Radial variation of wood properties of eight years-old fast-growing teak (*Tectona grandis* - Platinum teak wood)

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**Abstract.** The objective of this research was to determine the wood basic properties of eight years-old fast-growing teakwood (*Tectona grandis* – Platinum teak wood), in the radial direction of the stem. The anatomical features of the examined teak wood showed semi-ring porous and in general, they had a similarity to those of the conventional teak wood. The ray cell proportion was increased along with the increased distance from the pith area. The size of vessel cell tended to change from pith to the outer part. The radial (R) and tangential (T) shrinkage had improvement compared to those of five years-old Platinum teak wood. The R and T shrinkages were 2.89% and 6.2%, respectively. The present results suggested that wood properties of eight years-old Platinum teak wood is more stable than those of five years-old as reported in the previous study. The compression strength was also increased during the increase of growth age. The values of compression perpendicular and parallel to the grain were 76.74 kg/cm² and 367.9 kg/cm², respectively. The increasing of the radial properties indicated that eight years-old Platinum teak wood was still in juvenile stage.

1. Introduction

The popularity of teak wood (*Tectona grandis* L.f.) as a raw material for many purposes in Indonesia is still high because it provides an excellent property. Not only for heavy construction materials, such as for boat building, housing, rails, but it can also be used for a furniture, bridge, docks, as well. [1, 2]. Teak wood is also a durable material because it has natural resistance against wood deterioration organisms. However, teak wood is a slow-growing wood species and the rotation plantation reach 60 years-old [3–6]. Therefore, this condition leads to insufficient supply of quality timbers and the timber price is extremely high due to high demand.

Studies on the improving of productivity and shortening the rotation of teak wood have been conducted through the provenance and tree breeding programs [7, 8]. Utilization of the short-rotation teak wood from the community forest is growing high [6]. It was usually harvested at the age 10 to 15 years-old and it had annually increment rate of the diameter more than 1.5 cm. However, wood properties evaluation is yet to provide reliable data to meet the expected quality of timber material because the fast-growing teak wood has inferior properties than those of the conventional teak wood. On the other hand, Indonesian Institute of Sciences (LIPI) through Research Center for Biology and Research Center for Biotechnology has been developing a genetically modified fast-growing teak wood, which is called Platinum teak wood [9, 10].

Recording the properties since early stage of the growth is important to develop a new modified trees [11]. It is important as a guidance for the plantation management and it provides a valuable input
to minimize the risk of unexpected yield. Previous studies had reported the properties of Platinum teak wood at the age of two and five years-old [9, 12], which indicated that the woods were still in the juvenile stage. All recorded properties showed rapid changes in the radial position of the stem. The present study is part of research series that evaluating the properties of Platinum teak wood along with the increase of their age. Therefore, the aim of this study is to observe the radial variation of wood properties of eight years-old the Platinum teakwood. This study is expected to update the information regarding maturation of the fast-growing teak wood and its harvesting time.

2. Materials and methods

2.1. Materials
This study used eight years-old Platinum teak wood from Research Center for Biomaterials, Indonesian Institute of Sciences (LIPI), Indonesia. The tree diameters were 42.95 cm, 39.14 cm, and 38.18 cm. To prepare the samples, we only used the bottom part of the trees since it was in the young stage, with the average length was 50 cm. The samples were cut successively at every 2 cm in the radial direction from pith to the outer part at both sides, whilst the sample’s size of the transversal section was 2 x 2 cm.

2.2. Observation of anatomical properties
The microscopic sections were taken from each 2 cm interval block sample in radial direction of the stem. The samples were cut into 15 µm in thickness by a sliding microtome to get cross, radial, and tangential section. The sections were colored with a safranin solution and dehydrated with ethanol analysis-grade series and soaked in xylene solution. In the end of the process, the sections were mounted in the microscopic slide glasses [12]. Then, microscopic images were captured with a conventional light microscope: Olympus BX-51 equipped with digital camera DP-73 (Olympus Corp., Tokyo, Japan). Microscopic images were captured at 2x and 4x magnification of the objective lens.

The anatomical features were analyzed according to the International Association of Wood Anatomist (IAWA) list for hardwood species [13]. In addition, other observation parameters were wood cell proportion and vessel characteristics. Wood cell proportion, such as fiber, parenchyma, vessel, and rays, were digitally analyzed on ImageJ, an open source image processing program. On the other hand, vessel characteristics, such as lumen diameter and area, were performed by using some library in wood vision tool (wvtool), which run by R programming [14].

2.3. Shrinkage and dimensional stability
The sample dimension for shrinkage analysis was 2 x 2 x 4 cm in the radial, tangential and longitudinal directions, respectively. The samples were measured by a caliper on all directions in wet, air-dried, and oven-dried conditions. However, the calculation for shrinkage analysis used only the wet and oven-dried conditions, with the formula as follows:

\[ S = \frac{(D_0 - D_1)}{D_0} \times 100\% \]  

(1)

S= shrinkage; D0: wet dimension; D1: oven-dried dimension

The wet dimension was used in this study because it was difficult to maintain the green or fresh condition of the sample. As we know, there were many factors which could be affected by the water condition on the wood after cutting the trees. The wet condition was obtained by immersing the wood samples into the water for around 30 days until they submerged. In addition, dimensional stability was determined by a ratio of tangential (T) and radial (R) shrinkage or T/R ratio. Wood will be in stable condition if the ratio is ~1 [15]. It means that the R and T shrinkages were similar.

2.4. Compression strength
Compressions strength, i.e. compression parallel and perpendicular to the grain, were conducted according to the British Standard 373 [16] by using Shimadzu Universal Testing Machine Type AG-IS
50 kN (Shimadzu Corp., Kyoto, Japan). The compression strength value was then used to estimate the strength class of the Platinum teak wood based on the Indonesian Forestry Classification in Table 1 [17].

| Strength class | Specific gravity | Absolute bending strength (kg/cm²) | Absolute compression strength (kg/cm²) |
|----------------|-----------------|----------------------------------|--------------------------------------|
| I              | over 0.90       | over 1100                         | over 650                             |
| II             | 0.60 to 0.90    | 725 to 1100                       | 425 to 650                           |
| III            | 0.40 to 0.60    | 500 to 725                        | 300 to 425                           |
| IV             | 0.30 to 0.40    | 360 to 500                        | 215 to 300                           |
| V              | under 0.30      | under 360                         | under 215                            |

3. Results and discussion

3.1. Anatomical properties

Figure 1 represents the microscopic features of eight years-old Platinum teak wood in different radial position. In general, the anatomical properties of the eight years-old Platinum teak wood was similar to those of conventional teak wood, two and five years-old Platinum teak woods [2, 12]. The growth ring was distinct and semi-ring porous because the size was gradually decreased from early to the latewood (Figure 1A). Vessel cell had characteristics, such as solitary, simple perforation plates, and simple perforation. Vessel sizes tend to change in the radial direction of the stem (Figure 1A, 1B, and 1C). Eight years-old Platinum teak wood has paratracheal parenchyma, which is called vasicentric sheath narrow. In addition, there was also parenchyma in marginal at the growth ring area. Ray cells consist of 1 – 2 seriate in the near pith (Figure 1F) and 4 – 10 seriate in the intermediate and near bark region (Figure 1D and 1E). The ray cells were procumbent (Figure 1G, 1H, and 1I).

Figure 1. Microscopic images of 8 years-old Platinum teak: cross section of near bark (A), intermediate region (B), and pith region (C); tangential section of near bark (D), intermediate region (E), and pith region (F); radial section of near bark (G), intermediate region (H), and pith region (I). Bar scale showed 500 µm.
Figure 2 shows the cell proportion in radial direction of the stem. The wood cell consists of 64% of fibers, 22% of rays, 11% of vessels, and 3% of parenchyma. The proportion of ray cells were increased from the pith region toward the outer part (Figure 2A). The proportion of ray cells in fast- and slow-growing teak wood have been reported at 20.3% and 18.7%, respectively [18]. In addition, the teak wood from Bangladesh was reported to have ray cells proportion at 10.6 – 14% [19]. Ray cells were ignored in relation to the other properties, especially in the wood mechanical properties because the proportion was lower than that of fiber cells. However, there was some report stated that ray cells might have influence on the compression strength [19]. The fibers proportion was slightly higher in the pith area than in the outer part. The fibers proportion of the juvenile teakwood was reported to be higher than that of the mature teak wood [18, 20]. The juvenile wood is a region in the near pith area [21, 22]. Vessels proportion was slightly increased from the outer to the pith area, whilst parenchyma tended to decrease (Figure 2B). This condition was affected by the other cells such as rays and fibers proportion.

Figure 2. Cell proportion of 8 years-old Platinum teak wood in interval 2 cm in radial direction. A: fiber and ray cells proportion; B: Vessel and parenchyma cells proportion. Zero (0) cm in the radial direction indicated the pith area, while negative value indicated the opposite region of the positive value in the one parallel line.

Figure 3 shows the vessel characteristics of eight years-old Platinum teak wood. Figure 3A shows that the pith area had high number of vessels per square mm, while on the contrary, the vessels number in the outer part were low. The change from 2 cm region from the pith area to the outer part was remain constant. The vessel frequency had an effect on the wood dimensional stability, in which the lower the number, the higher dimensional stability [6]. Vessel cells in the pith area were smaller than those in the outer part (Figure 3B), thus the number in 1 square mm was higher than that in the near bark region. The diameter and area of lumen vessels were slightly increased from the pith to the bark.
The current results were in accordance to those of the 70 years-old teak wood from East Timor [23]. However the results was in contrast to a previous report of 5 years-old teak wood from Indonesia which stated that the vessel cell diameter in the outer part was lower than pith area [24]. Furthermore, the vessel diameter was reported higher in earlywood than that in latewood, but the vessel frequency was in the contrary result [25]. Vessels affected the longitudinal flow of liquids [25].

3.2. Dimensional stability

Figure 4 shows the variation of radial and tangential shrinkages of the eight years-old Platinum teak wood. It showed that both shrinkages were slightly increased from pith to the several cm, and then they were decreased to the bark. This condition might be affected by the increasing of mature wood from the pith region to the near bark. It was well known that the juvenile wood was located in the area surrounding the pith, while the mature wood was in the near bark. The juvenile wood was characterized by the rapid change in their properties [26, 27]. However, further research is required to clarify the existence of mature wood in the eight years-old Platinum teak wood.

Previous study on the dimensional stability of two and five years-old Platinum teak wood revealed that the radial shrinkage of those both trees were 5% and 3.83%, respectively. On the other hand, the tangential shrinkages were 4.63% and 8.23%, respectively [9]. The present study obtained that the radial and tangential shrinkages of the eight years-old Platinum teak wood was decreased, i.e., at 2.89% and 6.2%, respectively, although it was still higher than those of sixty years-old conventional teak wood, at 2.8% and 5.2%, respectively [2]. The results indicated that wood quality tend to improve along with the increasing of the age. The results also confirmed that the proportion of mature wood was a function of the ages [26].

Dimensional stability was often described as the ratio of Tangential (T) and radial (R) shrinkages. It was common that the tangential shrinkage was double times of the radial shrinkage, thus the value of T/R ratio ranges from 1.4 to > 2 [26]. The T/R ration obtained in the present study was 2.15, which was lower than the previous reports [2, 5, 28–30]. However, the previous reports were conducting tests on the older ages of teak wood, and therefore, the proportion of mature wood might higher than that of eight years-old Platinum teak wood. Wood is hygroscopic materials, which means that water contain can alter the dimension of the wood. The low dimensional stability of eight years-old Platinum teak wood indicated that the wood was sensitive toward environment changes, such as temperature and humidity. Therefore, further treatment was needed to prevent wood deformation.
3.3. Compression strength

Figure 5 shows the compression strength of eight years-old Platinum teak wood. It showed that the strength increases from the pith to the bark for both compression perpendicular to the grain (Figure 5A); and compression parallel to the grain (Figure 5B). The ray cells proportion was supposed to be a factor that affected radial variation [19]. This strength was slightly increased from the five years-old Platinum teak wood as reported in a previous study [9]. Compression perpendicular to the grain is important in the design of beam connection, while compression parallel to the grain is important to determine the maximum load of column [15].

Figure 5 also provides an information that the compression strength was not in constant value, which means the stem might consist high proportion of juvenile wood. Delaying the harvesting time might be a good solution. In general, wood properties will increase along with the increasing of wood ages and mature wood proportion. According to the Vademecum of Indonesian Forestry, the results of current study indicated that the eight years-old Platinum teak wood is classified on the class strength III [17]. Therefore, the wood is not suitable for heavy construction material. However, the wood is promising for the light construction or the furniture material.

![Figure 5. Compression strength of 8 years-old Platinum teak wood: (A) compression perpendicular to the grain, (B) compression parallel to the grain. Zero (0) cm in radial direction indicated the pith area, while negative value was the opposite region of the positive value in the one parallel line.](image)

4. Conclusion

Anatomical features of eight years-old fast-growing Platinum teak wood was identical to the conventional teak wood. The wood was a semi-ring porous, in which the vessel size changed gradually from earlywood to latewood. The ray cells proportion had a unique pattern, which was increased in radial direction from the pith to the bark. Tangential and radial shrinkages were lower than those of five years-old Platinum teak wood, which indicated that eight years-old Platinum teak wood was more stable. However, the dimensional stability was relatively low, thus it required any further improvement in the future. The compression strength was higher than that of five years-old Platinum teak wood. The results suggested that the wood is classified into strength class III, according to the Vademecum of Indonesian Forestry.

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