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# Fiber Morphology and Physical Characteristics of *Gigantochloa atter* at Three Different Ages and Heights of Culms for Better Utilization[1]

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## ABSTRACT

Fiber morphology and basic characteristics of Legi bamboos (*Gigantochloa atter*) growing on Yogyakarta were studied considering their age and height positions in the culms. Culms of 4, 16, and 40 months were harvested, and their total lengths were measured. The length, diameter, and wall thickness of each internode were measured. All the sample culms were divided into three different parts along the height, and their fiber dimension and physical properties were observed. The data obtained were analyzed by analysis of variance.

The results showed that the culms had a diameter of 5.8 to 10.8 cm. The lowest internodes always showed the shortest length and the thickest wall. The culms had an average fiber length of 2.41 mm and Runkel ratio of 0.61. Fiber length was affected by the height, while fiber diameter, lumen diameter, and fiber wall thickness were affected significantly by the age of the culms. The culms had high green moisture content (GMC) of 157.89%, and basic density (BD) of 456.67 kg.m$^{-3}$, a total longitudinal shrinkage of 0.35%, and relatively low R/T shrinkage ratio. The interactions between age and height were affected GMC and BD.

***Keywords :*** Legi bamboos, culm dimension, fiber dimension, physical properties

## 1. INTRODUCTION

Bamboos are important multipurpose plant material. It is one of the fastest-growing plants. Some of bamboos are used for producing edible shoot, making basket, handicrafts, bridge, transport system, housing, and as a source of long fiber material for the pulp and paper industries. Bamboo is also an important plant for preventing soil erosion because after harvesting, it roots remain in place and it can grow itself back again with the same growth rate.

Bamboo in Indonesia plays an important role particularly in rural life as well as rural community economic. However, very limited information is available in the literature regarding

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its quality. Studies on the effect of culms age and height have been conducted on some Malaysian bamboo, and reported their significant effects on anatomical, physical, and mechanical properties (Mohmod *et al*. 1990; Mohmod and Mustafa 1992; Hisham *et al*. 2006; Nordahlia *et al*. 2012), and on Bangladesh bamboo (Kamruzzaman *et al.* 2008).

In Korea, a few studies on bamboo have been focused on the utilization for composite board (Roh *et al.* 2004) and antioxidant and anticancer activity of extractives (Kim *et al.* 2014).

Legi bamboo (*Gigantochloa atter*) is one of the bamboo plants that can easily be found in many rural areas in Java Island. It is commonly growing on low land and it has been observed growing from near the coast of up to 1400 m above sea level with an annual precipitation of 2,500 mm. Bamboos are usually grown in inter-mixed sites with other plants like coconut, banana etc. The plant could reach up to 25 meter height and of about 5～10 cm DBH (Verde 2012). It is usually grown in clumps with the inner part consisted of older culms while the outer part consisted of younger one. This makes the harvesting difficult, and even many of the damaged young bamboos after harvesting are left as wastes. In an effort to minimize the wastes and at the same time to see the possibility of utilizing young bamboo, this study on the fiber morphology and physical properties of Legi bamboo at different culms age and height has been carried. The objective of the study on Legi bamboo is therefore to clarify some of these less researched properties i.e. culms characteristics, fiber dimension, and physical properties of common harvesting age (3 years old, and in this study we used 40 months) at three different height (axial) positions. All of those properties were compared with those of young bamboos aged 16 and 4 months.

## 2. MATERIALS and METHODS

### 2.1. Materials

Legi bamboos used in this study were from community forest grown on Trihanggo Village, Gamping Sub-district, Sleman Regency/District, Yogyakarta province, 7° 45’08” South and 110°20’08” East of 148 m above sea level. They were in healthy and free of defect condition culms and from three different ages of 4, 16, and 40 months. The 4 month culms were determined by monitoring the growth since the new shoots emerged from the ground, while the 16 and 40 months culms were based on visual inspection by experienced field personnel familiar with the history of the clump.

Three healthy Legi bamboos of each age were harvested 5 cm above ground level, and their total height were measured. Diameter, length and thickness of each internode in each culm were also measured. Each culm (Fig. 1) was then cut into three different axial (height) positions of bottom, middle, and top, and the internodes in those positions were taken. The highest top part of bamboo was limited up to minimum diameter of 5 cm only. A bamboo

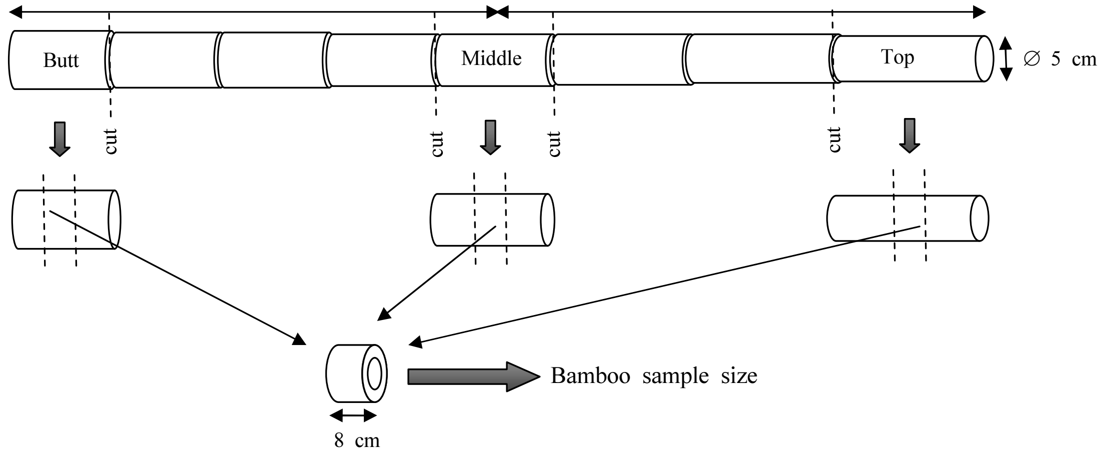


**Fig. 1.** Sample cutting scheme.

disk of 8 cm length longitudinally was made from the middle part of each position. Each disk was manually split longitudinally to the size of sample for the observation of anatomical structures, fiber dimensions, and physical properties of each position.

Except for the culm characteristics, the data collected were then analysed statistically using analysis of variance (ANOVA) and the differences were significant followed by Tukey's post hoc test at P\0.05.

## 2.2. Fiber morphology

Slivers of matchstick size (1 × 1 × 20 mm) were obtained from the bamboo disks and macerated with a mixture of equal volumes of glacial acetic acid and hydrogen peroxide, and heated at 60℃ for 1 or 2 days (Kitin *et al.* 1999). Fiber morphology as fiber length, fiber diameter, lumen diameter and wall thickness of fiber and Runkel ratio of 100 fibers were then measured using an optical microscope.

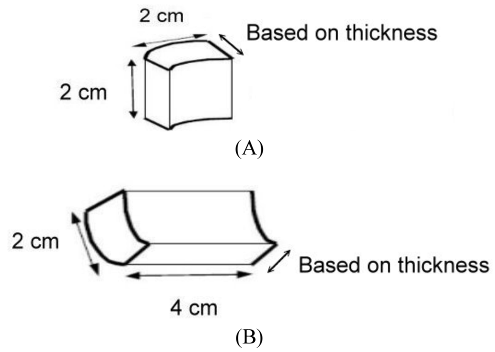


**Fig. 2.** Samples for GMC and BD (A) and for shrinkage (B) measurements.

## 2.3. Physical properties

Three different physical properties measured in this study were green moisture content (GMC), basic density (BD), and shrinkages. Samples for the determination of GMC and BD were the dimension of 2 cm (L) × 2 cm (T) × thickness (R) of the culms (Fig. 2A) while those for shrinkage measurements were the dimension of 4 cm (L) × 2 cm (T) × thickness (R) of the bamboo (Fig. 2B).

Moisture content was determined by oven-dry method. Basic density was determined by oven-dry weight or mass, and green volume. Shrinkage of bamboo was determined from green to air-dry and to oven-dry conditions (Panshin and de Zeeuw 1980).

## 3. RESULTS and DISCUSSION

### 3.1. General Characteristics

Legi bamboo (*Gigantochloa atter*) of four months old had culms with a length of 7 m and DBH of 5.8～7.1 cm, while those of 16 months or older could had the length of the culms of about 15 m with a DBH of 8.6～10.8 cm. The diameter of the culms was bigger than *Schizostachyum lima* of 3.2 cm and *Bambusa blumeana* of 7.5 cm (Liese 1980) but smaller than *Gigantochloa scortechinii* of 14.8, 10.5, and 11.5 cm for 0.5, 1.5, and 3.5 years, respectively (Hisham *et al.* 2006). Thickness of the internodes wall in the bottom of the culms of 1.28～1.71 cm was also bigger than *G. scortechinii* of 8, 6, and 7 mm for 0.5, 1.5, and 3.5 years, respectively (Hisham *et al.* 2006).

The internodes in the bottom (first internodes) of the culms always showed the shortest length, but it had the thickest wall. The length of the internodes in the bottom of the culms for 4 months bamboo was 20.5～24 cm, 22～30 cm for 16 months, and 26.5～30 cm for 40 months bamboo. The longest internodes of different ages also increased from 45.5～48.2 cm for 4 months, 51～55.5 cm for 16 months, and 57～59.7 cm for 40 months bamboo. Such internodes lengths were longer than the internodes of *G. scortechinii* of 32.5, 35.2, and 49.5 cm for 0.5, 1.5, and 3.5 years, respectively (Hisham *et al.* 2006).

### 3.2. Fiber Morphology

Fiber dimensions such as fiber length, fiber diameter, lumen width, cell-wall thickness and their derived indices are important indicators in predicting properties of the pulp produced (Amidon 1981), and physical as well as mechanical properties (Mohmod *et al.* 1993; Kamruzzaman *et al.* 2008; Nordahlia *et al.* 2012).

Bamboo was reported to have fiber length in the range of 1.36 mm to 3.78 mm with most of the species having fibers that are longer than 1.6 mm (Tamolang *et al.* 1957). The fiber dimensions of Legi bamboo (*G. atter*) are shown in Table 1. Legi bamboo had average fiber length of 2.41 mm. Such fiber length is longer than mangium wood fiber of 0.78～1.02 mm (Marsoem 2003) which is commonly used for making pulp in Indonesia, and is longer than *Bambusa blumeana* from Malaysia of 1.74～2.13 mm (Mohmod *et al.* 1990, Mohmood and Mustafa 1992). Fiber length was reported to have effect on the MOE of the bamboo and a negative correlation exist between fibre lengths and shear strength (Mohmod *et al.* 1990). Fiber length also affects the strength properties

**Table 1.** Fiber dimensions of Legi bamboo at three different age and height of culms

| Cell Dimension | Average | Age of Bamboo Culms (month) | | | Height positions | | |
|---|---|---|---|---|---|---|---|
| | | 4 | 16 | 40 | Butt | Middle | Top |
| Fiber length (mm) | 2.41 ± 0.31 | 2.38 ± 0.42[a] | 2.39 ± 0.26[a] | 2.45 ± 0.24[a] | 2.43 ± 0.29[ef] | 2.62 ± 0.16[e] | 2.17 ± 0.28[f] |
| Fiber diameter (μm) | 13.20 ± 1.54 | 13.43 ± 1.10[f] | 11.72 ± 0.90[e] | 14.45 ± 1.22[f] | 12.52 ± 1.56[b] | 13.31 ± 1.42[b] | 13.77 ± 1.55[b] |
| Lumen diameter (μm) | 8.17 ± 1.16 | 8.78 ± 0.97[f] | 7.16 ± 0.86[e] | 8.58 ± 0.96[f] | 7.78 ± 1.14[c] | 8.19 ± 1.03[c] | 8.54 ± 1.29[c] |
| Fiber (cell) wall thickness (μm) | 2.51 ± 0.57 | 2.32 ± 0.20[e] | 2.28 ± 0.11[e] | 2.94 ± 1.83[f] | 2.37 ± 0.46[d] | 2.56 ± 0.56[d] | 2.61 ± 0.70[d] |
| Runkel ratio | 0.61 ± 0.06 | 0.53 ± 0.03 | 0.64 ± 0.03 | 0.69 ± 0.08 | 0.61 ± 0.05 | 0.63 ± 0.06 | 0.61 ± 0.07 |

Notes: Value following by the same letter is not significantly different by Tukey's Test at 5% level.

of the pulp and that the extensibility of the bonding sites was a function of the fiber length (Horn 1974). Fiber length strongly affects tearing resistance of the pulp (Seth and Page 1988), and in the hard-wood pulps the increase in fiber length enhances the tearing strength of the pulps produced (Horn 1978). The longer the fiber length the stronger the pulp produced, and Legi bamboo is predicted to produce strong enough pulp fiber.

Although the result in Table 1 indicated an increase trend of fiber length with age, however, the trend did not cause a significant effect on the fiber length among different culms ages. This was in contrary with the result observed by Hisham *et al.* (2006) who found a significant difference between fiber length of *G. scortchenii* of 0.5 and 1.5 years. The fiber length phenomenon differences between *G. atter* and *G. scortchenii*is likely due to the fact that bamboo properties are characterized by its own individual characteristics (Liese 1987).

Statistical analysis indicated that the height (axial positions) did affect fiber length significantly. In a study on fiber dimensions of various plant materials Ververis *et al.* (2004) found that fiber length increased from basal to the top, while in Legi bamboo although the fiber length from the basal (bottom) part to the middle height of the culms increased as much as 7.82%, on the contrary a further higher height (axial position) seemed to cause a decrease in fiber length. This cause the longest fiber length was in the middle height while the shortest was in the top part of the Legi bamboo culms. The longest fiber length in the middle height were also found in *G. pseudoarundinacea* (Soeprayitno *et al.* 1988) and in *B. blumeana* (Mohmod and Mustafa 1992), however there are also bamboo species with the longest length in its basal such as in the *B. vulgaris* and *G. scortechinii* (Mohmod and Mustafa 1992). Among three different heights of the culms, fiber from the middle height is therefore estimated to produce the strongest pulp fiber.

Except its length, all other fiber dimension in this study showed a smaller dimension as compare to fiber diameter, lumen diameter, and fiber wall thickness of *B. blumeana* of 18.5～

24 μm, 9.5～13.0 μm, and 4.5～8.5 μm respectively (Mohmod *et al.* 1993). Fiber diameter, lumen diameter, and fiber wall thickness showed a decrease trend in the culm grown from 4 to 16 months and then increased again in 40 months culms, but they were not significantly different. The thickening of fibre wall is caused by the deposition of additional lamellae with the increasing age of bamboo (Nordahlia *et al.* 2012). The life history of bamboo culms should account for some of the fibre morphology variations (Liese 1998).

Those three dimensions were significantly different among axial (height of the culm) positions. The increase in height position caused an increase in all of the three fiber dimensions (fiber diameter, lumen diameter, and fiber wall thickness). Mohmod *et al*. (1990) in their study on three Malaysian bamboo reported that lumen diameter had the strongest correlation with the mechanical properties, especially shear strength, stress at proportional limit, modulus of elasticity and modulus of rupture. A different result was found in some studies which reported an insignificant difference of fiber lumen diameter with height in *B. blumeana*, *B. vulgaris* and *G. scortechinii* (Mohmod and Mustafa 1992).

In this study the biggest fiber diameter and the thickest fiber wall were found in the top part of the culms. This means that top part of the Legi bamboo culms can be expected to produce stronger culms mechanically. Nordahlia *et al*. (2012) reported that in *G. levis* of 4 years, no significant different was found with the height positions of the internode in the culms. However they found that in 2 years old culms the fiber diameter and fiber wall thickness decreased upwards.

Besides fiber length, the suitability of a fiber material for making pulp and paper is also determined by its derived indices such as a ratio between double cell wall-thickness to its lumen diameter known as Runkel ratio. The lower the Runkel ratio the better the fiber material for paper making (Thongpukdee *et al.* 2013). Legi bamboo in this study had an average Runkel ratio of 0.61 which is much better than the value of bamboos grown in the Philippines. Tamolang *et al*. (1980) reported that bamboo fiber grown in the Philippines showed a range of Runkel ratio from 1.33 for *Dendrocalamus merrillianus* to 8.00 for *Bambusa multiplex*. Legi bamboo is therefore considered as a promising fiber source for paper making which will produce a good density and strength of sheet.

## 3.3. Physical Properties

### 3.3.1. Green moisture content (GMC) and basic density (BD)

Legi bamboo showed an average green moisture content (GMC) of 158% (Table 2). Such GMC is quite high when compare to the most average GMC previously reported by Espiloy (1987), Mohmod *et al*. (1990), Mohmod *et al*. (1993), Anwar *et al*. (2005), Hisham *et al*. (2006), and (Kamruzzaman *et al.* 2008).

In the present study GMC decreased with the age and with the height position in the culms

**Table 2.** Green moisture content and basic density of Legi bamboo at three different age and height of culms

| Physical properties | Culm Ages (Months) | Height Positions | | |
|---|---|---|---|---|
| | | Butt | Middle | Top |
| Green Moisture Content (%) | 4 | 219 ± 21.3[a] | 201 ± 5.1[ab] | 197 ± 12.3[ab] |
| | 16 | 175 ± 12.1[ad] | 155 ± 9.6[bd] | 138 ± 20.2[cd] |
| | 40 | 168 ± 5.7[ad] | 101 ± 33.1[ce] | 68 ± 22.9[e] |
| Basic Density ($kg.m^{-3}$) | 4 | 330 ± 26.5[a] | 360 ± 10.0[a] | 370 ± 20.8[a] |
| | 16 | 390 ± 15.3[a] | 430 ± 20.0[a] | 460 ± 40.4[ab] |
| | 40 | 400 ± 11.5[a] | 660 ± 135.8[bc] | 710 ± 134.5[c] |

Notes: Value following by the same letter is not significantly different by Tukey's Test at 5% level.

but the interaction between them caused a different trend of GMC in the culms. Therefore the decrease in the GMC of different height was only found in the culms of 40 months culms while two other ages did not show a significant GMC different. With regard to the age and height position Hisham *et al.* (2006) observed a decrease of GMC following with age the in *G. scortechinii* while in *G. levis* and *B. blumeana* (Espiloy 1987) and in *B. balcoa, B. tulda, B. salarkhanii, M. baccifera* (Kamruzzaman *et al.* 2008) GMC decreased with height. Such variation is probably related to the variation of parenchyma proportion (Liese 1987). The lowest GMC at the top of 40 months bamboo is probably due to the fact that the culms in that position were also composed of the highest BD bamboo. Li *et al*. (2007) in their study on one, three, and five years old bamboos found a higher extractive and ash contents in the top than in the middle and bottom sections of culms of 3 years old or older. Therefore the lowest GMC at the top of the 40 months culms Legi bamboo is probably could also be affected by such condition.

### 3.3.2. Basic density (BD)

A basic density of 330～710 $kg.m^{-3}$ was observed in Legi bamboo of various ages and height positions. The value is much lower than the density of 751 $kg.m^{-3}$ in 4 year old or even of 733 $kg.m^{-3}$ in 2 year old *G. levis* (Nordahlia *et al.* 2012). A density of 595 $kg.m^{-3}$ in *B. balcooa*, and of 870 $kg.m^{-3}$ in *B. salarkhanii* were reported by Kamruzzaman *et al.* (2008), while Liese (1987) reported a range of density of 0.5～0.8 $g/cm^3$ equal to 500～800 $kg.m^{-3}$.

A variation in the basic density with age and height were observed in several previous studies (Hisham *et al.* 2006; Li *et al.* 2007; Kamruzzaman *et al.* 2008; Nordahlia *et al.* 2012). In this study basic density increased with age and height, but a statistical analysis indicated that the interaction between the age and height position in the culms has caused a significant different effect on the BD of the observed Legi bamboos. As seen in Table 2 that in all ages of the bamboo, upper part of the culms always showed the highest BD but in young culms (4 months) the increase in BD did not caused a significant effect. A higher

**Table 3.** Air-dry and oven-dry shrinkage of Legi bamboo at three different age and height of culms

| Shrinkage (%) | Average | Age of Bamboo (months) | | | Height positions | | |
|---|---|---|---|---|---|---|---|
| | | 4 | 16 | 40 | Butt | Middle | Top |
| Air- Dry | | | | | | | |
| Longitudinal | 0.23 ± 0.16 | 0.27 ± 0.24$^{a}$ | 0.23 ± 0.03$^{a}$ | 0.20 ± 0.14$^{a}$ | 0.21 ± 0.14$^{b}$ | 0.16 ± 0.06$^{b}$ | 0.32 ± 0.21$^{b}$ |
| Tangential/Width | 8.74 ± 5.12 | 10.79 ± 4.41$^{g}$ | 8.61 ± 3.40$^{f}$ | 6.81 ± 5.46$^{e}$ | 9.74 ± 2.65$^{i}$ | 10.25 ± 4.42$^{i}$ | 6.22 ± 5.85$^{h}$ |
| Radial/Thickness | 12.21 ± 2.65 | 15.76 ± 1.73$^{f}$ | 11.66 ± 2.50$^{ef}$ | 9.23 ± 2.16$^{e}$ | 9.82 ± 1.77$^{g}$ | 15.99 ± 1.79$^{h}$ | 10.84 ± 2.38$^{g}$ |
| Oven- Dry | | | | | | | |
| Longitudinal | 0.35 ± 0.23 | 0.41 ± 0.29$^{c}$ | 0.36 ± 0.23$^{c}$ | 0.28 ± 0.08$^{c}$ | 0.30 ± 0.15$^{d}$ | 0.29 ± 0.20$^{d}$ | 0.45 ± 0.29$^{d}$ |
| Tangential/Width | 9.32 ± 5.55 | 10.96 ± 5.09$^{g}$ | 9.24 ± 5.45$^{f}$ | 7.75 ± 4.39$^{e}$ | 10.13 ± 2.63$^{i}$ | 10.78 ± 5.02$^{i}$ | 7.04 ± 5.62$^{h}$ |
| Radial/Thickness | 14.34 ± 2.34 | 17.78 ± 1.76$^{f}$ | 14.13 ± 1.82$^{ef}$ | 11.11 ± 2.35$^{e}$ | 11.14 ± 1.55$^{h}$ | 18.84 ± 1.36$^{i}$ | 13.04 ± 2.13$^{h}$ |

Notes: Value following by the same letter is not significantly different by Tukey's Test at 5% level.

BD in the upper part was also observed in *B. blumeana* and in *G. levis* (Espiloy 1987), in *G. pseudoarundinacea* (Soeprayitno *et al.* 1988), in *G. levis* (Nordahlia 2012), in *Phyllostachys pubescens* (Li *et al.* 2007; Wang *et al.* 2010). Observation in the cell wall thickness in Table 1 indicated that the higher basic density in the upper part could be related to the thicker cell wall.

### 3.3.3. Shrinkage

As seen in Table 3, Legi bamboo showed a relatively small average longitudinal shrinkage from green to air dry as well as to oven dry of 0.23% and 0.35% respectively and along the culms the shrinkage values did not differ significantly. In the woody material, such percentage of shrinkage is considered normal and is usually produced by mature wood (Bowyer *et al.* 2007).

Legi bamboo showed relatively lower tangential (width) as well as radial (thickness) direction shrinkages, compare with those reported by Anwar *et al*. (2005). Compare to woods, an opposite phenomena was shown by bamboo shrinkage in transverse direction. Wood shrinkage in tangential direction commonly has higher value than that in radial direction with a ratio of about 2, but Legi bamboo showed higher shrinkage in radial direction than in tangential direction. A similar phenomenon was also reported by Anwar *et al.* (2005). This condition is probably due to the absence of rays in bamboo.

In the tangential (width) and radial (thickness) directions, although the shrinkage to the air dry as well as to oven dry condition were high, the R/T ratios are considerably low of 1.40 and 1.54 respectively.

The age and the position along the culms affected their shrinkages significantly. Bamboo of oldest age significantly showed the smallest shrinkage on width (tangential direction) from green to air dry and to oven dry conditions while on thickness (radial direction), although the oldest bamboo also showed the smallest shrinkage, statistically the value only significantly different with bamboo of 16 months.

Along the culms, shrinkage in width (tangential) and thickness (radial) direction increased from the bottom part to the middle height but then decreased again to the top position, and middle height position always showed the highest shrinkage. In width direction, the smallest shrinkage was shown from the top part, while in the thickness direction from the bottom part.

## 4. CONCLUSION

The results showed that the diameter of Legi bamboo culm of 4 months was 5.8～7.1 cm while those of older than 16 months were 8.6～10.8 cm. The internodes in the bottom (first internodes) of the culms always showed the shortest length but had the thickest wall. Legi bamboo had average fiber length of 2.41 mm and Runkel ratio of 0.61 which are good properties for pulp and paper making. Fiber length was affected by height but not by age, while fiber diameter, lumen diameter, and fiber wall thickness were affected significantly by the age of the culms. The culms had high green moisture content (GMC) of 158%. Average basic density (BD) was 457 $kg.m^{-3}$. The interaction between age and height was affected by the GMC and BD of the internode in the culms. The culms had a total longitudinal shrinkage of 0.35% almost similar to the normal mature timber, and relatively low average tangential as well as radial shrinkages of 9.32% and 14.34%, respectively. The culms showed a low R/T shrinkage ratio, and shrinkage decreased with age and height.

## REFERENCES


Amidon, T.E. 1981. Effect of the wood properties of hardwood on kraft paper properties. Tappi 64: 123~126.

Anwar, U.M.K., Zaidon, A., Hamdan, H., Tarmizi, M.M. 2005. Physical and mechanical propertiesof *Gigantochloa scortechinii* bamboo splits and strips. Journal of Tropical Forest Science 17(1): 1~12.

Bowyer, J.L., Shmulsky, R., Haygreen, J.G. 2007. Forest Products and Wood Science An Introduction, 4th Ed. Iowa State University Press, Iowa, USA.

Espiloy, Z.B. 1987. Physico-Mechanical Properties and Anatomical Relationship of Some Philippine Bamboos. In: Rao, A.-N., Dhanarajan, G., Sastry, C.-B., (eds), Proc. Recent Research on Bamboos. Hangzhou, The Chinese Academy of Forestry, People's Republic of China, Proc. of the International Bamboo Workshop (1985), pp. 257~264.

Hisham, H.N., Othman, S., Rokiah, H., Latif, M.A., Ani, S., Tamizi, M.M. 2006. Characterization of bamboo Gigantochloa scortechinii at different ages. Journal of Tropical Forest Science 18(4): 236~242.

Horn, R.A. 1974. Morphology of wood pulp fibre from softwoods and influence on paper strength. USDA Forest Service Research Paper FPL 242. For. Prod. Lab. Madison, WI. USA.

Horn, R.A. 1978. Morphology of pulp fiber from hardwoods and influence on paper strength. USDA Forest Service Research Paper FPL 312.

For. Prod. Lab. Madison, WI. USA.

Kamruzzaman, M., Saha, S.K., Bose, A.K., Islam, M.N. 2008. Effect of age and height on physicaland mechanical properties of bamboo. Journal of Tropical Forest Science 20(3): 211~217.

Kim, J.S., Lee, H.C., Jo, J.S., Jung, J.Y., Ha, Y.L., Yang, J.K. 2014. Evaluation of antioxidant and anticancer activity of steam extract from the bamboo species. Journal of Korean Wood Scienc and Technology 42(5): 543~554.

Kitin, P., Funada, R., Sano, Y., Beeckman, H., Ohtani, J. 1999. Variation in the lengths of fusiform cambial cells and vessel elements in Kalopanax pictus. Annal Botany 84(5): 621~632.

Li, X.B., Shupe, T.F., Peter, G.F., Hse, C.Y., Eberhardt, T.L. 2007. Chemical changes with maturation of the bamboo species Phyllostachys pubescens. Journal of Tropical Forest Science 19: 6~12.

Liese, W. 1980. Anatomy of Bamboo. In: Lessard, G., Chouinard, A., (eds). Bamboo Research in Asia. Singapore, Proc. of A Workshop. pp. 228.

Liese, W. 1987. Anatomy and Properties of Bamboo. In: Rao, A.-N., Dhanarajan, G, Sastry C.-B., (eds). Recent Research on Bamboos. Hangzhou, The Chinese Academy of Forestry, People's Republic of China, Proc. of the International Bamboo Workshop, pp. 196~208.

Liese, W. 1998. The anatomy of bamboo culms. Technical Report 18, International Network for Bamboo and Rattan(INBAR), Beijing.

Marsoem, S.N. 2003. Pemanfaatan Hasil Hutan Tanaman Acacia mangium. In: Pembangunan Hutan Tanaman Acacia mangium: Pengalaman di PT Musi Hutan Persada, Sumatera Selatan, Ed. by Hardiyanto, E.B., Arisman, H., P.T Musi Hutan Persada Palembang, Sumatera Selatan, Indonesia.

Mohmod, A.L., Tarmeze, W., Ariffin, W., Ahmad, F. 1990. Anatomical featuresand mechanical properties of three malaysian bamboos. Journal of Tropical Forest Science 2(3): 227~234.

Mohmod, A.L., Mustafa, M.T. 1992. Variation in anatomical properties of three malaysian bamboos from natural stands. Journal of Tropical Forest Science 5(1): 90~96.

Mohmod, A.L., Amin, A.H., Kasim, J., Jusuh, M.Z. 1993. Effects of anatomical characteristics on the physical and mechanical properties of Bambusa blumeana. Journal of Tropical Forest Science 6(2): 159~170.

Nordahlia, A.S., Anwar, U.M.K., Hamdan, H., Zaidon, A., Paridah, M.T., Razak, O.A. 2012. Effects of age and height on selected properties of malaysian bamboo (*Gigantochloa levis*). Journal of Tropical Forest Science 24(1): 102~109.

Panshin, A.J., De Zeeuw, C. 1980. A Textbook on Wood Technology. McGraw Hill Inc., NewYork.

Roh, J.K., Kim, J.K, Sa, I.K., Ra, J.B., Kim, Y.J., Park, S.J. 2004. Manufacture of wood veneer-bamboo zephyr board-properties of bamboo zephyr and composite board made from Moso, Giant Timber and Hachiku Bamboo. Journal of Korean Wood Scienc and Technology 32(3): 42~51.

Seth, R.S., Page, D.H. 1988. Fiber properties and tearing resistance. Tappi 71(2): 103~107.

Soeprayitno, T., Tobing, T.L., Widjaja, E.A. 1988. Why the Sundanese of West Java Prefer Slope-inhabiting Gigantochloa pseudoarundinacea to those Growing in the Valley. In: Rao, I.V.-R., Gnanaharan, R, Sastry, C.-B., (eds). Bamboos Current Research. Cochin, India, Proc. of the International Bamboo Workshop.

Tamolang, F.N., Mabesa, E.O., Eusebio, M.A., Sagrade, M.J., Lomibao, B.A. 1957. Fiber dimensions of certain Philippine broad-leaved woods and bamboos. Tappi 40: 671~676.

Tamolang, F.N., Lopez, F.R., Semana, J.A., Casin, R.F., Espiloy, Z.B. 1980. Properties and Utilizationof Philippine Erect Bamboos. In: Lessard, G. Chouinard, A., (eds). Bamboo Research in Asia. Singapore, Proc. of A Workshop, pp. 14~27.

Thongpukdee, A., Thepsithar, C., Timchookul, S. 2013. Fiber microstructure in solanum foundin Thailand. World Academy of Science, Engineering and Technology International. Journal of Biological, Veterinary, Agricultural and Food Engineering 7(8): 458~461.

Verde, B.N. 2012. Katalog Bambu Perkebunan. P.T. Bambu Nusa Verde, Sleman, Yogyakarta, Indonesia.

Ververis, C., Georghiou, K., Christodoulakis, N., Santas, P., Santas, R. 2004. Fiber dimensions, lignin and cellulose content of various plant materials and their suitability for paper production. Industrial Crops and Products 19(3): 245~264.

Wang, X.C., Li, X.Z., Ren, H.Q. 2010. Variation of microfibril angle and density in moso bamboo (*Phyllostachys pubescens*). Journal of Tropical Forest Science 22(1): 88~96.