Physical and mechanical properties of five Indonesian bamboos

A H D Abdullah1*, N Karlina2, W Rahmatiya2, S Mudaim2, Patimah2 and A R Fajrin2
1Research Unit for Clean Technology, Indonesian Institute of Sciences (LIPI)
Jalan Cisitu 21/154 D, Bandung 40135, Indonesia
2 Department of Physics, UIN-Sunan Gunung Djati, Bandung, Indonesia
*Email : dawamdullah@yahoo.com

Abstract. Indonesia is a country with abundant bamboo. More than 100 species of bamboo are found in Indonesia, and the production of bamboo ranks second after China. Bamboo has great potential to be used as industrial raw materials due to its high mechanical properties. The properties of the bamboo’s fiber have been widely reported by several researchers, but the rarely properties of bamboo’s culm which is consist of fiber, parenchyma, and conducting tissue were reported. This research aimed to identify the culm in five most common bamboos in Indonesia namely Bamboo Temen (Gigantochloa Atter), Bamboo Apus (Gigantochloa Apus Kurz), Bamboo Kuning (Bambusa vulgaris schard var. Vitata), Bamboo Gombong (Gigantochloa pseudoarundinacea), and Bamboo Hitam (Gigantochloa verticillata). Properties identification were on the density, morphology, tensile strength, and modulus of elasticity. The density of different types of bamboo’s culm varied from 0.54 to 0.78 g/cm$^3$. Morphology of culm showed hollow structure which was consist of vessel and surrounded by fibers. Tensile strength of Bamboo Temen, Bamboo Apus, Bamboo Kuning, Bamboo Gombong, and Bamboo Hitam were of 195, 179, 82, 114, and 118 MPa, respectively whereas corresponding modulus of elasticity were of 16.7; 7.5; 14.3; 16.0; and 10.1 GPa. The best mechanical performance was found in Bamboo Temen.

1. Introduction
Indonesia is a tropical country, rich with the variety of bambu and becoming the biggest exporter of bamboo in the world after China [1]. Indonesia has around 154 types from 1,250 to 1,500 type of world bambu diversity [2]. Bamboo is found in many places, either grow naturally or cultivated deliberately. Bamboo is cultivated since its possess good mechanical strength for structural application.

The strength properties of bamboo increase with decreasing in water content and are closely related to density [3]. The anatomical structure of a transverse section of any culm is determined by the shape, size arrangement and number of vascular bundles which [4]. Due to its vascular shaped like a hollow so the number is more likely to lower the mechanical properties of culm. The culm tissue is mostly parenchyma and the vascular bundles which are composed of vessels and fibres. The total culm comprises about 50% parenchyma, 40% fiber, and 10% conducting tissue [4].

The properties of bamboo fibers have been widely reported by several researchers [5-8], but bamboo’s culm which is consist of fiber, parenchyma, and conducting tissue hardly reported. This research aimed to identify the culm of five most common bamboos in Indonesia, namely Bamboo Temen (Gigantochloa atter), Bamboo Apus (Gigantochloa Apus Kurz), Bamboo Kuning (Bambusa vulgaris Schard var. Vitata), Bamboo Gombong (Gigantochloa pseudoarundinacea), and Bamboo Hitam (Gigantochloa verticillata). Properties identification were on the density, morphology, tensile strength, and modulus of elasticity.
2. Experimental

2.1. Material

Five kind of bamboos of which approximately three years old were taken from several places in Bandung, West Java, Indonesia. It was taken about 4 weeks after plant cutting (Figure 1). The skin and inner-most were removed from the culm and resulted the clean culm.

![Bamboo Culm](image)

**Figure 1. Bamboo Culm**

2.2. Density measurement

Each sample of bamboo culm was weighed (mass of bamboo, m gr) by using micro-balance (Type Metler-Toledo). Empty pycnometer was weighed, filled fully with distilled water, and reweighed. Sample of bamboo culm were then put into pycnometer and led distilled water comes out through the hole, then weighed. This process was repeated for 3-4 times. Each bamboo’s volume was measured as an equal to the volume of water displaced (volume, v cm$^3$). Density calculation was as $m/v$.

2.3. Scanning Electron Microscope

SEM (JEOL JSM-T330A) image was performed to identify morphology of bamboo. Dimension of samples was of 0.5cm x 0.5cm x 0.5cm. Each samples was coated with gold by ion sputtering. The image was obtained by secondary electron at accelerating voltage of 15 kV with 100 and 500 x magnification.

2.4. Tensile Test

Tensile test consist of modulus of elasticity (MOE) and tensile strength test. Specimens was cut with dimensional 25 cm x 2 mm x 3 cm. Tensile test was conducted based on ASTM D3039 reference at 2 mm/min speed, and load cell of 5,000 kgf. Elastic modulus measurement was performed on extensometer. Each sample was measured 2-3 times.
3. Result and discussion
Density of five kinds of bamboos is presented in Table 1.

| Name of bamboo | Density (g/cm$^3$) |
|----------------|-------------------|
| Bamboo Temen   | 0.76              |
| Bamboo Apus    | 0.60              |
| Bamboo Kuning  | 0.62              |
| Bamboo Gombong | 0.78              |
| Bamboo Hitam   | 0.54              |

Table 1 shows that Bamboo Gombong shows the highest density than other types whereas Bamboo Hitam reveals the lowest density. The density of bamboo can be related with the macro-structure of culm, shape and size of vessel. The vessel are usually in the hollow form, so that more vessels will reduce its density values. Moreover, high density contributes to fiber content in vascular tissue.

Morphology image of bamboos is presented in Figure 2. It reveals that Bamboo Temen shows rare of vascular (vessel) structure indicated by less of hollow structure as dark area on cross-section. The culm looks more solid than four other bamboos. This might be due to the high density of the Bamboo Temen. It is also found that Bamboo Kuning has a hollow structure (vascular) which is different from the other vessel structure. The shape tends to be irregular, unlike other bamboo vessels which possesses a circular form. Irregular shape may produce stress concentrations and affects on its mechanical properties.
Figure 2. Morphology image of bamboos with 100 and 500x magnification.

Tensile strength and modulus of elasticity of bamboos are presented in Figure 3 and 4. Figure 3 and Figure 4 show that Bamboo Temen has the highest strength and elastic modulus among the four others types of bamboo. This is might be due to the structure of Bamboo Temen which is solid and less-vessel as already proved by its density and morphology (Table 1 and Figure 2). Bamboo Kuning has a lowest strength (82 MPa), but the modulus of elasticity values were relatively high (14.35 GPa). As showed in Figure 2, Bamboo Kuning has vascular structure which is tend to be irregular and may caused stress concentrations and finally weaken its strength. Elastic modulus of Bamboo Gombong is quite high which might be due to its high fibers content [9].

Figure 3. Tensile strength of bamboos.
4. Conclusion
Based on the results, it can be proved that the macro-structure of the vascular and parenchyma affected the physical and mechanical properties of bamboo. Morphological observation with SEM and verification by density measurements could be performed to analyze these correlations. Bamboo vessels were usually in the form of a hollow and more vessels will reduce its density.

Acknowledgement
The Authors are grateful to the Indonesian Institute of Science through Mandiri Project 2015, Research Unit for Clean Technology LIPI for financial support.

References
[1] H.P.S Abdul Khalil, I.U.H Bhat, M.Jawaid, A. Zaidon, D. Hermawan, Y.S.Hadi 2012 J. Mat. and Design. 42 353-368
[2] Elizabeth A. Widjaja and Karsono 2005 Biodiversitas. Vol. 6 No. 2 959-99
[3] S Dransfield and E.A. Widjaja 1995 Plant Resources of South-East Asia (PROSEA) No.7 : Bambus Backhyus Publisher. Leiden
[4] Liese W 1985 Institute of Wood and Wood Preservation of the Federal Research Center for Forestry and Forest Product, Federal Republic of Germany. 196-208
[5] Kabir H, Md. Ghafur A, Ahmed F, Begum F, Md. Qadir R 2014 Universal J. Mat. Scie. 2(6) 119-124
[6] Sreenivasulu S and Reddy A.C 2014 Int. J. Eng. Res. Vol.3 Issue No: Special 1 187-194
[7] Shito T, Okubo K, Fujii T 2002 J. High Perf. Struct. and Compos. ISBN 1-85312-904-6 175-182
[8] Rassiah K and Megat Ahmad MM. H 2013 Australian J. Basic and Appl. Scie. 7 (8): 247-253
[9] Xiaobo Li 2004 A Thesis of Graduate Faculty of Lousiana State University Agriculture and Mechanical College 27-46