IAWA Journal, Vol. 33 (1), 2012: 15–23

# RADIAL VARIATION IN MICROFIBRIL ANGLE AND COMPRESSION PROPERTIES OF *PARASERIANTHES FALCATARIA* PLANTED IN INDONESIA

**F. Ishiguri**[1,*], **T. Hiraiwa**[1], **K. Iizuka**[1], **S. Yokota**[1], **D. Priadi**[2], **N. Sumiasri**[2] and **N. Yoshizawa**[1]

SUMMARY

*Paraserianthes falcataria* (L.) Nielsen is an important plantation species in Indonesia. The objective of this study was to understand the radial variation of microfibril angle in the $S_2$ layer of the wood fiber wall (MFA) in *P. falcataria*, and its relationship to compression properties parallel to the grain, including modulus of elasticity ($E$) and compression strength ($\sigma$). MFA gradually decreased from pith to bark while both $E$ and $\sigma$ increased from pith to bark. Significant differences in MFA, $E$, and $\sigma$ were found among the five sample trees. Single-regression analysis of wood and compression properties revealed that the compression properties of core wood were affected mainly by density, whereas those in outer wood were affected by both MFA and air-dry density (AD).

***Key words:*** Compression strength, density, microfibril angle, modulus of elasticity, *Paraserianthes falcataria*.

## INTRODUCTION

*Paraserianthes falcataria* (L.) Nielsen (syn. *Albizia falcataria* (L.) Fosberg) is an important fast-growing plantation species in Indonesia (Wahyudi *et al*. 2000; Nemoto 2002). The wood has been used for furniture, lightweight packing materials, veneer, pulp, and light construction materials (Soerianegara & Lemmens 1994). In previous papers (Ishiguri *et al*. 2007, 2009), we reported that the wood of *P. falcataria* could be classified into core wood and outer wood from anatomical characteristics and wood properties, with the boundary between core and outer wood located at 10 cm from the pith. For basic density, there were no significant differences among trees for whole tree averages. However, when the wood was categorized into core and outer wood, significant differences in basic density of the core wood were observed among the trees, suggesting that it is possible to select trees with high density wood at a relatively early stage. Based on these results, we have concluded that there is a strong potential for breeding for wood quality in *P. falcataria*.

1) Faculty of Agriculture, Utsunomiya University, Utsunomiya 321-8505, Japan.
2) Research Center for Biotechnology, Indonesian Research Institute of Sciences (LIPI), Cibinong, Indonesia.
*) Corresponding author [E-mail: ishiguri@cc.utsunomiya-u.ac.jp].

*Associate Editor: Lloyd Donaldson*

It has been shown both experimentally and theoretically that microfibril angle (MFA) is just as important as density for the prediction of strength and stiffness in solid wood (Evans & Ilic 2001). In several species of *Eucalyptus*, Yang and Evans (2003) reported that both MFA and density have significant and independent effects on the modulus of elasticity in static bending of small clear specimens. Softwood species often show a relationship between MFA and modulus of elasticity (Dhubháin & Evertsen 2000; Via *et al*. 2009). Dhubháin and Evertsen (2000) reported that a strong negative linear relationship occurs between MFA and modulus of elasticity in static bending for *Picea sitchensis* (Bong.) Carr. Thus, it is important to know the relationship between MFA or density, and strength properties in *P. falcataria*.

The objective of this study was to understand radial variation in MFA of the $S_2$ layer in wood fiber walls and its relationship to modulus of elasticity in compression parallel to the grain ($E$), and compression strength parallel to grain ($\sigma$), in *P. falcataria* planted in Indonesia. Based on the results obtained, the effects of MFA and air-dry density (AD) on compression properties are discussed, along with the relationship between the core wood and outer wood properties.

## MATERIALS AND METHODS

Stem diameter at 1.3 m from the ground was measured in 96 trees of 13-year-old *Paraserianthes falcataria* planted in the Serpong Botanical Garden, Indonesia. As described in a previous paper (Ishiguri *et al*. 2007), the mean and standard deviation of stem diameter measurements in these 96 trees were 38.5 cm and 13.8 cm, respectively. In general the rotation age of this species is less than 10 years. Thus, sample trees used in the present study were regarded as fully mature. Of the 96 trees, 5 trees with a stem diameter close to the mean were used in the present study (Table 1). The mean stem diameter and tree height were 38.1 cm and 25.3 m respectively. After the trees were cut down, disks 10 cm in thickness were collected from each tree at 1.3 m above the ground, and radial strips 2 cm in width and 2 cm in thickness were obtained from pith to bark. As growth rings were indistinct, the MFA and compression properties were measured in relation to the distance from the pith.

Table 1. Diameter and height of the sample trees (Ishiguri *et al*. 2007).

| Characteristics | Sample number | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | mean |
| Diameter (cm) | 40.4 | 38.1 | 33.7 | 37.0 | 41.5 | 38.1 |
| Height (m) | 24.4 | 26.0 | 25.2 | 26.2 | 24.6 | 25.3 |

Radial sections 30 μm in thickness were prepared at 2 cm intervals from pith to bark for measurement of MFA in the $S_2$ layer of wood fibers. MFA was measured for at least 30 fibers, according to the iodine method (Kobayashi 1952). The iodine method was performed as follows: 1) immersion in Schulze's solution (100 ml 35 % nitric acid plus 6 g potassium chlorate) for 15 minutes; 2) dehydration in a graded ethanol series;

3) application of a few drops of iodine-potassium iodide solution; 4) addition of one drop of 60 % nitric acid; 5) mounting the section with a cover slip.

For the compression test parallel to the grain, small clear specimens 20 (R) × 20 (T) × 40 (L) mm, were prepared at 2 cm intervals from pith to bark. All specimens were conditioned for at least 1 year under laboratory conditions (c. 25 °C and 65 % relative humidity). After conditioning, the mean moisture content of each specimen was 11.6 ± 0.3 %. Air-dry density (AD) was measured before undertaking the compression test. A total of 115 specimens (about 3 specimens at each radial position) from five trees were tested using a universal testing machine, with the load speed adjusted to 0.4 mm/min. The strain was measured using a strain gage and a strain amplifier. The modulus of elasticity in compression parallel to the grain ($E$) and the compression strength ($\sigma$) were calculated using the following equations:

$$E \text{ (GPa)} = \Delta P / \varepsilon A$$
$$\sigma \text{ (MPa)} = P / A,$$

where $\Delta P$ is the load corresponding to the strain ($\varepsilon$) measured by a strain gage under the proportional limit, $P$ is the maximum load, and $A$ is the area of the cross section of the specimen. In addition, the mean values of $E$ and $\sigma$ were calculated at each radial position.

The mean values of wood properties in core wood and outer wood were calculated according to the boundary between core wood (xylem up to 10 cm from the pith) and outer wood (from 10 cm to the bark) determined in a previous study (Ishiguri *et al.* 2007).

## RESULTS AND DISCUSSION

### *MFA*

Figure 1 shows the radial variation of MFA in the five sample trees. MFA gradually decreased from pith to bark in most trees except for one sample tree (No. 4), in which

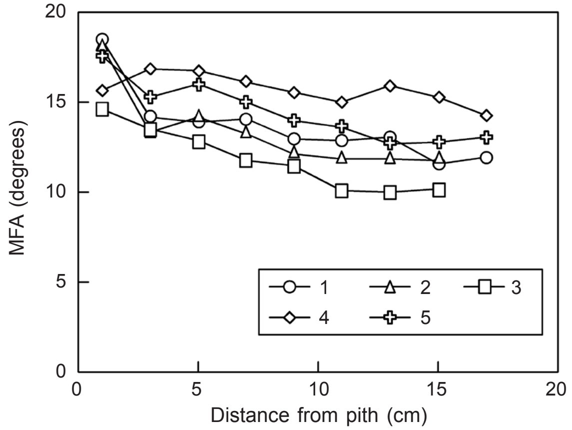


Figure 1. Radial variation of microfibril angle in the $S_2$ layer of the wood fiber wall (MFA) in five sample trees.

a nearly constant value was found. The mean value of all samples was 13.9 ± 2.1°. Watanabe *et al*. (1966) reported that the MFA of three hardwood species growing in a temperate zone, gradually decreased from pith to bark, and then became almost constant toward the bark from 15 to 20 annual rings from the pith. Our results in *Paraserianthes falcataria* grown in a tropical zone, are similar to those obtained by Watanabe *et al*. (1966). Significant differences in MFA among the five trees were recognized by analysis of variance (ANOVA) (1% level) (Table 2), suggesting that the selection of trees with a smaller MFA might be possible.

Table 2. Mean value of the microfibril angle, air-dry density of the specimen, modulus of elasticity in compression, and compression strength.

| Characteristics | Sample number | | | | | Significance among trees |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | |
| MFA (degree) | 13.7 (2.0) | 13.4 (2.1) | 11.9 (1.8) | 15.8 (0.8) | 14.5 (1.6) | ** |
| AD ($g/cm^3$) | 0.37 (0.05) | 0.39 (0.06) | 0.39 (0.04) | 0.31 (0.05) | 0.39 (0.04) | * |
| $E$ (GPa) | 8.65 (2.00) | 9.95 (1.89) | 10.61 (2.35) | 7.56 (1.75) | 9.83 (1.13) | * |
| $\sigma$ (MPa) | 31.8 (4.8) | 34.6 (7.11) | 35.4 (6.2) | 25.0 (4.1) | 35.8 (4.8) | ** |

Note: Values in parentheses indicate standard deviation. MFA = microfibril angle; AD = air-dry density; $E$ = modulus of elasticity in compression; $\sigma$ = compression strength; * = significance at 5% level; ** = significance at 1% level.

### *Compression properties*

Figures 2 and 3 show the radial variation of $E$ and $\sigma$ respectively, both of which gradually increase from near the pith towards the bark. The radial patterns of variation

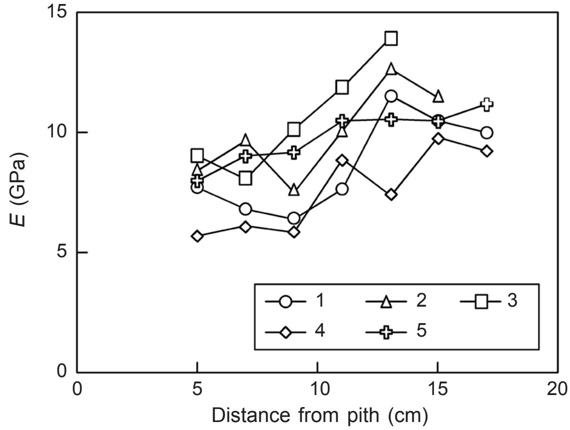


Figure 2. Radial variation of modulus of elasticity in compression parallel to the grain (E) in five sample trees.

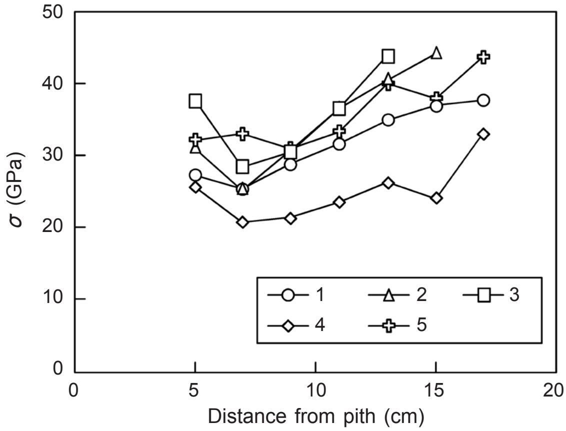


Figure 3. Radial variation of compression strength parallel to the grain ($\sigma$) in five sample trees.

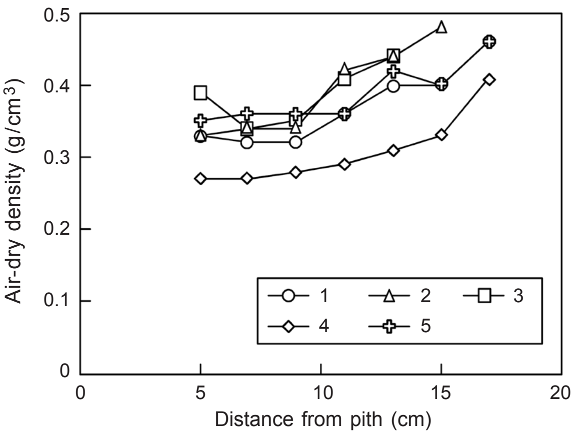


Figure 4. Radial variation of air-dry density in five sample trees.

in both $E$ and $\sigma$ were very similar to each other, and to that of AD (Figure 4). The mean values of $E$ and $\sigma$ were 9.22 ± 2.02 GPa and 32.3 ± 6.5 MPa respectively. Bolza and Kloot (1976) reported that $\sigma$ of *P. falcataria* growing in New Guinea was 26.5 MPa at a 12% moisture content, a lower value than that found in the present study.

It is well known that significant correlations are found between density and the mechanical properties of wood (Kollman & Côté 1984). Table 3 shows the correlation coefficients between compression properties and other wood properties. Significant positive correlation coefficients were obtained between the compression properties and AD. These results suggest that density strongly affects the compression properties in both core wood and outer wood in *P. falcataria*. Zhang and Zhong (1992) found that tensile strength in *Quercus liaotungensis* was closely related to MFA, and that wood density was not always a good estimator of strength. Yang and Evans (2003) reported that in *Eucalyptus* spp., MFA alone accounted for 87 percent of the variation in modulus of

Table 3. Correlation coefficients of compression and wood properties.

| Compression property | Position | n | Wood property | | | |
|---|---|---|---|---|---|---|
| | | | MFA | | AD | |
| *E* | Core | 15 | -0.563 | * | 0.830 | ** |
| | Outer | 17 | -0.731 | ** | 0.641 | ** |
| *σ* | Core | 15 | -0.401 | ns | 0.868 | ** |
| | Outer | 17 | -0.774 | ** | 0.924 | ** |

Note: n = number of samples; MFA = microfibril angle; AD = air-dry density of specimen; *E* = modulus of elasticity in compression; *σ* = compression strength; * = significance at 5% level; ** = significance at 1% level; ns = no significance.

elasticity in static bending (MOE), while density alone accounted for 81 percent. They also reported that MFA and density together (as density/MFA) accounted for 92 percent of the variation in MOE. Similar results were obtained in *E. delegatensis* by Evans and Ilic (2001). In the present study, significant negative correlations were found between compression properties and MFA, except for *σ* in core wood. In a comparison of the correlation coefficients between compression properties and MFA in core and outer wood, the correlation coefficients in outer wood were higher than those in core wood. These results indicate that the compression properties in outer wood are affected by both MFA and AD. In *P. falcataria* therefore, the compression properties of core wood are affected mainly by density, whereas those of outer wood are affected by both MFA and density.

Figure 5 shows the relationship between *E* and *σ*. A positive correlation between *E* and *σ* was found in both core and outer wood, suggesting that *σ* can be predicted by using *E* determined by non-destructive testing. However, the correlation coefficient values of core and outer wood were slightly different – the value for outer wood was higher than that for core wood.

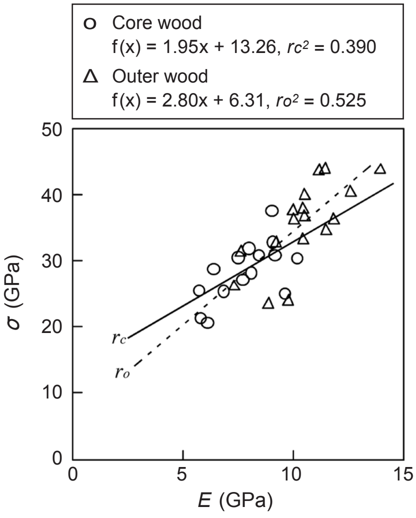


Figure 5. Relationship between modulus of elasticity in compression parallel to the grain (*E*) and compression strength parallel to the grain (*σ*). Values in this figure are the mean of *E* and *σ* at a radial position. Solid and dotted lines show the regression lines in core wood and outer wood, respectively.

In a previous paper (Ishiguri *et al.* 2007), log properties, such as green density, stress-wave velocity, and dynamic Young's modulus, showed differences among trees. In the present study, a significant difference in $E$ and $\sigma$ was found among five sample trees (Table 2). In addition, as described before, a significant positive correlation was found between AD and $E$ or $\sigma$ (Table 3). Thus, trees superior in mechanical properties could be predicted by density in tree breeding programs of this species.

***Differences in the MFA and compression properties between core and outer wood***

Ishiguri *et al.* (2012) reported that xylem maturation in *Shorea acuminatissima* Sym., which is not a fast-growing species, depends on the cambial age. In contrast, Kojima *et al.* (2009) reported that xylem maturation in *Paraserianthes* spp., which was estimated by radial variation of fiber length, depends on diameter growth. They also reported that mean values of diameter at breast height for the start of xylem maturation was 21.6 cm and 22.2 cm for Java-origin and Solomon-origin samples, respectively. In a previous study (Ishiguri *et al.* 2007), we reported that, according to the radial variation of basic density and fiber length, wood is categorized as core wood for xylem up to 10 cm from the pith, and outer wood for xylem from the 10 cm position to the bark. Table 4 shows differences in wood properties between core and outer wood among the sample trees. MFA in outer wood showed lower values than in core wood, while AD and compression strength were greater in outer wood than in the core wood. Thus, it can be concluded that the boundary between core wood and outer wood determined by basic density and fiber length, *i.e.* about 10 cm from the pith, can be also applied to MFA and compression strength in this species.

Table 4. Microfibril angle, air-dry density of the specimens, modulus of elasticity in compression, and compression strength in core and outer wood.

| Property | Position | Sample number | | | | |
|---|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 | 5 |
| MFA | Core | 14.8 (2.2) | 14.3 (2.3) | 12.9 (1.3) | 16.3 (0.6) | 15.6 (1.3) |
| (degree) | Outer | 12.4 (0.7) | 11.9 (0.0) | 10.1 (0.1) | 15.2 (0.7) | 13.1 (0.5) |
| | Ratio | 1.19 | 1.20 | 1.28 | 1.07 | 1.19 |
| AD | Core | 0.33 (0.01) | 0.34 (0.01) | 0.36 (0.02) | 0.27 (0.01) | 0.36 (0.01) |
| ($g/cm^3$) | Outer | 0.40 (0.04) | 0.45 (0.03) | 0.42 (0.02) | 0.34 (0.05) | 0.41 (0.04) |
| | Ratio | 0.83 | 0.76 | 0.86 | 0.79 | 0.88 |
| $E$ (GPa) | Core | 6.96 (0.67) | 8.52 (1.06) | 9.08 (1.05) | 5.87 (0.21) | 8.73 (0.65) |
| | Outer | 9.91 (1.64) | 11.38 (1.30) | 12.91 (1.49) | 8.82 (1.06) | 10.66 (0.35) |
| | Ratio | 0.68 | 0.75 | 0.70 | 0.67 | 0.82 |
| $\sigma$ (MPa) | Core | 27.2 (1.7) | 28.9 (3.3) | 32.1 (4.9) | 22.6 (2.7) | 32.0 (1.0) |
| | Outer | 35.2 (2.7) | 40.4 (3.9) | 40.2 (5.3) | 26.7 (4.3) | 38.7 (4.4) |
| | Ratio | 0.77 | 0.72 | 0.80 | 0.85 | 0.83 |

Note: Values in parentheses indicate standard deviation. The ratio was calculated using the core wood value divided by the outer wood value. MFA = microfibril angle; AD = air-dry density; $E$ = modulus of elasticity in compression; $\sigma$ = compression strength.

## CONCLUSIONS

In the present study, radial variation of MFA in the $S_2$ layer in wood fiber walls, and compression properties, were examined. Results obtained are as follows:

1) MFA gradually decreased from pith to bark in all but one sample tree, in which a nearly constant value of MFA was found. Significant differences in MFA were recognized among the five sample trees.
2) Both $E$ and $\sigma$ gradually increased from near the pith toward the bark, with mean values of $E$ and $\sigma$ of 9.22 ± 2.02 GPa and 32.3 ± 6.5 MPa, respectively. There were significant differences in compression properties among the five sample trees.
3) Significant correlations were found between compression properties and AD or MFA, except for the correlation between $\sigma$ and MFA in core wood, suggesting that the compression properties of core wood are affected mainly by density, whereas those of outer wood are affected by both MFA and density.

## ACKNOWLEDGEMENTS

The authors express their appreciation to T. Handa, J. Eizawa, and Y. Saito, students of Utsunomiya University, and the staff members of the Research Center for Biotechnology, Indonesian Research Institute of Science (LIPI), for their assistance in the field experiments in Indonesia. The authors are also grateful to K. Matsumoto, H. Sanpe, and H. Oyama, students of Utsunomiya University, for their assistance with the measurement of cell morphology and compression testing.

## REFERENCES

Bolza, E. & N.H. Kloot. 1976. The mechanical properties of 81 New Guinea timbers. Division of Building Research Technical Paper (Second Series) 11: 4–39.

Dhubháin, T.M. & J. Evertsen. 2000. The influence of microfibril angle on modulus of elasticity and modulus of rupture in four provenances of Irish grown Sitka spruce (*Picea sitchensis* (Bong.) Carr.). J. Inst. Wood Sci. 15: 211–220.

Evans, R. & J. Ilic. 2001. Rapid prediction of wood stiffness from microfibril angle and density. Forest Prod. J. 51 (3): 53–57.

Ishiguri, F., J. Eizawa, Y. Saito, K. Iizuka, S. Yokota, D. Priadi, N. Sumiasri & N. Yoshizawa. 2007. Variation in the wood properties of *Paraserianthes falcataria* planted in Indonesia. IAWA J. 28: 339–348.

Ishiguri, F., T. Hiraiwa, K. Iizuka, S. Yokota, D. Priadi, N. Sumiasri & N. Yoshizawa. 2009. Radial variation of anatomical characteristics in *Paraserianthes falcataria* planted in Indonesia. IAWA J. 30: 343–352.

Ishiguri, F., M. Takeuchi, K. Makino, I. Wahyudi, Y. Takashima, K. Iizuka, S. Yokota & N. Yoshizawa. 2012. Cell morphology and wood properties of *Shorea acuminatissima* planted in Indonesia. IAWA J. 33: 25–38.

Kobayashi, Y. 1952. A simple method of demonstrating the fibrillar orientation in lignified walls. J. Jap. For. Soc. 34: 392–393 [in Japanese with English summary].

Kojima, M., H. Yamamoto, M. Yoshida, Y. Ojio & K. Okumura. 2009. Maturation property of fast-growing hardwood plantation species: A view of fiber length. For. Ecol. & Managem. 257: 15–22.

Kollman, F.F.P. & W.A. Côté. 1984. Principles of wood science and technology Vol. 1: Solid wood. Springer, Berlin.

Nemoto, A. 2002. Farm tree planting and the wood industry in Indonesia: a study of falcataria plantations and the falcataria product market in Java. Policy Trend Report: 42–51.

Soerianegara, I. & R.H.M.J. Lemmens. 1994. Plant resources of South-East Asia 5 (1): Timber trees: Major commercial timbers. Prosea, Bogor, Indonesia.

Via, B.K., C.L. So, T.F. Shupe, L.H. Groom & J. Wikaira. 2009. Mechanical response of longleaf pine to variation in microfibril angle, chemistry associated wavelengths, density, and radial position. Composites, Part A 40: 60–66.

Wahyudi, I., T. Okuyama, Y.S. Hadi, H. Yamamoto, M. Yoshida & H. Watanabe. 2000. Relationship between growth rate and growth stresses in *Paraserianthes falcataria* grown in Indonesia. J. Trop. Forest Prod. 6: 95–105.

Watanabe, H., T. Matsumoto & H. Hayashi. 1966. Studies on juvenile wood. III. Experiment on stems of poplar, Shiinoki and Mizunara. Mokuzai Gakkaishi 12: 259–265 [in Japanese with English summary].

Yang, J.L. & R. Evans. 2003. Prediction of MOE of eucalypt wood from microfibril angle and density. Holz Roh- Werkstoff 61: 449–452.

Zhang, S.Y. & Y. Zhong. 1992. Structure-property relationship of wood in east-liaoning oak. Wood Sci. Technol. 26: 139–149.