if $x < x_0$, the equation relating y and x is quadratic and

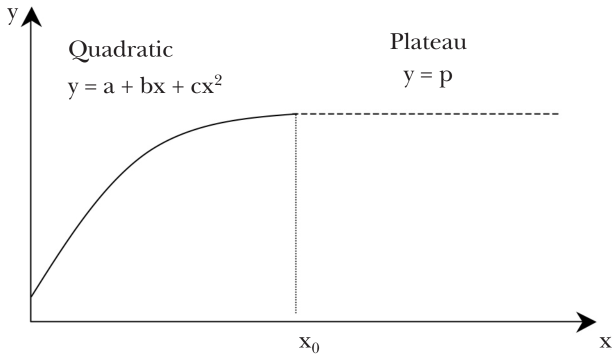

Figure 2 Fitting a segmented model using nonlinear least squares procedure; y = independent variable, a = intercept, b and c = regression coefficients for the equation, x = experimental data

$y = p$ if $x \geq x_0$, the equation is constant (horizontal line)

where x_0 = ring number at which wood changes from juvenile to mature wood, p = fibre length or microfibril angle or density at which wood changes from juvenile to mature wood, a = intercept, b and c = regression coefficients for the equation.

With segmented regression, the statistical model (equation 1) can simultaneously estimate parameters of the model and a transition ring between juvenile and mature wood. The transition ring can be directly obtained using non-linear least squares procedures (PROC NLIN) in SAS (1990, Version 6), which minimises the mean squared error. The PROC NLIN in SAS was used to obtain estimates of regression parameters and the transition ring. PROC NLIN could fit segmented model as in Figure 2. The curve in Figure 2 must be continuous (the two sections must meet at x_0) and the curve must be smooth (the first derivate with respect to x are the same at x_0). These conditions implied that $x_0 = -b/(2c)$, and $p = a - b^2/(4c)$ where b and c = regression coefficients, p = fibre length or microfibril angle or density, at which wood changes from juvenile to mature wood.

RESULTS AND DISCUSSION

Density

Density average of 5- and 6- year-old sengon and jabon wood are shown in Figure 3. Generally, densities of sengon and jabon increased from pith to bark. Jabon had larger density compared with sengon (Figure 3). Density near the pith for the 5-year-old jabon wood was 234 kg m^{-3} and 6-year-old, 297 kg m^{-3}. While the density of jabon wood near the bark was 573 and 606 kg m^{-3} respectively, density of 5-year-old sengon wood near the pith was 237 kg m^{-3} and 6-year-old, 259 kg m^{-3}. Density of sengon wood near the bark was 393 kg m^{-3} (5 years old) and 456 kg m^{-3} (6 years old). Martawijaya et al. (2005) reported that the density of sengon wood ranged from 0.24 to 0.49 g cm^{-3} (average 0.33 g cm^{-3}) and density of jabon wood, 0.29 to 0.56 g cm^{-3} (0.42 g cm^{-3}), although no information was given on whether the samples were near the bark or pith. In the current study, since density near the pith was lower than that near the bark for both sengon and jabon, attention should be given for the utilisation of these woods in certain wood-processing technologies, e.g. production of sawn timber, drying, plywood and laminated veneer lumber.

These results concurred with results of Bendtsen (1978) who reported that specific gravity or density, cell length, strength, cell wall thickness, transverse shrinkage and per cent latewood increased towards the bark, while microfibril angle, longitudinal shrinkage and moisture content decreased. It showed that sengon and jabon of 5 and 6 years old (as fast-growing species in Indonesia) had similar trends of wood properties with intensively-managed stands and could also be considered as indicator for the presence of juvenile wood.

When 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. Thus, density could not be considered as a suitable parameter for determining demarcation point of 5- and 6-year-old sengon and jabon. It has been reported that density trend from pith to bark was also not suitable for determination of transition age between juvenile and mature wood of 7-year-old sengon and jabon (Darmawan et al. 2013). On the contrary, two variables, i.e. maximum ring density and ring area, were used to determine the transition age for black spruce (*Picea mariana*) (Alteyrac et al. 2006).

Fibre length

Average fibre length at dbh from pith to bark is presented in Figure 4. Fibre length was highest near the bark. In sengon (5 and 6 years old), average fibre lengths of the first to third segmented rings began from less than 1 mm while in the fourth ring onwards, they exceeded 1 mm. In jabon (5 and 6 years old), the average fibre lengths of the first to second segmented ring began from less than 1 mm, while, starting from the third ring, lengths exceeded 1 mm. Mean fibre length of sengon and jabon increased with increasing tree age. Sengon and jabon of 5 and 6 years old still showed gradual increase in fibre length until near bark. For comparison, fibre length of both species aged 7 years old reached

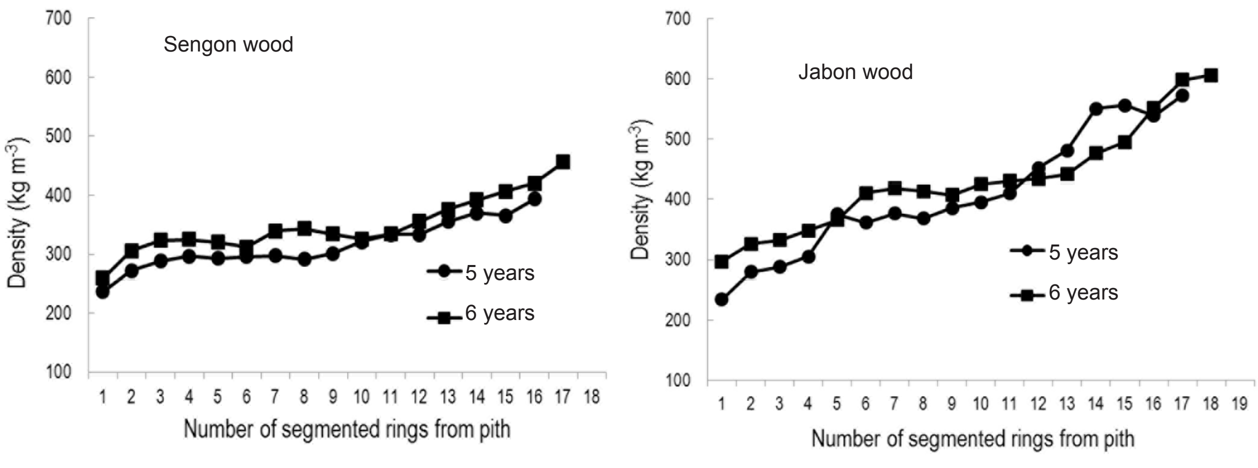

Figure 3 Comparison of radial variation of average values of density profiles in 5- and 6-year-old sengon and jabon

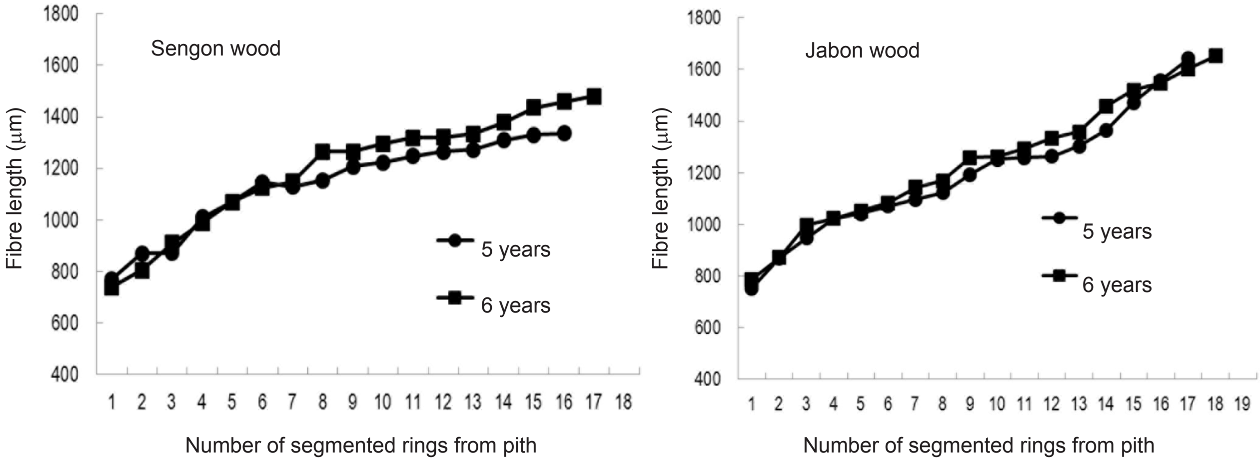

Figure 4 Comparison of radial variation of average fibre length in 5- and 6-year-old sengon and jabon

1400 µm at segmented ring 15 (Darmawan et al. 2013)

Fibre from stems of the 5- and 6-year-old trees at dbh showed differences in length whereby jabon tended to produce slightly longer fibres compared with sengon on the same number segmented rings. These differences gave an indication that the species have different impacts on their utilisation. Further, average fibre lengths at the dbh from pith to bark for sengon at the age of 5 and 6 years were 1131 and 1170 µm respectively while for jabon, 1190 and 1245 µm respectively. These findings were close to the value obtained for 7-year-old sengon and jabon, i.e. 1224 and 1147 µm respectively (Darmawan et al. 2013). These results also corresponded with results from Kiaei et al. (2012) who reported that fibre length of *Acer velutinum* increased along the radial direction from pith to bark. The proportional increase of fibre length from pith to bark proved fibre length as a reliable indicator of the presence juvenile wood. Shorter fibre length near pith is caused by accelerated rate of anticlinal division in fusiform initial cell while longer fibre length near the bark is due to this rate slowing down (Panshin & De Zeuw 1980).

Statistical analysis suggested that fibre length was an appropriate trait to determine the transition ring from juvenile to mature wood in both sengon and jabon. The transition rings according to the fibre length values are presented in Table 2. Using segmented model approach, we concluded that juvenility of 5- and 6-year-old sengon occurred until the 17^{th} ring while that of jabon, 24^{th} and 23^{rd} rings. Thus, based on fibre length trait, we concluded that 5- and 6-year-old jabon and sengon were all juvenile.

We estimated the diameter size (based on fibre length) of sengon and jabon stems that contained mature wood. For sengon, it was approximately after segmented ring 17, i.e. at dbh > 34 cm and for jabon, after segmented ring 24, i.e. at dbh > 48 cm. Unfortunately, sengon and jabon in Indonesia are felled at the ages between 5 and 7 years because dbh of about 35 cm is large enough for wood industry and selling at shorter cycle will mean more income for the communities.

Microfibril angle

The demarcation point (transition ring) could also be determined with microbril angle by the segmented regression model. The average value of microbril angle at 1.3 m sampling height from pith to bark are presented in Figure 5. Unlike from fibre length, microbril angle values of 5- and 6-year-old sengon and jabon decreased exponentially from pith to bark. Microbril angle values decreased sharply from pith until segment ring 14 (for sengon) and ring 15 (for jabon), then it decreased gradually toward the bark. Microbril angle values near pith reached over 65° for both wood species. After the 14th segmented ring, microbril angle values decreased until less than 30°. These results showed that microbril angles for 5- and 6-year-old sengon and jabon would be constant at values less than 30°.

Microbril angles near the pith for 5-year-old sengon varied from 56° to 71° (average 63°) and near the bark, from 29° to 35° (average 31°) (Figure 5). The 6-year-old sengon varied from 55° to 70° (average 62°) and from 27° to 30° (average 29°) respectively. Microbril angle values of 5-year-old jabon near pith (Figure 5) varied from 50°

Table 2 Estimated demarcation point (transition ring) from juvenil to mature wood for sengon and jabon based on fibre length and microbril angle using segmented approach

Species	Age (years)	Number of segmented rings	
		Fibre length (µm)	Microfibril angle (°)
Sengon	5	17	19
	6	17	17
	7 (Darmawan et al. 2013)	16	18
Jabon	5	24	24
	6	23	22
	7 (Darmawan et al. 2013)	21	19

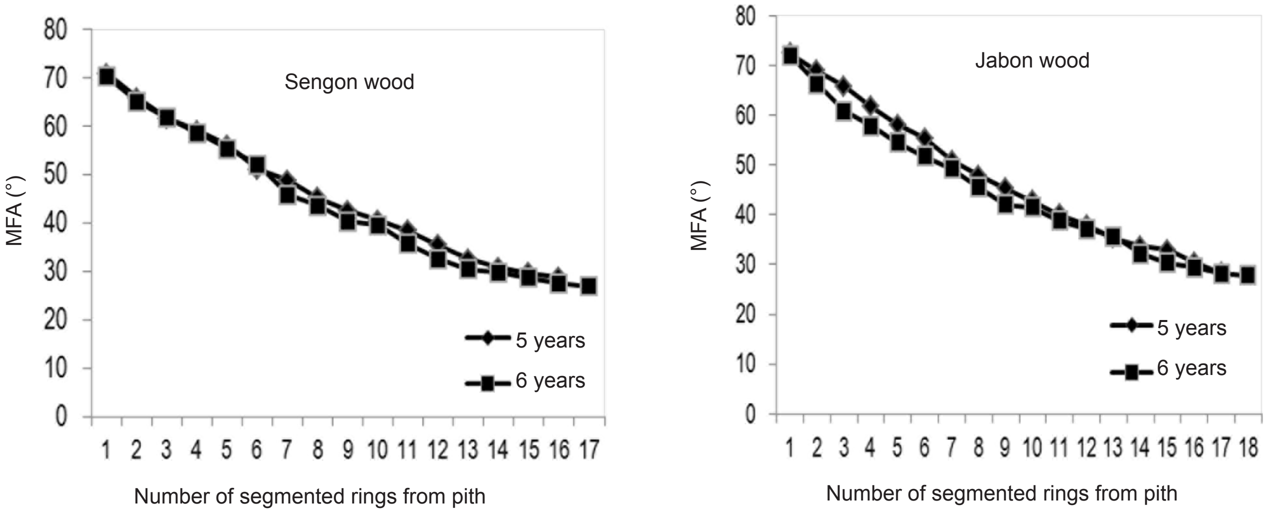

Figure 5 Comparison of radial variation of average microfibril angle (MFA) in 5 and 6-years old sengon and jabon

to 71° (average 65°) and near bark, from 28° to 35° (average 32°). Microbril angles of 6-year-old jabon near pith varied from 54° to 72° (average 62°) while near bark, from 27° to 32° (average 30°) (Figure 5). These results confirmed that microbril angle decreased from pith towards bark (Bendtsen 1978).

Figure 5 show the transition between juvenile and mature wood began at segmented ring-18 (indicated constant values after segmented ring 18). Both wood species showed declined microfibril angle towards the bark (Figure 5). We were able to estimate the demarcation point (transition ring) from juvenile to mature wood according to microfibril angle and fibre length (Table 2).

Based on statistical analyses with segmented model approach, we concluded that juvenile periods of 5- and 6-year-old of sengon occurred up to the 19th and 17th segmented rings. Juvenile periods for jabon were at the 24th (5 years old) and 22nd (6 years old) segmented rings. From the microfibril angle values, we concluded that 5- and 6-year-old sengon and jabon were all juvenile wood. Using microfibril angles, we estimated the diameter size of sengon and jabon stems which contained mature wood, i.e. approximately after segmented ring 19 (at dbh > 38 cm) for sengon and 24 (> 48 cm) for jabon.

Microfibril angles affect the dimensional stability of wood. Greater microbril angle can cause greater longitudinal shrinkage (Panshin & De Zeuw 1980, Tsoumis 1991, Bowyer et al. 2007). In order to minimise the juvenile wood proportion, we made sure that there were no silvicultural treatments such as fertilisation and irrigation especially in early growth years.

Modulus of rupture

MOR of 5- and 6-year-old sengon and jabon showed an increasing trend from pith to bark (Figure 6). The results indicated that wood of sengon and jabon near pith had significantly lower MOR values than wood near bark due to lower density and larger microbril angle. However, the proportional increase of MOR values from pith to bark proved that MOR was a reliable indicator of the presence of juvenile wood.

Mean MOR values from pith to bark for 5- and 6-year-old sengon were 367 and 377 kg cm^{-2} respectively. For jabon they were 454 and 464 kg cm^{-2} respectively. According to Martawijaya et al. (2003), MOR values of sengon and jabon wood were 526 and 691 kg cm^{-2} respectively.

CONCLUSIONS

Results of segmented regression model on fibre length and microbril angle showed different results for transition ring at dbh. Thus, the demarcation point (transition ring) between juvenile and mature wood was dependent on the traits or parameter used.

Density, fibre length, microbril angle and strength values of juvenile sengon and jabon wood obtained in this study were expected to provide practical information for industries and silviculturists of these species. This would eventually provide more appropriate utilisation of these species especially for construction purposes. The presence of juvenile wood affected bending and dynamic strength properties of the species. Lower strength properties of juvenile wood implied that strength properties of sengon and jabon trees depended on the proportion of juvenile wood. Thus, timber with large percentages of juvenile wood, especially from fast-growing trees, will be less desirable for solid wood products.

Considering efficiency in utilising sengon and jabon timber, reducing the volume of juvenile wood would be beneficial. There are long- and short-term alternative solutions for reduction of juvenile wood proportion. The former would include genetic and silvicultural treatments while the latter, improvement in wood utilisation methods, e.g. producing laminated veneer lumber from sengon and jabon which will help solve problems linked to shrinkage of raw material for construction and protection of natural forest. However, a major problem in the production of laminated veneer lumber is ensuring veneer surface quality whereby advanced research is needed to optimise peeling process of logs containing large amounts of juvenile wood.

Fibre length and microfibril angle appeared to be the best anatomical indicators of demarcation point between juvenile and mature wood. Segmented regression analysis proved to be a practical and objective method to estimate demarcation point (transition ring) from juvenile to mature wood in sengon and jabon.

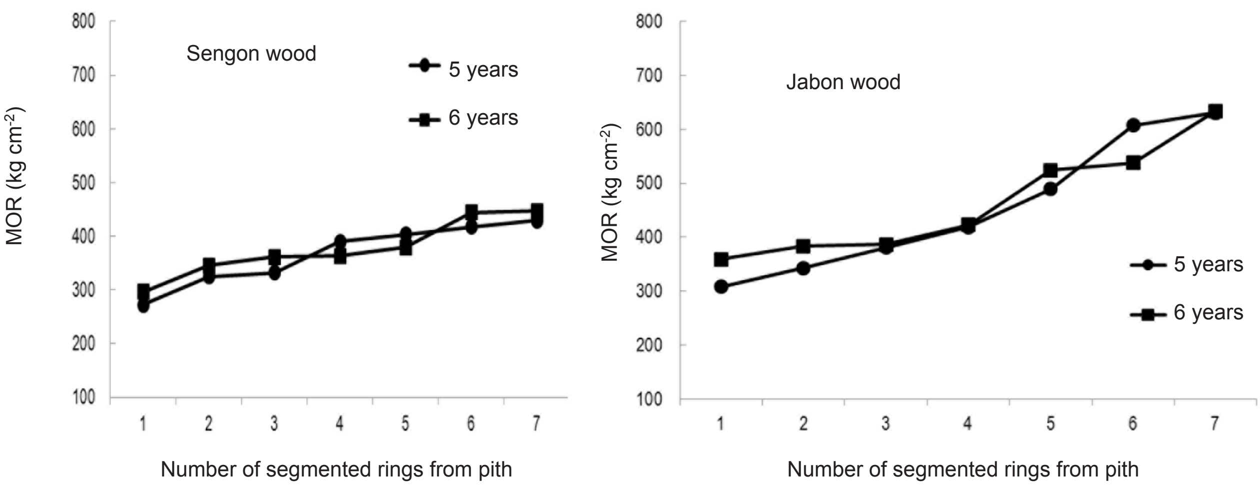

Figure 6 Comparison of radial variation of average modulus of rupture (MOR) in 5 and 6-years old sengon and jabon

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