Physical and mechanical properties of four wood species from community forests in Binjai Regency, North Sumatra

E Herawati*, R Hartono and H M M Sinaga
Faculty of Forestry, Universitas Sumatera Utara, Medan, North Sumatra 20155, Indonesia
*E-mail: evalina@usu.ac.id

Abstract. The fundamental properties of wood are significant to determine the purposes of wood used. This study aims to determine the physical and mechanical properties of four wood species namely terap (*Artocarpus odoratissimus*), durian (*Durio zibethinus*), mindi (*Melia azedarach* L.), and karet or rubber wood (*Hevea brasiliensis* Muell. Arg) from community forests in the Binjai Regency, North Sumatra. The physical properties were determined as described in ASTM D4442 and ASTM D2395 while the mechanical properties were conducted according to ASTM D143 and BS 373. The results showed the moisture contents of four wood species ranged 12.66–15.28%, densities 0.35–0.59 g cm$^{-3}$, and specific gravities (SG) 0.33–0.55. The compression, tensile and shear strengths parallel to the grain, hardness, modulus of elasticity (MOE), and modulus of rupture (MOR) ranged 20–35 MPa, 36–80 MPa, 6.5–9.7 MPa, 1713–3226 N, 5463–7497 MPa and 43–71 MPa, respectively. Based on the SG and MOR values, the terap wood is included in strength class IV, while the other woods are in strength class III. Meanwhile, based on the compression strength values, the terap wood is included in strength class V, durian and mindi wood are in strength class IV, while karet wood is in strength class III.

1. Introduction
According to Statistics of Environment and Forestry, the supply of logs from community forests in 2018 was around 6 million m$^3$. It was far below the supply of logs from plantation forests (40 million m$^3$) but higher than other supply sources such as natural forests, plantations, and others [1], so it is worth considering. The woods from community forests is available at small community sawmills, the production of which is usually intended for local needs.

The use of wood for various purposes such as woodworking, pulp and paper, and energy, requires knowledge of the basic properties of wood. The important basic properties according to [2] are physical properties, mechanical properties, and chemical components of wood. These three basic properties play a very important role in determining the suitability of a wood species that can be processed in the wood processing industry and the suitability of processing products that can be made from the species for certain purposes.

The woods from community forests were used by the society for various purposes, including for furniture and building materials [2,3]. For such uses, it is necessary to know the physical properties, especially specific gravity, and some mechanical properties. Studies showed a very close relationship between density or specific gravity and strength properties, the higher the density or specific gravity, the higher the strength of the wood [4-6]. The study [5] showed that relationship between mechanical
properties and wood density was strongest for modulus of rupture, followed by compression strength and modulus of elasticity.

This study used woods from community forests, which consisted of terap wood, durian, mindi, and karet (rubberwood). Terap and durian are classified as lesser-used species, mindi is a major plantation species [2], while karet is known as a species that widely cultivated for natural rubber [7]. Although some physical and mechanical properties of the wood species have been studied but still very limited with wide variation in wood properties, so studies on the wood species are important. There are natural factors that affect the physical and mechanical properties of wood, based on the study of many wood species in Indonesia [8]. The factors are classified into wood species, age and place of growth, location in the stem, diameter, humidity, moisture content and temperature, weather and fungi, and forest fires [6, 8, 9]. Studies showed the fungal attack on wood can cause changes in color, texture, and a decrease in wood hardness. Meanwhile, forest fires can cause a decrease in the mechanical properties of wood because exposed to high temperatures [8].

The purpose of this study was to determine the physical and mechanical properties of four wood species obtained from community forests in Binjai Regency, North Sumatra. The information about physical and mechanical properties is expected to be a consideration in the use of wood.

2. Materials and Method

The wood blocks used in this study were purchased from a community sawmill in Binjai Regency, North Sumatra. The specimens were taken from terap (Artocarpus odoratissimus), durian (Durio zibethinus), mindi (Melia azedarach L.) and karet or rubber wood (Hevea brasiliensis) Muell. Arg. Each wood block specimen was sized 6 cm x 12 cm x 220 cm for terap, durian and mindi, and 6 cm x 12 cm x 130 cm for karet because the trunks are shorter than the others and tend not to be straight. The specimens were seasoned until a constant air-dry weight was achieved before testing. Specimens were prepared for physical and mechanical properties tests.

The physical properties (moisture content, density, and specific gravity of the wood) were determined as described in ASTM D4442 [10] and ASTM D2395 [11]. Specimens were measured and weighed to determine the volume of each specimen and its equilibrated air dry weight. Then, specimens were placed in an oven at 103 ± 2 °C for 24 h to obtain the oven dry weight and volume. The air dry weight and the oven dry weight were used to calculate the moisture content (MC) of each specimen. The air dry weight and the specimen volume were used to calculate the density (D) at the time of testing. The oven dry weight and volume were used to calculate specific gravity (SG).

The mechanical properties (compression and tensile strengths parallel to the grain, shear strength parallel to the grain, end hardness) were conducted according to ASTM D143 [12], whilst modulus of elasticity (MOE) and modulus of rupture (MOR) were conducted according to BS 373 [13]. The mechanical properties were tested on a universal testing machine Merk Tension with a capacity of 50 kN. The physical and mechanical properties were measured on 10 replications for each test.

Compression, tensile, and shear strength parallel to the grain were calculated by the maximum load divided by cross-sectional area for each sample. MOE was calculated by the following equation:

\[ MOE = \frac{PL^3}{4bh^3} \]

MOR was calculated by the following equation:

\[ MOR = \frac{3P_{max}L}{2bh^2} \]

where, P is increment of applied load below proportional limit, Pmax is maximum load borne by specimen loaded to failure, L is span of specimen, b is width of specimen and h is depth of specimen.
3. Results and Discussion

3.1. Physical properties

The average moisture contents (MCs), densities (Ds) and specific gravities (SGs) values are presented in Table 1. The MC ranged from 12.66% in terap to 15.28% in mindi. The wood samples were equilibrated with the low air MC in Medan, Indonesia, which ranged from 12 to 20%. The coefficients of variation (CoV) show the MCs are relatively homogeneous (6–8%).

| Wood species | MC (%) | D (gcm⁻³) | SG  |
|--------------|--------|-----------|-----|
| Terap        | 12.66  | 0.35      | 0.33|
| Durian       | 14.63  | 0.51      | 0.47|
| Mindi        | 15.28  | 0.52      | 0.48|
| Karet        | 14.29  | 0.59      | 0.55|

Coefficients of variation (%) are given within parentheses.

The Ds values for terap, durian, mindi and karet were 0.35, 0.51, 0.52 and 0.59 gcm⁻³, while the SGs values were 0.33, 0.47, 0.48 and 0.55, respectively. The CoV of D (18%) and SG (19%) in durian wood is higher than the others so the result for them is less homogeneous than for the others. The Ds values were higher than the SGs values. It was because the D value was influenced by the MC, while the SG value was not affected by the MC. The SG was calculated based on the oven-dry weight. SG varies between wood species and it is a parameter used to estimate the strength of wood. Based on the SGs values the terap wood is classified as strength class IV (SGs range 0.3 to 0.4), while durian, mindi and karet wood are included in strength class III (SGs range 0.4 to 0.6) [14].

Terap has a lower SG than the other wood species. The average SG value of terap wood obtained in this study was lower than the SG in another study [15] of 0.44 and [16] of 0.41. Likewise, SG durian wood in this study was lower than in other studies [17] of 0.57 (0.42–0.69), and [18] of 0.53. Furthermore, the SG of mindi wood is also lower than other studies [19] of 0.53 (0.42–0.65), and [9] ranged from 0.52 to 0.57 but higher than [3] of 0.42. Karet wood has the highest SG in this study, it is the same as the SG in Shukari's study [7] of 0.55 based on air-dry volume, but smaller than the [20] and [21] study of 0.59. The variation of SG between this study and other studies for the same species are mainly caused by age and place of growth as well as moisture content [9].

3.2. Mechanical properties

Table 2 presents the average compression strengths (CS), tensile strengths (TS), shear strengths (SS), hardness (H), MOE and MOR values. The strength properties were lower in the terap wood than in the other woods in line with the SG values.

| Wood species | Compression (MPa) | Tensile (MPa) | Shear (MPa) | Hardness (N) | MOE (MPa) | MOR (MPa) |
|--------------|------------------|---------------|-------------|--------------|-----------|-----------|
| Terap        | 20 (20)          | 36 (38)       | 6.5 (14)    | 1713 (32)    | 5463 (12) | 43 (18)   |
| Durian       | 24 (12)          | 48 (52)       | 6.9 (23)    | 1910 (10)    | 6329 (37) | 61 (35)   |
| Mindi        | 28 (13)          | 63 (12)       | 8.7 (13)    | 2643 (9)     | 7497 (18) | 71 (12)   |
| Karet        | 35 (15)          | 80 (34)       | 9.7 (17)    | 3226 (12)    | 6874 (12) | 66 (13)   |

Coefficients of variation (%) are given within parentheses.
3.2.1. **Compression strength.** The average CS value for terap, durian, mindi and karet were 20, 24, 28 and 35 MPa, respectively. The CoV in terap wood (20%) is higher than the others but is within the usual values for mechanical tests in wood specimens. Terap has a lower CS than the other wood species. The average CS value of terap wood obtained in this study was lower than the CS in another study [15] of 33 MPa. Likewise, the CSs of durian and mindi wood was lower than in other studies [17] of 35 MPa and [19] of 31 MPa, respectively. Furthermore, karet wood has the highest CS in this study, the CS was higher than CS in Shukari's study in [7] of 32.5 MPa. Based on the CS values according to Den Berger classification in [2], the terap wood is classified as strength class V (CS < 21 MPa), while durian and mindi wood are included in strength class IV (CS range 21–29 MPa) and karet wood is classified as strength class III (CS 29–42 MPa).

3.2.2. **Tensile strength.** The average TS value for terap, durian, mindi and karet were 36, 48, 63 and 80 MPa, respectively. The CoV in durian wood is too high (52%) and is above the usual values for mechanical tests in wood specimens. The average TS values obtained in this study was lower than the TS in another study [4], for SG values ranged from 0.43 to 0.84 obtained TS values ranged from 93 to 154 MPa. The difference is due to species and SG of wood. The value of the tensile strength parallel to the grain was very limited, so the comparisons given are from the different species.

3.2.3. **Shear strength.** The average SS values for four wood species ranged from 6.5 to 9.7 MPa. The CoV in durian wood is higher (23%) than the others and is within the usual values for mechanical tests in wood specimens. Terap has a lower SS than the other wood species. The average SS values obtained in this study were higher than the CS in another study which were 5.7 MPa [15], 4.8 MPa [17], and 6.0 MPa [19] respectively, except karet wood of 11.0 MPa [7].

3.2.4. **Hardness.** The average H value for four woods species ranged from 1713 to 3226 N and coefficients of variation ranged from 9 to 32%. The CoV in terap wood (32%) is higher than the others so the result for them is less homogeneous than for the others. The H values of the four wood species in this study varied compared to the H values in other studies. The H value of terap wood was 2788 N [15], durian wood of 3570 [17], mindi wood of 3217 [19], and karet wood of 4320 N [7].

3.2.5. **Modulus of elasticity and modulus of rupture.** The average MOE values obtained in this study was lower than the MOE in another study which were 7239 MPa [15], 9601 MPa [17], 8041 MPa [19] and 9240 MPa [7], respectively. The average MOR values obtained in this study was lower than the MOR in another study which were 38 MPa [15], and 54 MPa [19] for terap and mindi wood. But MOR values of durian and karet wood were similar [17] of 61 MPa and [7] of 66 MPa, respectively. The CoV of MOE (37%) and MOR (35%) in durian wood is higher than the others so the result for them is less homogeneous than for the others. Another study [9] showed MOE and MOR values of mindi wood were 9260 MPa and 78 MPa, respectively. Based on the MOR values according to Den Berger classification [2], the terap wood is classified as strength class IV (MOR ranged 35 to 49 MPa), while durian, mindi and karet wood are included in strength class III (MOR ranged 49 to 71 MPa).

The SG value of the four wood species is related to the wood strength. Terap wood with the lowest SG value can be used for applications that not supported heavy loads, as applied to the other three wood species.
4. Conclusion
The MCs of four wood species ranged from 12.66 to 15.28%, Ds ranged from 0.35 to 0.59 g/cm³, and SGs from 0.33 to 0.55. The CSs, TSs and SSs, H, MOE, and MOR were 20–35 MPa, 36–80 MPa, 6.5–9.7 MPa, 1713–3226 N, 5463–7497 MPa and 43–71 MPa, respectively. Based on the SG and MOR values, the terap wood is included in strength class IV, while the other woods are in strength class III. Meanwhile, based on the CS values, the terap wood belongs to strength class V, durian and mindi wood belong to strength class IV, while karet wood belongs to strength class III.

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