Physical and Mechanical Properties of Black Wood (Ebony) as a Construction Material

Fengky Satria Yoresta
Department of Forest Product, Faculty of Forestry
Bogor Agricultural University, Bogor
syfengky@gmail.com

ABSTRACT

This research is aimed to determine physical and mechanical properties of Ebony wood as a construction material. The physical and mechanical properties test is conducted based on ASTM D 143-94 code. The mean value of moisture content and specific gravity of Ebony wood is obtained 12.90% and 0.92 gr.cm\(^{-3}\) respectively. Meanwhile MOE, bending strength, compressive strength parallel to grain, shear strength, and tensile strength parallel to grain are 180.425,87 kg.cm\(^{-2}\); 1656,22 kg.cm\(^{-2}\); 861,55 kg.cm\(^{-2}\); 119,61 kg.cm\(^{-2}\); dan 2.319,03 kg.cm\(^{-2}\) respectively. Based on the test results, it can be concluded that Ebony wood is classified to Strength Class I due to PKKI 1961, so it can be recommended for use in heavy construction such as bridge and building structures.

Keywords: physical properties, mechanical properties, Ebony wood

1. Introduction

Good quality material is one of the main requirements to be able to create a strong building (Boen 2009). Wood is a material that has a good properties in ductile compared to other construction materials such as concrete. Therefore, the use of wood is in great demand, especially for residential construction. In United States, more than 80% of all buildings are wood construction (Aghayere et al. 2007).

Wood is widely used for dwelling houses, especially in rural areas either as a building frame (columns and beams) or as a roof truss (Figure 1). Such function requires that the timber used carry a heavy load, including the weight of non-structural building components.

Ebony wood which is also known as black wood was used by Indonesian traditional society in ancient times because of hard and strong. However, its use as a construction material even until now is not based on scientific knowledge to the mechanical properties of it which is the core of understanding, but through the experience gained by generations from their ancestors. It would be fatal if there is external load exceeds the wood strength capacity.

For example is when houses are shaked by an earthquake. The survey showed that 25% of wood-frame dwelling houses
sustained losses more than 5% of the dwelling’s value on San Fernando earthquake California 1971 (Yancey et al. 1998). The damage could start from destruction of wood component on the houses. That is why the basic properties of wood (mechanical and physical) should be known well to be taken into account in structural design.

The mechanical properties of wood that most commonly measured and represents the “strength properties” consists of tensile strength parallel to grain, compressive strength perpendicular to grain, tensile strength perpendicular to grain, flexural strength, compressive strength parallel to grain, as well as shear strength and hardness. Construction experts will consider that values of mechanical properties in buildings structural design, especially for large scale of wood frame constructions.

Figure 1: Typical structural components of wood buildings. Source: Aghayere et al., 2007

2. Materials and Methods

Ebony wood in this study was obtained from Sulawesi island, Indonesia. Testing of physical and mechanical properties of Ebony is conducted using 5 tons capacity of Instron machine and based on code ASTM D 143-94 (Figure 2). A total of 20 test samples was prepared for each test. Physical properties tested consist of moisture content and specific gravity. While the mechanical properties tested consist of Modulus of Elasticity (MOE), bending strength, compressive strength parallel to grain, shear strength and tensile strength parallel to grain. The test results are then analyzed and classified based on the Indonesian Timber Construction Code (PKKI) 1961.

Specific gravity G is calculated by ratio of the density of the wood to the density of water $\rho_w$ at a specified reference temperature, typically 4°C (39°F), where $\rho_w$ is 1 g.cm$^{-3}$. Moisture content (MC) is expressed as a percentage and calculated by

$$MC = \frac{m_{\text{wet}} - m_{\text{dry}}}{m_{\text{dry}}} \times 100\% \quad (1)$$

where $m_{\text{wet}}$ is the mass of the specimen at a given moisture content and $m_{\text{dry}}$ is the mass of the ovendry specimen.

Modulus of Elasticity (MOE) and bending strength ($\sigma_t$ or MOR) are calculated by
equation (2) and (3) respectively. Meanwhile, compressive strength parallel to grain ($\sigma_{tk//}$), shear strength ($\tau$) and tensile strength parallel to grain ($\sigma_{tr//}$) are calculated by equation (4).

$$MOE = \frac{PL^3}{4ADh^3}$$ (2)

$$MOR = \frac{3PL}{2bh^2}$$ (3)

$$\sigma_{tk//}, \tau, \text{ or } \sigma_{tr} = \frac{P}{A}$$ (4)

where $P$ is maximum load, $L$ is bending span, $\Delta$ is deflection, $b$ is section width, $h$ is section thickness, and $A$ is area (compressive, shear, or tensile). Especially for equation (2), $P$ is load is elastic area of bending curve.

3. Result and Discussion

Indonesian Timber Construction Code (PKKI) 1961 divide wood into five classes strength level plus teak wood namely class I, II, III, IV, and V (Table 1). These classes are distinguished based on the strength of wood. Wood in class I and II is also known as structural timber because it is used for manufacture of heavy constructions such as bridges (girder and floor) and bulding structure (column, beam and floor). Wood in class I has a specific gravity greater than 0.90, while in class II has a specific gravity between 0.60 to 0.90. Table 3 shows a comparison of physical and mechanical properties of Ebony and some wood in class I and II.

![Typical test setup: (a) compression parallel to grain, (b) bending test](image-url)
Table 1: Wood classification based on strength (PKKI 1961)

| Strength level | Specific gravity, air dry condition (gr.cm⁻³) | MOE (kg.cm⁻²) | Allowable stress (kg.cm⁻²) |
|----------------|-----------------------------------------------|---------------|---------------------------|
|                |                                               |               | σₘ∥/                       | σₘ∥ = σₘ∥//                  | σₘ∥┴/         | τ∥/         |
| teak wood      | 0,70                                          | -             | 130                       | 110                        | 30           | 15          |
| I              | > 0,90                                        | 125.000       | 150                       | 130                        | 40           | 20          |
| II             | 0,90 – 0,60                                   | 100.000       | 100                       | 85                         | 25           | 12          |
| III            | 0,60 – 0,40                                   | 80.000        | 75                        | 60                         | 15           | 8           |
| IV             | 0,40 – 0,30                                   | 60.000        | 50                        | 45                         | 10           | 5           |
| V              | < 0,30                                        | -             | -                         | -                          | -            | -           |

Note, σₘ∥/ : flexural strength parallel to grain, σₘ∥┴/ : compressive strength perpendicular to grain, σₘ∥:// : tensile strength parallel to grain, τ∥/ : shear strength parallel to grain, σₘ∥// : compressive strength parallel to grain.

Table 2: The average value of physical and mechanical properties of Ebony

| Physical and mechanical properties | Range           | Mean* |
|-----------------------------------|-----------------|-------|
| Moisture content, MC (%)          | 9,18 – 16,82    | 12,90 |
| Specific gravity, G (gr.cm⁻³)     | 0,86 – 1,21     | 0,92  |
| Modulus of Elasticity, MOE (kg.cm⁻²) | 111.411,23 – 215,771,95 | 180.425,87 |
| Bending strength, σₘ∥ (kg.cm⁻²)   | 1.077,53 – 2.148,84 | 1.656,22 |
| Compressive strength parallel to grain, σₘ∥┴/ (kg.cm⁻²) | 719,51 – 993,51 | 861,55 |
| Shear strength, τ (kg.cm⁻²)       | 72,39 – 155,71  | 119,61 |
| Tensile strength parallel to grain, σₘ∥// (kg.cm⁻²) | 2.015,67 – 2.904,45 | 2.319,03 |

*20 test samples

Table 3: Physical and mechanical properties of several wood in strength level I-II (Martawijaya et al. 2005)

| Wood               | Specific gravity gr.cm⁻³ | MOE kg.cm⁻² | σₘ∥/ kg.cm⁻² | σₘ∥┴/ kg.cm⁻² | τ kg.cm⁻² |
|--------------------|--------------------------|-------------|--------------|---------------|-----------|
| Shorea leavifolia  | 0,91                     | 187 x 10³   | 1.243        | 680           | 102,8     |
| Shorea elepatica   | 0,95                     | 199 x 10³   | 1.545        | 730           | 96,7      |
| Maranthes corymbesa | 0,96                     | 170 x 10³   | 1.286        | 620           | 67,4      |
| Aglaia subcuprea   | 0,91                     | 159 x 10³   | 1.371        | 721           | 76,8      |
| Intsia bijuga      | 0,84                     | 158 x 10³   | 1.478        | 777           | 104       |
| Dalbergia latifolia | 0,83                     | 115 x 10³   | 1.162        | 617           | 90,2      |
| Eusideroxyylon zwa-geri | 1,04                     | 184 x 10³   | 1.431        | 734           | 117,4     |
| Trichadenia philippinensis | 0,86                   | 157,7 x 10³ | 1.023,7      | 629,4         | 162       |
| Elateriospermum tapos | 0,81                     | 168,7 x 10³ | 1.116,4      | 78,7          | 118,8     |
| Dillenia grandifolia | 0,80                     | 178 x 10³   | 1.045        | 131           | 97        |
| Ebony (Diospyros celebica)* | 0,821                  | 180.425,87  | 1.656,22     | 861,55        | 119,61    |

*Present study
3.1 Physical Properties

Physical properties are quantitative characteristic of wood and its behavior against environmental influences (not including external applied forces) (Winandy 1994). Physical properties is very important because it affects on performance and strength of the wood used in structural applications. The often determined physical properties are moisture content and specific gravity. This value depends on the species and type of wood.

Test results of physical and mechanical properties test of Ebony wood are shown in Table 2. Based on the table it can be seen that moisture content of Ebony is in range of 9.18 - 16.82% with an average of 12.90%. These results were in the range of air dried moisture content in Indonesia which ranged between 10 - 18%. On standing trees (living trees) moisture content of wood could be in range of 25% - 250% (Winandy 1994).

Moisture content is one of the most important variables that has to be considered when designing timber structures. Since it affects virtually all mechanical properties of timber, any inspection of wood buildings should include testing of the moisture content (Dolan 2004).

The physical properties test also found that specific gravity of Ebony is in range of 0.86 - 1.21 gr.cm⁻³ with an average of 0.92 gr.cm⁻³. This value is greater than specific gravity at 12% moisture content of 10-year-old of teak wood (0.64 gr.cm⁻³) from Laos (Wanneng et al. 2014). Wood specific gravity is usually influenced by age of the trees. The older trees would have higher values of wood specific gravity. In addition, site and clone also influence wood specific gravity significantly (Kim et al. 2011).

Based on the specific gravity, Ebony wood can be classified into strength level class I (Table 1). This class of wood is also called as structural wood. Wood classified into this class can be used for heavy construction, not protected, and exposed to moist soil. Its use requires a structural analysis calculation.

3.2 Mechanical Properties

The mechanical properties is characteristics of material in response to an acting external force (external applied forces) (Winandy 1994). Engineers, architects and carpenters must consider this properties for design wooden structures. Mechanical properties consist of elastic properties (modulus of elasticity MOE, modulus of rigidity G, and poison ratio u) which shows a resistance to deformation and distortion, and strength properties which shows resistance in sustaining load.

MOE indicates the slope of stress-strain relationship curve in elastic conditions (elastic range) as in figure 3. Mechanical properties test shows that MOE of Ebony wood is ranging from 111.411,23 – 215.771,95 kg.cm² with an average of 180.425,87 kg.cm⁻². This value is greater than Shorea leavifolia namely 187 x 10³ kg.cm⁻³, Shorea eleptica 199 x 10³ kg.cm⁻², Cotilelobium spp. 190 x 10³ kg.cm⁻², and Eusideroxylon zwageri 184 x 10³ kg.cm⁻².

However, it is smaller than Dillenia grandifolia 178 x 10³ kg.cm⁻², Shorea uliginosa 175 x 10³ kg.cm⁻², Intsia bijuga 167 x 10³ kg.cm⁻³, Maranthes corymbesa 170 x 10³ kg.cm⁻², and Garcinia nervosa 175,7 x 10³ kg.cm⁻² (Martawijaya et al., 2005). Based on MOE, Ebony wood is also classified into strength level class I (MOE > 125.000 kg.cm⁻²) (PKKI 1961).

Bending strength represents the maximum load capacity that is able to be borne by a bending element. Bending strength of wood is also affected by moisture content. Bending strength may increase as much as 4% for each 1% decrease in moisture content below the fiber saturation point (Dolan 2004). The results show that the bending strength values of Ebony wood ranged from 1077,53 to 2148,84 kg.cm⁻² with an average of 1655,22 kg.cm⁻². This value is still greater than another strong wood such as Shorea eleptica 1545 kg.cm⁻², Eusideroxylon zwageri 1431 kg.cm⁻² (Martawijaya et al. 2005), and Shorea leavifolia 1243 kg.cm⁻² (Chauf 2005).
The compressive strength parallel to grain is a maximum value of stress that is still able to be borne by wood when receiving the compressive load in same direction to grain. Compressive testing to determine the stress should use specimen with ratio of its length dimension smaller than 11 (Wood Handbook 2010). Based on test results, the compressive strength parallel to grain of Ebony wood is ranged from 719.51 to 993.51 kg.cm⁻² with an average of 861.55 kg.cm⁻². This value is greater than other woods like Eusideroxylon zwa-geri 734 kg.cm⁻², Kokoona reflexa 782,1 kg.cm⁻², Xanthophyllum flavescens 747.7 kg.cm⁻², Intsia bijuga 777 kg.cm⁻², and Shorea eleptica 730 kg.cm⁻² (Martawijaya et al., 2005). Compressive strength parallel to grain, at 15 percent moisture content, varies from 305.91 to 790,28 kg.cm⁻² (30.0 to 77.5 N.mm⁻²) (Duggal 2008).

The other mechanical properties belonging to strength properties are shear strength and tensile strength parallel to grain. Shear strength is the resistance to the acting shear loads. Based on the conducted research, the value of shear strength of Ebony is found ranged between 72,39 to 155,71 kg.cm⁻² with an average of 119.61 kg.cm⁻². This value reaches 1,57 times the shear strength of wood Kumea Batu (Manilkara merrilliana) namely 76.01 kg.cm⁻² (Lempang et al. 2008).

Tensile strength parallel to grain is the maximum tensile stress that is capable detained by an element that receives a tensile load parallel to grain. Tensile strength parallel to the grain is two to four times the compressive strength and usually order 815.77 to 1937.46 kg.cm⁻² (80.0 to 190.0 N.mm⁻²) (Duggal 2008). Tensile strength parallel to grain of Ebony ranges from 2015.67 to 2904.45 kg.cm⁻² with an average of 2319.03 kg.cm⁻².

4. Conclusion
The average moisture content of Ebony is 12,90% and specific gravity is 0,92 gr.cm⁻³. The average value of MOE dan bending strength of Ebony are 180.425,87 kg.cm⁻² and 1656,22 kg.cm⁻² respectively. Meanwhile compressive strength parallel to grain, shear strength, and tensile strength parallel to grain are 861,55 kg.cm⁻², 119,61 kg.cm⁻², and 2.319,03 kg.cm⁻² respectively.

The results conclude that Ebony wood could be classified into class I in strength level due to Indonesian Timber Construction Code, PKKI 1961 (MOE > 125,000 kg.cm⁻² and specific gravity > 0.90). Thus, this wood can be recommended for use in heavy constructions such as bridges (girder and floor) and the building structure (column, beam and floor).

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