

Radial Variation of Wood Property in *Agathis* sp. and *Pinus insularis* Growing at Plantation in Indonesia

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Abstract

To obtain basic knowledge of wood properties in plantation coniferous species growing in tropical countries, the radial variation of wood properties, such as the basic density (BD) and microfibril angle of the S₂ layer in tracheid (MFA), and the compressive properties were investigated in 45-year-old *Agathis* sp. and 32-year-old *Pinus insularis* growing in Indonesia. In *Agathis* sp., the BD showed an almost constant value from the pith to the bark. In *P. insularis*, the BD of heartwood clearly decreased by the extraction with organic solvent. As a result, the BD extracted with organic solvent showed a constant value up to 5 cm from the pith and then gradually increased toward the bark. In the radial variation of the MFA, the highest value was observed near the pith in both species. In the compressive property parallel to the grain, the modulus of elasticity (E) and compressive strength (σ) showed an almost constant value from the pith to the bark in *Agathis* sp., whereas, in *P. insularis*, both E and σ increased from the pith to the bark. In both species, the E was affected by the MFA. In addition, in *Agathis* sp., σ was affected by the BD, while in *P. insularis*, it was affected by the BD extracted with organic solvent and the MFA.

Key words: *Agathis* sp. *Pinus insularis*, compressive property, microfibril angle.

Introduction

In tropical Asia, several types of tree species have been selected for afforestation. Of those selected, many researchers focused on fast-growing ones, such as *Paraserianthes falcataria* and *Acacia mangium* (Wahyudi *et al.* 1999, 2000; Ishiguri *et al.* 2007, 2009). Several reports dealing with the basic wood properties of plantation trees in these species are available (Wahyudi *et al.* 1999, 2000; Ishiguri *et al.* 2007). On the other hand, long-term-rotation species have been considered useful for preventing the land from deteriorating. In addition, in coniferous species, such as *Agathis* spp. and *Pinus* spp., from which it takes a comparatively long time to harvest timber, one of the chemical raw materials, resin, can be obtained during their growing periods. Thus, basic wood properties after harvesting the resin should be examined for these species. However, only a few reports on the wood properties of these species are available (Sekhar and Rawat 1960; Wood Technology Division and Forest Products Chemistry Division 1974; Chudnoff 1980; Ogata *et al.* 2008). To promote the planting of these species, it is very important to know the basic wood properties and radial variation of the wood properties.

In the present study, to obtain the basic knowledge of wood properties of coniferous plantation species in Indonesia, two coniferous species, *Agathis* sp. and *Pinus insularis* Endl., which were planted in Java, Indonesia, were collected to examine the radial variation of wood and compressive properties.

Materials and Methods

Two types of coniferous plantation trees were used in this study, *Agathis* sp. and *Pinus insularis* Endl. These two trees were collected from the Educational Forest, Bogor Agricultural University. Samples were collected from a tree that had been felled by the wind. Detailed information on the sample trees is shown in Table 1. Discs of 2 cm and 7 cm in thickness were collected, respectively, for examining the wood basic density (BD) and microfibril angle of the S₂ layer in the tracheid (MFA) and compressive properties.

The wood properties were determined at intervals of 1 cm from the pith to the bark because the annual ring was obscure in both species. The BD and MFA were measured by a method described previously (Ishiguri *et al.* 2005). To determine the MFA, 30 tracheids were measured at one radial position. In *P. insularis*, the effect of resin on the BD was examined. After determining the oven-dried weight, the blocks were extracted with ethanol-toluene (1 : 2 = v : v) solvent for 24 hours using a Soxhlet extractor.

For a compression test, specimens of 20 (R) by 20 (T) by 50 (L) mm were prepared at 2 cm intervals from the pith to the bark. The average moisture contents of specimens in *Agathis* sp. and *P. insularis* in the test were 12.1±0.1% and 12.4±1.1%, respectively. To determine the modulus of elasticity in compressive strength parallel to the grain (E), the strain was measured with a strain gage and a handheld strain meter at a load range of 3,000 to 4,000 N within the range of elasticity. A compression test for determining the E was conducted using a

Table 1. Outline of sample trees used in the present study.

Species	Tree age (year)	Sampling height (m)	Diameter of collected log or discs (cm)	Number of sample tree	Provenance
<i>Agathis</i> sp.	45	7.0	17.9	1	Gunung Walat, Sukabumi, Indonesia
<i>Pinus insularis</i> Endl.	32	14.0	29.5	1	

universal test machine (Tokyo Testing Machine, MSC-5/500-2). The load was applied at 0.5 mm/min. To determine the compressive strength parallel to the grain (σ), a compression test was conducted with a universal test machine (Shimadzu, DCS-5000).

Results and Discussion

In *Agathis* sp., the value of the BD was almost constant from the pith to the bark (Figure 1). The mean value of the BD was 0.35 ± 0.04 g/cm³ (Table 2). Chudnoff (1980) reported that the BD of *Agathis* spp. ranged from 0.41 to 0.47 g/cm³. In *Agathis* sp. harvested at Kalimantan, the minimum, maximum, and mean BD were 0.35, 0.40, and 0.37 g/cm³, respectively (Wood Technology Division and Forest Chemistry Division, 1974). The mean value obtained in the present study was relatively smaller than the results obtained by other researchers (Wood Technology Division and Forest Products Chemistry Division 1974; Chudnoff 1980). The BD in *Agathis* sp. harvested at Kalimantan decreased slightly with an increase in the relative distance from the pith (Wood Technology Division and Forest Products Chemistry Division 1974). However, the results obtained in the present study did not coincide with those from another report (Wood Technology Division and Forest Products Chemistry Division 1974). In *P. insularis*, the BD decreased gradually up to 7 cm from the pith and then gradually increased toward the bark (Figure 1). As a result, the mean value of the BD was 0.53 ± 0.06 g/cm³ (Table 2). Several researchers have reported on the value of the BD in *P. insularis* (Sekhar and Rawat 1960; Chudnoff 1980). For example, Sekhar and Rawat (1960) reported that the mean value of the specific gravity for the wood adjusted to 12% moisture content was 0.46 g/cm³. In addition, Chudnoff (1980) reported that the average BD of *P. insularis* was 0.57 g/cm³. The value of the BD obtained in the present study was similar to that obtained by Chudnoff (1980). It has been considered that many resinous and phenolic deposits in wood greatly influence the density of wood (Zobel and van Buijtenen 1989). In ponderosa pine (*Pinus ponderosa*), the presence of extractives results in excessively high density; the density was reduced by 12% with the removal of extractives with an alcohol-benzene solvent (Zobel and van Buijtenen 1989). In addition, when the wood density value was compared before and after extraction with a 95% ethanol-toluene solution for 19 young-growth western hemlock

samples, the ring density showed lower values for extracted samples than for unextracted samples across rings (Singleton *et al.* 2003). The radial variation of BD for the samples extracted with an ethanol-toluene solvent in *P. insularis* is shown in Figure 1. The BD showed an almost constant value up to a 5 cm distance from the pith and then gradually increased toward the bark. The BD within 6 cm from the pith clearly decreased with extraction with an organic solvent.

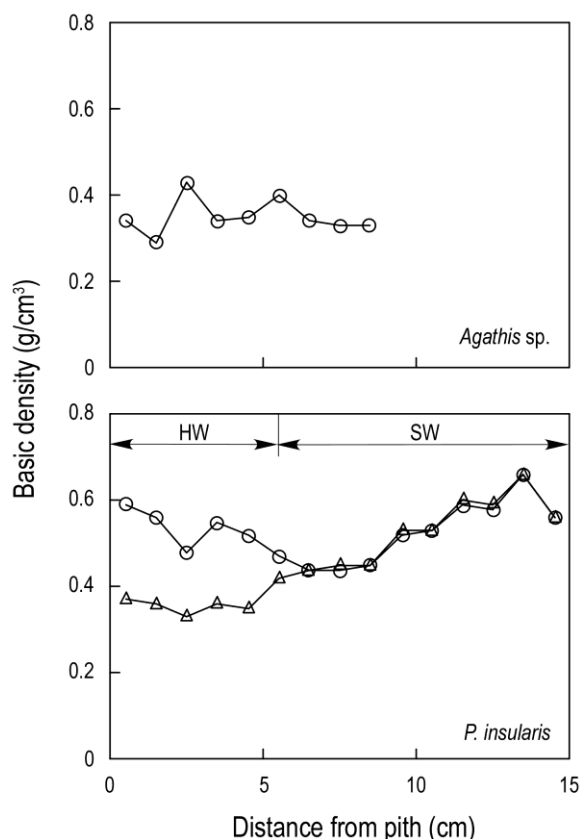


Figure 1. Radial variation of basic density in *Agathis* sp. and *Pinus insularis*. Open circle, basic density; open triangle, basic density extracted with organic solvent; HW, heartwood; SW, sapwood.

As shown in Figure 2, the highest content of extracts was observed in the inner core of the wood, and the content decreased up to 6 cm from the pith. As a result, the mean value of the BD was lower (0.47 ± 0.11 g/cm³) than that of unextracted samples (Table 2). Visual inspection showed that the color of the heartwood

apparently differed from the sapwood color: the heartwood color was dark red. Thus, the wood within 6 cm of the pith is regarded as heartwood, which shows that extracts gave higher values of the BD in heartwood. These results indicate that, to determine the BD of *P. insularis*, extraction treatment with organic solvent must be conducted in a heartwood sample.

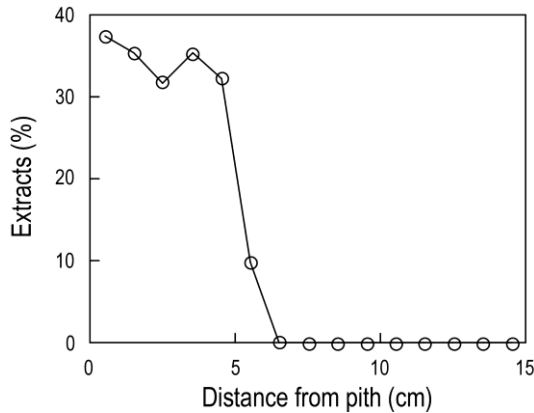


Figure 2. Radial variation of amounts of extracts in *Pinus insularis*.

Table 2. Mean value of wood properties.

Property	<i>Agathis</i> sp.			<i>Pinus insularis</i>		
	n	Mean	SD	n	Mean	SD
BD (g/cm ³)	9	0.35	0.04	15	0.53	0.06
Ex BD (g/cm ³)	-			15	0.47	0.11
MFA (degree)	9	9.5	3.7	15	14.0	6.3

Note: n, number of radial position; SD, standard deviation; BD, basic density; Ex BD, BD extracted with organic solvent; MFA, microfibril angle of S₂ layer in tracheid.

Figure 3 shows the radial variation of the MFA from the pith to the bark. The maximum value of the MFA was found near the pith in both species. In *Agathis* sp., the MFA rapidly decreased up to 2 cm from the pith and then showed an almost constant value. On the other hand, the MFA in *P. insularis* decreased gradually toward the bark and then showed an almost constant value. As a result, the mean values of the MFA in *Agathis* sp. and *P. insularis* were $9.5 \pm 3.7^\circ$ and $14.0 \pm 6.3^\circ$, respectively (Table 2). It is well known that the MFA in softwood shows the maximum value near the pith and then gradually decreases from the pith to the bark, after which it finally shows an almost constant value (Hirakawa *et al.* 2003; Ishiguri *et al.* 2005). In this study, similar results were obtained in two species.

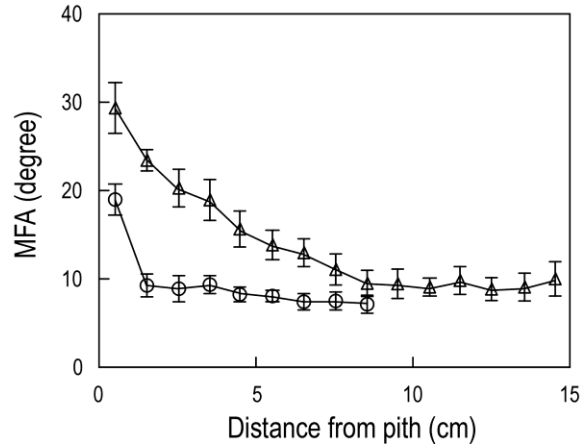


Figure 3. Radial variation of microfibril angle of the S₂ layer in tracheid. Open circle, *Agathis* sp.; open triangle, *Pinus insularis*; Bars indicate the standard deviation.

The radial variation of E and σ in *Agathis* sp. is shown in Table 3. The E and σ showed an almost constant value from the pith to the bark. The mean values of the E and σ were 10.56 ± 2.69 GPa and 33.5 ± 3.1 MPa, respectively. The E in *P. insularis* showed a minimum value (5.30 GPa) near the pith and then rapidly increased up to a 6 cm distance from the pith (Table 3). After that, it increased gradually toward the bark side. The maximum value of E was 20.46 ± 4.11 GPa. The mean value was 14.79 ± 5.32 GPa. On the other hand, σ in *P. insularis* showed an almost constant value up to a 6 cm distance from the pith and then gradually increased toward the bark (Table 3). The mean value was 52.4 ± 13.0 MPa.

The compressive properties in *Agathis* spp. and *P. insularis* have been studied elsewhere (Sekhar and Rawat 1960; Wood Technology Division and Forest Products Chemistry Division 1974; Chudnoff 1980). For example, the average values of the E and σ in *Agathis* sp. were 11.58 GPa and 34.1 MPa, respectively (Wood Technology Division and Forest Products Chemistry Division 1974). Chudnoff (1980) also reported that the average values of σ at 12% moisture content in three sample trees in *Agathis* sp. were 38.6 MPa, 40.7 MPa, and 47.6 MPa. In *P. insularis*, on the other hand, Sekhar and Rawat (1960) reported that the average values of the E and σ at 12% moisture content were 11.39 GPa and 41.9 MPa, respectively. In this study, the average values in the E and σ obtained for both species were almost the same as those of the previous studies (Sekhar and Rawat 1960; Wood Technology Division and Forest Products Chemistry Division 1974; Chudnoff 1980).

Table 3. Radial variation of compressive properties.

Position	<i>Agathis</i> sp.							<i>Pinus insularis</i>						
	n	ρ (g/cm ³)		E (GPa)		σ (MPa)		n	ρ (g/cm ³)		E (GPa)		σ (MPa)	
		Mean	SD	Mean	SD	Mean	SD		Mean	SD	Mean	SD	Mean	SD
I	1	0.43	-	9.72	-	33.1	-	1	0.63	-	5.30	-	31.6	-
II	3	0.44	0.01	9.46	1.63	33.7	1.1	1	0.50	-	6.11	-	30.8	-
III	3	0.44	0.02	11.46	4.34	36.0	3.7	4	0.46	0.05	8.08	0.47	32.4	1.8
IV	6	0.42	0.01	10.80	2.70	32.2	3.3	7	0.59	0.02	14.37	4.36	47.2	2.9
V		-	-	-	-	-	-	7	0.65	0.03	15.61	3.86	55.7	3.7
VI		-	-	-	-	-	-	7	0.76	0.02	18.38	2.77	64.9	3.2
VII		-	-	-	-	-	-	3	0.80	0.02	20.46	4.11	68.7	1.9
Mean	13	0.43	0.01	10.56	2.69	33.5	3.1	30	0.64	0.11	14.79	5.32	52.4	13.0

Note: n, number of compression test specimen; SD, standard deviation; ρ , air-dried density of specimen; E, Young's modulus in compression parallel to grain; σ , compressive strength parallel to grain; Position I, specimen collected within 2 cm from pith; II, specimen collected from 2 to 4 cm; III, specimen collected from 4 to 6 cm; VI, specimen collected from 6 to 8 cm; V, specimen collected from 8 to 10 cm; VI, specimen collected from 10 to 12 cm; VII, specimen collected from 12 to 14 cm.

The relationship between mechanical properties is shown in Figure 4. A significant correlation was recognized in the relationship between the E and σ in *Agathis* sp. ($r = 0.626$) and *P. insularis* ($r = 0.746$). It has been reported that a significant correlation between the E and σ was found in *Cryptomeria japonica* (Oda *et al.* 1990; Koga *et al.* 1992). Oda *et al.* (1990) reported that, in a *Cryptomeria japonica* stand of 25 to 30 years of age, a significant correlation was obtained between the E and σ . The results obtained in this study were in agreement with those reported by others (Oda *et al.* 1990; Koga *et al.* 1992).

The relationship between wood and the compressive properties is shown in Table 4. In *Agathis* sp., no significant correlation between wood and the compressive properties was observed. However, a relatively high correlation coefficient was obtained between the MFA and E and the BD and σ . On the other hand, a significant correlation coefficient was observed in *P. insularis* between the compressive properties and BD extracted with organic solvent or MFA. A highly positive correlation was reported between the density and the mechanical properties (Kollman and Côté 1984). In the present study, as shown in Table 4, a relatively high, but insignificant, correlation coefficient between the BD and σ was found in *Agathis* sp. In *P. insularis*, a significant positive correlation was observed between the BD extracted with organic solvent and σ . These results indicate that the σ in both

Table 4. Correlation coefficient between wood and compressive properties.

Property 1	Property 2	<i>Agathis</i> sp.			<i>Pinus insularis</i>		
		n	r	ns	n	r	ns
E	BD	4	0.106	ns	7	0.238	ns
	Ex BD	4	-		7	0.965	**
	MFA	4	-0.598	ns	7	-0.890	**
σ	BD	4	0.613	ns	7	0.368	ns
	Ex BD	4	-		7	0.983	**
	MFA	4	-0.184	ns	7	-0.821	*

Note: n, number of radial position; r, correlation coefficient; BD, basic density; Ex BD, basic density extracted with organic solvent; MFA, microfibril angle of S2 layer in tracheid; E, Young's modulus in compression test parallel to grain; σ , compressive strength parallel to grain; ns, no significance; *, significance at 5% level; **, significance at 1% level.

species was strongly affected by the extracted density. Ishiguri *et al.* (2006) suggested that, in the juvenile wood of *Chamaecyparis obtusa*, especially in the xylem up to the 10th annual ring from the pith, the σ was affected by

not only the density but also the MFA. In the present study, a significant negative correlation was observed between the MFA and σ in *P. insularis*, indicating that the MFA also affected the σ in *P. insularis*. On the other hand, a significant correlation between the MFA and E was recognized in *P. insularis*. In addition, a not significant but relatively high negative correlation was obtained between them in *Agathis* sp. Therefore, the E of both species was affected by the MFA.

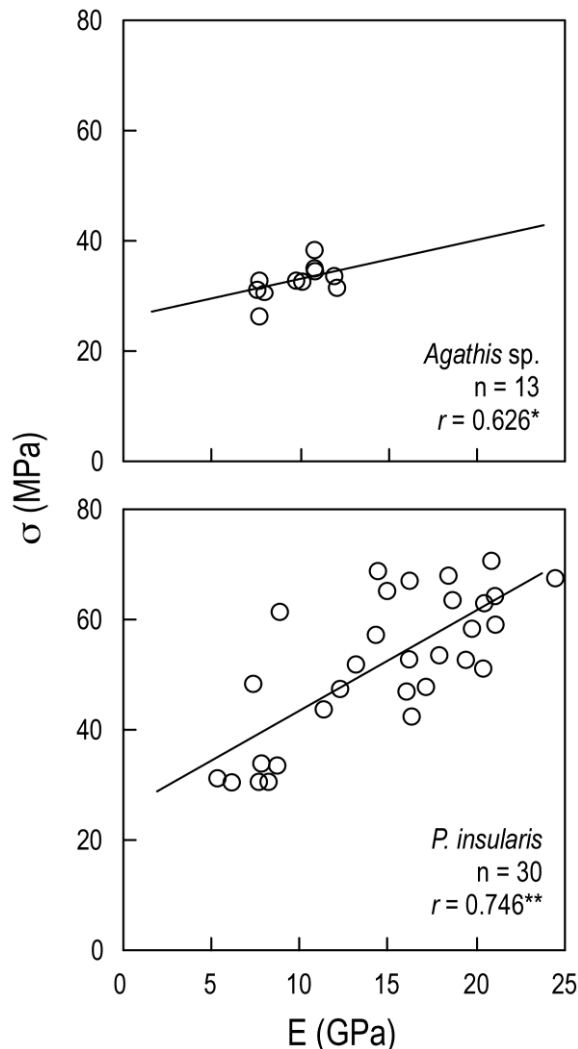


Figure 4. Relationship between the modulus of elasticity in the compression test parallel to grain (E) and the compressive strength parallel to grain (σ).

Note: n, number of specimens; r, correlation coefficients; single asterisk, significant at the 5% level; double asterisks, significant at the 1% level.

Conclusions

In the present study, the radial variation of the wood property was examined for *Agathis* sp. and *P. insularis* grown in Indonesia. The results obtained in the present study are as follows:

- 1) An almost constant value of the BD from the pith to the bark was observed in *Agathis* sp. On the other hand, the large amounts of resin contained in heartwood of *P. insularis* affected the values of the BD. The BD extracted with organic solvent showed a constant value up to 5 cm from the pith and then increased gradually from the pith to the bark.
- 2) In *Agathis* sp., the MFA rapidly decreased up to 2 cm from the pith and then showed an almost constant value. On the other hand, the MFA in *P. insularis* gradually decreased up to 10 cm from the pith and then showed an almost constant value.
- 3) An almost constant value in the E and σ from the pith to the bark was observed in *Agathis* sp. On the other hand, the E and σ in *P. insularis* gradually increased from the pith to the bark.
- 4) In both species, the E was negatively correlated with the MFA. On the other hand, the s in *Agathis* sp. positively correlated with the BD. In addition, the σ in *P. insularis* positively correlated with the BD extracted with organic solvent and negatively correlated with the MFA.

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