Compressive and tensile strength of bamboo species

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Abstract. Asia is the continent with the largest bamboo population in the world, so bamboo is a popular construction material in Asian countries such as China, India, and also Indonesia. There are 145 species of bamboo species that grow in Indonesia, and in the eastern region of Sumatera Utara (Deli Serdang, Langkat, and Sedang Bedagai district), 13 species can be found. But in this region, the use of bamboo in construction is limited, due to lack of knowledge about the strength of local bamboo. This study is conducted to determine the mechanical properties, namely the compressive and tensile strength of bamboo species that grow in the region. The results obtained are the preliminary data to conduct further studies to utilize bamboo in this region as a construction material. To obtain the compressive and tensile strength, compression and tension test are carried out based on ISO 22157 standard and performed on node and internode sections of bamboo samples. The result of this study shows that for a compression test, the compressive strength for node and internode samples did not show significant differences. But in the tension test, the internode tensile strength significantly higher than the node.

1. Introduction

Bamboo is a versatile plant that grows in many parts of the world, in particular, the tropical and subtropical areas. Figure 1 shows that about 65% of the area is in Asia. China and India are the two countries together have more than half the total bamboo resources globally [1]. Aside from Asian countries, some African countries also develop some studies to utilize their local bamboo species as construction material [2] [3].
As a country with bamboo resources in the world, bamboo has been used as a building material in Indonesia for hundreds of years. But the use of bamboo as a building material is limited and not too developed. There are several factors that discourage bamboo development: the lack of knowledge and technology dissemination in bamboo treatment, inadequate information about bamboo, limited Indonesian bamboo research activities, and capital constraints. However, in recent times, bamboo has been receiving more attention, since advanced technology of bamboo treatment, the involvement of expertise in bamboo building technology, and modern design application to bamboo products have given bamboo new appearances and performances [4]. Recent research for engineered bamboo showed some good use of bamboo. Bamboo has similar mechanical behavior to wood but has higher tensile strength and excellent formability, so it is possible to make use of high strength properties of bamboo to use it as reinforcement in composite beams [5]. Other research engineered and utilized bamboo as Single Layered Bamboo Scaffolds (SLBS) and Double Layered Bamboo Scaffolds (DLBS) [6][7].

Based on several works, it is found that there are 145 species (20 genera) grow in Indonesia. Seventy-Five species among them grow endemic in Indonesia. Sumatera is the most diverse region with 75 species [8]. In Sumatera Utara, there were fifteen species of bamboo found, where thirteen of them were found in Deli Serdang and Langkat district. Genera and different species of bamboo in the eastern region of Sumatera Utara are presented in Table 1, while their distribution map in Sumatera Utara is presented in Figure 2 [9].

| No | Genus              | Species                | Location | Note |
|----|--------------------|------------------------|----------|------|
| 1  | Bambusa            | Bambusa blumeana.      | √        | W    |
| 2  | Bambusa            | Bambusa glaucescens.   | -        | P    |
| 3  | Bambusa glaucophylla. | Bambusa vulgaris.     | √        | P/W  |
| 4  | Bambusa            | Bambusa multiplex.     | -        | P/W  |
| 5  | Gigantochloa       | Dendrocalamus asper.   | √        | P/W  |
| 6  | Gigantochloa       | Gigantochloa atrovioleacea. | - - - - - - - - - - - - | W    |
| 7  | Gigantochloa       | Gigantochloa atter.    | √ - - - - √ √ - | W    |
| 8  | Gigantochloa       | Gigantochloa achmadii. | - - - - - √ √ √ | P/W  |
| 9  | Gigantochloa       | Gigantochloa pruriens. | - - - - - √ √ - | P/W  |
| 10 | Gigantochloa       | Gigantochloa robusta.  | √ - - - - √ √ √ - | W    |
| 11 | Schizostachyum     | Schizostachyum bracycladum. | √ √ - - √ √ √ √ - | P/W  |
Some previous research has examined the strength of several types of bamboo in Indonesia. 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) density, morphology, tensile strength, and modulus of elasticity already studied [10], but the source of the bamboo was from West Java. Research on mechanical properties of local bamboo in the eastern region of Sumatera Utara is limited and this inadequate information could draw back the use of bamboo as engineered material in this region. This research will investigate the mechanical properties of different species of local bamboos from Langkat, Deli Serdang, and Serdang Bedagai in the eastern region of Sumatera Utara, especially compressive strength and tensile strength, and utilize it as a construction material.

In the research, Saputri [9] explains the physical description from fifteen species of bamboo, shown in Table 2. Bambusa Vulgaris and Dendrocalamus Asper are the most common species because it grows in all district in this region. From fifteen species, thirteen of them grows in Langkat, Deli Serdang, and Serdang Bedagai. This district is the closest district to Medan as the capital city of Sumatera Utara, and also supplies most of the bamboo in Medan. Based on the physical description and examination, only eight species are suitable for construction material, while the others are not suitable because the
diameter is too small or too thin. Those suitable species are Bambu Duri (Bambusa Blumeana), Bambu Kuning (Bambusa Vulgaris), Bambu Betung (Dendrocalamus Asper), Bambu Hitam (Gigantochloa Atroviolacea), Bambu Regen (Gigantochloa Pruriens Widjaya), Bambu Mayan (Gigantochloa Robusta Kurz), Bambu Nipis (Schizostachyum Zolingeri Steud), and Bambu Lemang (Schizostachyum Bracycladum Kurz).

Table 2. Physical description of bamboo in eastern region of Sumatera Utara.

| No | Genus                | Species                     | Diameter (mm) | Internode (mm) | Thickness (mm) |
|----|----------------------|-----------------------------|---------------|----------------|----------------|
| 1  | Bambusa              | Bambusa blumeana           | 100 - 200     | 250 - 300      | 10 - 30        |
| 2  | Bambusa glaucescens. | Bambusa glaucescens.       | 40 - 70       | 100 - 200      | 7 - 10         |
| 3  | Bambusa glaucescens. | Bambusa glaucescens.       | 40 - 70       | 150 - 250      | 5 - 8          |
| 4  | Bambusa vulgaris.    | Bambusa vulgaris.           | 50 - 100      | 200 - 450      | 7 - 15         |
| 5  | Bambusa multiplex.   | Bambusa multiplex.          | 20            | 150 - 250      | 5              |
| 6  | Dendrocalamus        | Dendrocalamus asper.        | 250 - 300     | 300 - 400      | 7 - 10         |
| 7  | Gigantochloa         | Gigantochloa atroviolacea. | 80 - 150      | 300 - 400      | 6 - 10         |
| 8  | Gigantochloa atroviolacea. | Gigantochloa atroviolacea. | 50 - 80       | 150 - 250      | 20 - 25        |
| 9  | Gigantochloa atroviolacea. | Gigantochloa atroviolacea. | 30 - 35       | 200            | 1 - 3          |
| 10 | Gigantochloa pruriens. | Gigantochloa pruriens.     | 200           | 250 - 350      | 20 - 25        |
| 11 | Gigantochloa robusta.| Gigantochloa robusta.       | 180 - 220     | 150 - 250      | 25             |
| 12 | Schizostachyum      | Schizostachyum bracycladum.| 80 - 100      | 300 - 350      | 2 - 4          |
| 13 | Schizostachyum      | Schizostachyum bracycladum.| 100 - 150     | 250 - 350      | 1 - 2          |
| 14 | Schizostachyum      | Schizostachyum bracycladum.| 150           | 70 - 150       | 2 - 3          |
| 15 | Thyrsostachys        | Thyrsostachys siamensis.    | 50 - 80       | 250 - 350      | 1              |

2. Method
2.1. Material preparation
This research involved eight species of bamboo that grow in Langkat, Deli Serdang, and Serdang Bedagai. Bambu Duri (Bambusa Blumeana), Bambu Kuning (Bambusa Vulgaris), Bambu Betung (Dendrocalamus Asper), Bambu Hitam (Gigantochloa Atroviolacea), Bambu Regen (Gigantochloa Pruriens Widjaya), and Bambu Mayan (Gigantochloa Robusta Kurz) are from Deli Serdang, Bambu Kuning (Bambusa Vulgaris), Bambu Betung (Dendrocalamus Asper), Bambu Regen (Gigantochloa Pruriens Widjaya), and Bambu Mayan (Gigantochloa Robusta Kurz), are from Langkat. Bambu Kuning (Bambusa Vulgaris), Bambu Betung (Dendrocalamus Asper), Bambu Nipis (Schizostachyum Zolingeri Steud), and Bambu Lemang (Schizostachyum Bracycladum Kurz) are from Serdang Bedagai. Two weeks of drying time were conducted to all specimens before the bamboo culm cut into the test specimen. The specimens were selected from the internode and node section to see the strength difference between both sections, as the specimen section may affect the material properties of bamboo [11]. The specimens are taken randomly from the bottom, middle, or top of the bamboo culm.
2.2. Specimen and Testing
Compress and tension test specimen were made from air-dried bamboo culm. Five specimens were provided for each testing procedure. Samples are taken randomly from the bottom, middle, or top of the bamboo culm. Figure 3 shows the specimen for compression and tension test, in the internode and node section. The specimen was tested on a constant speed of 0.01 mm/s, and the test was conducted until the specimen failed as described in ISO 22157-1:2004 [12]. The specimen for tension test has a unique shape as described in ISO 22157-2:2004 [13].

Figure 3. Specimen for compressive and shear test.

Figure 4 shows the conditions when the specimens test conducted. Figure 5a shows when the compression test specimen is tested on a pressing machine at a constant speed until the maximum load is reached and damage to the specimen occurs. Figure 5b shows failure starts to occur in the thinner section of the tension specimen when the constant load given at the Universal Testing Machine. The maximum load for each test carried out is recorded and then the average value of each type of test is calculated to determine the Compressive and Tensile Strength of each species of eight species of bamboo that grows in Langkat, Deli Serdang, and Serdang Bedagai.
3. Result and Discussion
The average value of Compressive and Tensile Strength from all bamboo species based on the test results is reported in Table 3.

| Origin          | Species                      | Test Condition | Compressive Strength (MPa) | Tensile Strength (MPa) |
|-----------------|------------------------------|----------------|---------------------------|------------------------|
| Deli Serdang    | Dendrocalamus Asper          | Node           | 42.52                     | 60.21                  |
|                 |                              | Internode      | 46.46                     | 208.19                 |
|                 | Bambusa Vulgaris             | Node           | 40.09                     | 64.28                  |
|                 |                              | Internode      | 41.99                     | 175.85                 |
|                 | Gigantochloa Pruriens widjaja| Node           | 31.62                     | 54.02                  |
|                 |                              | Internode      | 46.58                     | 182.93                 |
|                 | Gigantochloa Robusta Kurz    | Node           | 35.35                     | 42.09                  |
|                 |                              | Internode      | 41.24                     | 219.62                 |
|                 | Bambusa Blumeana             | Node           | 35.12                     | 45.13                  |
|                 |                              | Internode      | 45.38                     | 192.27                 |
|                 | Gigantochloa Atroviolacea    | Node           | 34.87                     | 37.97                  |
|                 |                              | Internode      | 32.12                     | 125.98                 |
| Langkat         | Dendrocalamus Asper          | Node           | 63.77                     | 93.14                  |
|                 |                              | Internode      | 62.45                     | 210.17                 |
|                 | Bambusa Vulgaris             | Node           | 48.99                     | 46.99                  |
|                 |                              | Internode      | 52.83                     | 186.13                 |
|                 | Gigantochloa Pruriens widjaja| Node           | 38.61                     | 52.72                  |
|                 |                              | Internode      | 58.24                     | 218.33                 |
|                 | Gigantochloa Robusta Kurz    | Node           | 47.01                     | 53.49                  |
|                 |                              | Internode      | 43.12                     | 198.05                 |
| Serdang Bedagai| Dendrocalamus Asper          | Node           | 41.40                     | 82.60                  |
|                 |                              | Internode      | 45.23                     | 202.96                 |
|                 | Bambusa Vulgaris             | Node           | 53.16                     | 60.95                  |
|                 |                              | Internode      | 45.09                     | 165.48                 |
|                 | Schizostachyum Zollingeri Steud | Node       | 67.44                     | 60.35                  |
|                 |                              | Internode      | 73.49                     | 228.89                 |
|                 | Schizostachyum               | Node           | 25.94                     | 73.23                  |
|                 | Bracycladum Kurz             | Internode      | 34.22                     | 230.09                 |
3.1. Compressive strength

From Compression Test shows that internode specimens and node specimens' results are not significantly different. The strength difference between internode and node specimens is 1.32 MPa at the minimum and 19.60 MPa at maximum. Previous studies show that the difference was at 1.77 MPa[11] and 2.30 MPa[14]. Highest Compressive Strength obtained from Bambu Betung (Dendrocalamus Asper) that grows on Langkat Regency at 62.45 MPa (internode), and 63.77 Mpa (node), while lowest Compressive Strength obtained from Bambu Lemang (Schizostachyum Bracycladum Kurz) that grows on Serdang Bedagai Regency at 34.22 MPa (internode), and 25.94 MPa (node). Comparison in Compressive strength of Dendrocalamus Asper, Bambusa Vulgaris, Gigantochloa Pruriens Widjaya, and Gigantochloa Robusta Kutz from the three regencies shows that specimens that taken from Langkat Regency have the highest Compressive Strength, as shown in Figure 5. Previous research on Bambu Betung (Dendrocalamus Asper) from Perak, Malaysia [15] reported that the average Compressive Strength of internode specimens was 63.21 MPa. Malaysia is a neighbor country of Indonesia with the Perak and eastern region of Sumatera Utara only separated by Malacca Strait. This previous research also recorded that the average Compressive Strength of Bambu Kuning (Bambusa Vulgaris) species was 67.62 MPa.

![Figure 5. Compressive strength comparison.](image-url)
3.2. Tensile strength
Different from the result of compressive strength testing where the average result of internode and node testing did not differ significantly, the tensile strength test result showed that there was a significant difference between the result of the internode and node specimen testing. Highest Tensile Strength from internode specimens obtained from Bambu Lemang (Schizostachyum Bracycladum Kurz) that grows on Serdang Bedagai Regency at 230.09 MPa, while lowest obtained from Bambu Hitam (Gigantochloa Atroviolacea) that grows on Serdang Bedagai Regency at 125.98 MPa. From node specimens, Highest Tensile Strength from internode specimens obtained from Bambu Betung (Dendrocalamus Asper) that grows on Langkat Regency at 93.14 MPa, while lowest obtained from Bambu Hitam (Gigantochloa Atroviolacea) that grows on Deli Serdang Regency at 37.97 MPa. Figure 6 shows the comparison in Tensile Strength of Dendrocalamus Asper, Bambusa Vulgaris, Gigantochloa Pruriens Widjaya, and Gigantochloa Robusta Kurz from the three regencies.

![Tensile strength comparison](image)

Figure 6. Tensile strength comparison.

A significant difference between the results of the tensile strength of the internode and node specimens conducted in this study in accordance with the previous research, which states that the tensile strength of the node specimens is only 30% of the internode specimens [16]. The use of bamboo tensile strength in the design of truss structure must pay attention to the presence of nodes because generally there are nodes on the bamboo culm used in tension members of the truss. Unless it can be proven well that the culm used in the tension member of the truss to be free of nodes.
3.3. Physical failure

Figure 7 shows the condition of the internode and node specimen after each test. For compression test, end bearing compression failure occurs in the node specimens, while vertical crack known as splitting failure occurs in the internode specimens as shown in Figure 6a. These two types of physical failure also found in compression test in mechanical properties study of Bambusa Pervariabilis (Kao Jue) and Phyllostachys Pubescens (Mao Jue) [17], but in the study, end bearing failure occurred in specimens with high moisture content, while splitting failure occurred in specimens with low moisture content. In other mechanical properties study with Gigantochloa Scortechinii bamboo samples, end bearing failure occurred in thick specimens, while splitting failure occurred in thin specimens [18].

Figure 7. Physical failure in compression and tensile specimens.

Grains parallel to the culm axis fails at the reduced area in the tensile test specimen. Internode specimens show a similar failure pattern to node specimens as shown in Figure 7b. Some other study also states that tensile failure occurred in the reduced area because the area has the smallest cross-section area along the specimen’s body [19][20].

4. Conclusion

Internode average Compressive Strength for a species with different growing areas give varied results. Bambu Betung (Dendrocalamus Asper) compressive strength is maximum at 62,45 MPa and minimum at 45,23 MPa. Bambu Kuning (Bambusa Vulgaris) strength is maximum at 52,83 MPa and minimum at 41,99 Mpa. Bambu Regen (Gigantochloa Pruriens Widjaya) strength is maximum at 58,21 MPa and minimum at 46,58 Mpa. And Bambu Mayan (Gigantochloa Robusta Kurz) strength is maximum at 43,12 MPa and minimum at 41,24 MPa. The same variation also occurs in tensile strength. Respectively, the maximum and minimum node specimens Tensile Strength for Bambu Betung (Dendrocalamus Asper, Bambu Kuning (Bambusa Vulgaris), Bambu Regen (Gigantochloa Pruriens Widjaya), and Bambu Mayan (Gigantochloa Robusta Kurz) are (93,14 / 60,21), (64,28 / 46,99), (54,02 / 52,72), and (53,49 / 42,09) MPa. Smaller variations may be obtained if the specimens are not taken randomly, but by taking from the bottom, middle, and top of the bamboo culm.

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