Characterization of Compression and Tensile Properties of Bamboo Jawa (Gigantochloa Atter) and Bamboo Apus (Gigantochloa Apus) for Application as Soil Reinforcement

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Abstract. In any construction design, two things should be taken into account are stability and settlement. In order to achieve target soil stability or soil bearing capacity, earthwork solutions and or ground improvement solutions can be conducted. Some solutions can vary such as using bamboo as a retaining wall or as a foundation. This study aims to determine the compression and tension properties of bamboos which can be used as data for soil reinforcement. Two types of bamboo, bamboo Apus (Gigantochloa Apus) and bamboo Jawa (Gigantochloa Atter) are selected as tested materials. Twenty-four samples from the two bamboos are tested to understand their compressive strength and other thirty for tensile strength. In order to determine the compression (ASTM C39/C39M-09a) and tension (SNI 03-3399-1994) properties of some parts of bamboo, the samples are taken from top, middle, and bottom location. From this experiment, from the two kinds of bamboo, bamboo Apus provides higher strengths (both compressive and tensile strength) than bamboo Jawa. For compressive strength, Bamboo Apus on average reaches 44.36 MPa while bamboo Jawa reaches 25.45 MPa. In tensile strength, on average bamboo Apus reaches 183 MPa which is higher than that of bamboo Jawa 140.3 MPa. From this finding, it assures that one type of bamboo can have higher strength than others.

1. Introduction
A natural fiber, instead of synthetic materials has been widely used due to its advantages such as low prices, renewable and harmless materials. One of natural fibers is bamboo which has many benefits. Bamboos can be used as a construction material since bamboos are economical and environmentally friendly materials. They have a good strength and easy to use [1]. Bamboo can grow well in Indonesia, having a rapid growth period from 120 cm / day to 5 cm / hour. With this behaviour, bamboo is easily found in Indonesia. In addition to the availability of bamboo, its low price and environmentally friendly material generate people to use it as construction material [2]. Bamboo contains fiber which is more advantageous than other natural fibers. Bamboo has high parallel fiber strength, antibacterial properties, small strain and high tensile strength. The bamboo surface which is very rough can provide a high shear resistance [2] that is why bamboo is able to be an alternative material since it can replace the geotextile function in soil reinforcement. A bamboo consists of nodes, internodes, and culm. The bamboo culm contains cellulose and sklerenkim fiber that influences bamboo’s strength. Cellulose content in bamboo
fiber affect tensile material which can function as soil reinforcement. Some researchers have been conducting studies on physic and mechanical properties of bamboos. A group of researchers [4] has performed several tests (fiber length, lignin level, and holocellulose) to determine the physical properties of bamboo. The aforementioned tests are to test fiber content, fiber length, intercellular adhesive of lignin. They used four types of bamboos (Apus, Gombong, Legi/Jawa, and Ori) as tested materials. From the result test and analysis: fiber content, fiber length, intercellular adhesive of lignin and diameter of bamboo fiber that is higher causing the bamboo stems are stronger and stiffer. Among the four tested bamboos, Gombong bamboo is the most powerful bamboo. Dissimilar with [4], a researcher [2] performed a study on mechanical properties of bamboo particularly tensile strength of woven bamboo and its application to soil reinforcement for embankment. She used outer and inner parts of bamboo as tested material. From the experiment, it is found that outer part is brittle whereas the inner part is ductile. The maximum tensile strength is 395.53 kN/m’. From aforementioned studies, different from [2] this study investigates the mechanical properties of bamboo: compressive and tensile strength from two bamboos (Apus and Jawa) which is taken from different parts of bamboo: top, middle, and bottom.

2. Research Method

In this study with the objective to determine the mechanical properties of bamboo: compressive and tensile strength, two kinds of bamboo that is bamboo Apus and bamboo Jawa are selected as tested materials.

2.1. Compression test

In order to determine compressive strength, as many as twenty-four samples from the two bamboos are tested. To determine the compression properties of some parts of bamboo, the samples are taken from different location of bamboo: top, middle, and bottom. Testing of compressive strength follows the method by [5] that is the samples’ height is twice much as the diameter of bamboo. The diameters of the samples are from 60 mm to 92 mm whereas the heights of the samples are from 120 mm to 150 mm (Table 1). The samples were tested using compression strength test machine with capacity 1000 kN and follows standard / test method [6]. All the samples are tested until they fail (the strength value increases till it is constant). The samples and bamboo testing for compressive strength are presented in Figure 1 and Figure 2 respectively.

![Figure 1. The bamboo samples for compressive strength](image-url)
2.2. Tensile test
Twenty-four samples from the two bamboos are tested to determine their tensile strength. The same with compressive strength test, the samples are taken also from different location of bamboo: top, middle, and bottom. The method used for sample dimension here is different from the method by [5]. In [5] the thickness of culm as tested diameter is made smaller in middle than in top and bottom location whereas in this study thickness of diameter in top, middle, and bottom location are the same. From the preliminary test, the tensile strength produced by method [5] is much smaller than if the diameter thicknesses in all locations are made the same. The length of samples is 200 mm with the diameters are from 6 mm to 11 mm. The samples were tested using tensile strength test machine with capacity 500 kN and follows standard / test method [7]. All the samples are tested until they fail. The samples and bamboo testing for tensile strength are presented in Figure 3 and Figure 4 respectively. Testing method for tensile strength, the sample is tested until failure (Figure 5).
3. Result and Discussion
In order to have good comprehension, in this first part compressive strength of tested bamboo is discussed and then tensile strength of tested bamboo. Afterward possible model of bamboo as soil reinforcement based on the mechanical properties obtained.

3.1. Compressive strength
Two kinds of bamboo Jawa and Apus is separated into three parts: bottom, middle, and top which each part is around 3 meter long. From this 3 meter-long, two samples were taken. The dimension of samples: the height is twice much as the outer diameter bamboo. Value of Area (A) is obtained from the thickness of culm (outer diameter minus inner diameter). Table 1 and Table 2 present the dimension of bamboo and compressive strength of bamboo Jawa and Apus respectively.
Table 1. Compressive strength of Bamboo Jawa

| Parameter of Bamboo | Bamboo Jawa 1 | Bamboo Jawa 2 |
|---------------------|---------------|---------------|
| Outer diameter (cm) | 6.5 6.5 6 6 6 9.2 9.2 9 8.6 8 7.8 |
| Outer radius (cm)   | 3.25 3.25 3 3 3 4.6 4.6 4.5 4.3 4 3.9 |
| Inner diameter (cm) | 4 4.4 4.4 4.4 4.4 7.5 7.5 7.2 7.1 6.1 6.1 |
| Inner radius (cm)   | 2 2.2 2.2 2.2 2.2 2.2 3.75 3.75 3.6 3.55 3.05 3.05 |
| Height (cm)         | 13 13 12 12 12 15 15 15 15 15 |
| Weight (gr)         | 235 185 130 175 140 110 280 215 215 210 305 220 |
| Stress (kg)         | 5712 4998 3978 4488 3978 3468 6936 8058 6426 6630 4590 5712 |
| Area (A) (cm²)      | 20.62 17.98 13.07 13.07 13.07 13.07 22.30 22.30 22.90 18.50 21.04 18.56 |
| Compressive strength (MPa) | 23.44 23.52 25.75 29.05 25.75 22.45 26.32 30.58 23.74 30.33 18.46 26.04 |
| Average value (Mpa) | 23.48 27.40 24.10 28.45 27.03 22.25 |
| Ave. values of bottom (Mpa) | 25.96 |
| Ave. values of middle (Mpa) | 27.22 |
| Ave. values of top (Mpa) | 23.18 |

From this experiment, it seems that from the two bamboos: 1) there is no significant in compressive strength with the location of bamboo either at the top, middle or bottom parts. Even though as physically bottom part has biggest dimension, but it does not always provide the highest compressive strength (for instance Bamboo Jawa 1, Table 1). On the contrary the top part which is the thinnest part can provide the highest compressive strength (for instance Bamboo Apus 1, Table 2). 2) From the two types of bamboos, it appears that compressive strength of all parts of bamboo Apus higher than that of bamboo Jawa. With the thinner culm, bamboo Apus can support more load than bamboo Jawa.

Table 2. Compressive strength of Bamboo Apus

| Parameter of Bamboo | Bamboo APUS 1 | Bamboo APUS 2 |
|---------------------|---------------|---------------|
| Outer diameter (cm) | 6 6 5.5 5.5 4.5 4.5 6 6 6 6 5.5 5.5 |
| Outer radius (cm)   | 3 3 2.75 2.75 2.25 2.25 3 3 3 3 2.75 2.75 |
| Inner diameter (cm) | 4.8 4.8 4.2 4.2 3.8 3.7 4.9 4.9 4.6 4.5 4.5 4.4 |
| Inner radius (cm)   | 2.4 2.4 2.1 2.1 1.9 1.85 2.45 2.45 2.3 2.25 2.25 2.2 |
| Height (cm)         | 12 12 11 11 9 9 12 12 12 12 11 11 |
| Weight (gr)         | 125 105 85 80 85 55 115 110 140 110 85 80 |
| Stress (kg)         | 4998 4794 4590 4488 3264 3366 5304 5712 5202 4998 4488 3876 |
| Stress (P) (kN)     | 49 47 45 44 32 33 52 56 51 49 44 38 |
| Area (A) (cm²)      | 10.18 10.18 9.90 9.90 4.56 5.15 9.42 9.42 11.66 12.37 7.85 8.55 |
| Compressive strength (MPa) | 41.54 39.85 39.21 38.34 60.52 55.28 47.65 51.32 37.76 34.18 48.35 38.34 |
| Average value (Mpa) | 40.70 38.78 57.90 49.49 35.97 43.34 |
| Ave. values of bottom (Mpa) | 45.09 |
| Ave. values of middle (Mpa) | 37.37 |
| Ave. values of top (Mpa) | 50.62 |

The compressive strengths of bamboo Jawa ranges from 23 to 28MPa whereas those of bamboo Apus ranges from 34 to 60 Mpa. On average bamboo Jawa reaches 25.45 MPa bamboo Apus reaches 44.36 MPa for compressive strength. This may relate to the stiffness of bamboo Apus which is higher than that of bamboo Jawa. This result is in line with [4] which is to the stiffness of bamboo Apus is higher than that of bamboo Jawa.
3.2. Tensile strength

The result of tensile strength of the two types of bamboo is presented in Table 3 and Table 4. Whole samples are 0.5 meter-long with diameter ranges from 5.5 mm to 11 mm. The difference of diameter merely depends on the thickness of bamboo culm. The number of tested samples of bamboo Jawa is 18 (Table 3) while bamboo Apus is 12 samples (Table 4). Identical to the result from compressive tests, it is very interesting that the tensile strength of bamboo Apus on average (183 MPa) is higher than that of bamboo Jawa (140.3 MPa). As given in Table 3, the tensile strength of bamboo Jawa ranges from 72 MPa to 200 MPa. However those of bamboo Apus ranges from 100 MPa to 308 MPa as presented in Table 4. These strengths are taken from bottom, middle, and top locations of bamboo. Comparing bamboo Jawa 2 to bamboo Jawa 3, it is not always the top locations provide higher tensile strength. For instance, bamboo Jawa 2 the highest strength comes from the top location whereas bamboo Jawa 3 is from middle location. Similar to compressive strength obtained from the experiment, it cannot be generalized which location of bamboo provides the highest tensile strength. However, from the two bamboos, Apus and Jawa, the minimum average tensile strength is always produced by the bottom location. This may be caused by short fiber length [8] and low content of lignin which reduces stiffness [9]. For purpose of material selection, however it may part of bamboo can be selected are middle and top parts for tensile strength.

| Specimens | Diameter (mm) | Maximum Tensile Strength (Mpa) |
|-----------|---------------|--------------------------------|
| Bamboo Jawa 1 | Bottom 1 8 | 106.4 |
| | Bottom 2 8 | 119.1 |
| | Middle 1 7.5 | 154.8 |
| | Middle 2 8 | 121.3 |
| | Top 1 8 | 72.8 |
| | Top 2 7 | 107.5 |
| Bamboo Jawa 2 | Bottom 1 8 | 105.4 |
| | Bottom 2 8 | 136.4 |
| | Middle 1 6 | 163 |
| | Middle 2 7 | 115.6 |
| | Top 1 7.5 | 213.6 |
| | Top 2 8 | 117.1 |
| Bamboo Jawa 3 | Bottom 1 11 | 94.2 |
| | Bottom 2 9 | 178.3 |
| | Middle 1 8.5 | 164.4 |
| | Middle 2 7.5 | 200.2 |
| | Top 1 7 | 180.5 |
| | Top 2 7.5 | 175.1 |
3.3. Modelling bamboo as soil reinforcement

Soil reinforcement can be reinforcement from either axial load or lateral force. Bamboo can be used as reinforcement from both axial load and lateral force. In this section, suggestion is given based on data obtained from the experiment. In order to support axial load, bamboo can function as pile using configuration consisting of 3 or 5 bamboos as shown in Figure 6 [10]. If using bamboo Apus for instance, the configuration of 3 bamboos can support 151.86 MPa (each bamboo is 50.62 MPa, Table 2). The number of bamboo used in one configuration relies on axial load must be supported. In perspective of lateral force, bamboo can be an alternative material replacing reinforcing bar although the tensile strength of bamboo is much lower than that or reinforcing bar. In [11], the tensile strength of bamboo Betung is 92.3% from that of medium-strength reinforcing bar and the yield strength of bamboo Betung is 94.6% from that of medium-strength reinforcing bar. In [12] maximum tensile strength of reinforcing bar ranges from 610 N/mm$^2$ to 670 N/mm$^2$. Compared to the tensile strength of bamboo Jawa (Table 3), from 72 to 200 MPa or from 72 to 200 N/mm$^2$), those of reinforcing bar are 3 to 8 times much higher. 

In addition, soil reinforcement from land slide, bamboo can replace gravity wall or sheet pile. Capability of bamboos to protect soil from sliding is due to their tensile strength.

Table 4. Tensile strength of Bamboo Apus

| Specimens | Diameter (mm) | Maximum Tensile Strength (Mpa) |
|-----------|---------------|-------------------------------|
| Bamboo 1  | Bottom 1      | 6                             | 189.1                         |
|           | Bottom 2      | 6                             | 215.7                         |
|           | Middle 1      | 6                             | 224.8                         |
|           | Middle 2      | 5.5                           | 231.8                         |
|           | Top 1         | 5.5                           | 308                           |
|           | Top 2         | 6                             | 194.8                         |
| Bamboo 2  | Bottom 1      | 5.5                           | 106.9                         |
|           | Bottom 2      | 6.5                           | 100.6                         |
|           | Middle 1      | 6.5                           | 122.9                         |
|           | Middle 2      | 6                             | 181.7                         |
|           | Top 1         | 6.5                           | 143.7                         |
|           | Top 2         | 5                             | 175.6                         |

![Figure 6. Bamboo as soil reinforcement supporting axial load [10]](image-url)
4. Conclusion
Comparing two kinds of bamboo, bamboo Apus (Gigantochloa Apus) and bamboo Jawa (Gigantochloa Atter), this experimental study tested twenty-four samples (from the two kinds of bamboo) to determine their compressive strength and other thirty for tensile strength. The result shows that both compressive and tensile strength of bamboo Apus are higher than those of bamboo Jawa. For compressive strength, Bamboo Apus on average reaches 44.36 MPa while bamboo Jawa reaches 25.45 MPa. However, for tensile strength, on average bamboo Apus reaches 183 MPa and bamboo Jawa reaches 140.3 MPa. The tensile strength of bamboo Jawa ranges from 72 to 200 MPa that is equivalent to one third to one eighth of that of medium-strength reinforcing bar thus bamboo can be an alternative material replacing medium-strength reinforcing bar.

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