Mechanical Properties of Culm Bamboo Endemic Banyuwangi Based on Tensile Strength Test

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ABSTRACT
The decreasing number of quality wood in accordance with the wood class as stipulated by the Indonesian Timber Construction Regulation (PKKI) requires the industry to innovate in providing construction materials from nature that are equivalent to wood. One of the natural materials with large numbers is bamboo material. One area with large number of potential is Banyuwangi. Bamboo is a material that can be used as a construction material in the field of civil engineering which has strength but cannot be used optimally. One of these limitations is the bamboo character itself. The natural character of smooth, cylindrical bamboo, but inconsistent in size, large at the base and smaller at the end. The use of bamboo as a construction material requires further research, especially on the characteristics of the building structure. One of them is tracing the characteristics of bamboo from the tensile strength and compressive strength of bamboo. This research aims to map the types and potentials of endemic bamboo in the Banyuwangi area based on their properties of tensile strength and compressive strength. Based on the results of tensile strength, Ater bamboo has the highest tensile strength followed by Ori bamboo, Tutul bamboo, Manggong bamboo, Andong bamboo, Hitam bamboo, Olet bamboo, Apus bamboo, Legi bamboo, Petung bamboo, Ampel bamboo and Jawa bamboo. Based on the tensile strength data and combined with the thickness and bamboo diameter, Petung bamboo, Tutul bamboo, Ampel bamboo, Ater bamboo and Kuning bamboo, it becomes a 5 priority of bamboo in determining construction materials and making laminated bamboo. For the selection of construction materials that withstand pressure, Batu bamboo, Pecut bamboo, Ater bamboo, Legi bamboo, Hitam bamboo and Jawa bamboo are priority choices. This is based on the compressive strength value of the material.

Keywords: bamboo, endemic, construction, material, tensile strength

1. INTRODUCTION

One of the natural materials with large numbers is bamboo material. One area with large number of potential is Banyuwangi. Banyuwangi has many bamboo varieties, where the old bamboo species are in the Alas Purwo ancient forest area. So far it is estimated that there are more than 143 types of bamboo in Indonesia, in Java there are only about 60 types of bamboo and 9 types of bamboo are endemic [1]. Java has various types of bamboo which are spread from west to east, especially in the Bogor Botanical Gardens, Cibodas Botanical Gardens, Sukabumi, Sunda, Banten, Semarang, Yogyakarta, Jember, Purwodadi Botanical Gardens, Mount Halimun National Park, Alas Purwo National Park. Several types are bamboo introduced from other islands such as Sumatra, Kalimantan, Sulawesi, Bali, Madura, Maluku, and Papua [1]. Bamboo is a material that can be used as a construction material in the field of civil engineering which has strength but cannot be used optimally. One of these limitations is the bamboo character itself. The natural character of smooth, cylindrical bamboo, but inconsistent in size, large at the base and smaller at the end [2]. Bamboo plants both on a small and large scale have a convincing economic value. The community culture uses bamboo in various life activities so that bamboo can be categorized as a Multipurpose Tree Species (MPTS) [1]. The use of bamboo as a construction material requires further research, especially on the characteristics of the building structure. One of them is tracing the characteristics of bamboo from the tensile strength and compressive strength of bamboo. The potential of Indonesian bamboo, especially the bamboo endemic Banyuwangi, can be developed as a potential bamboo substitute for wood. In developing this potential, it is necessary mapping the properties of the bamboo and then manipulation it into bamboo blocks or commonly known as laminated bamboo.
The property of bamboo is potency to substituting wood. The potential of bamboo when converted into laminate has the potential to replace the function of wood [3].

**Our Contribution**

This research aims to map the types and potentials of endemic bamboo in the Banyuwangi area based on their properties of tensile strength and compressive strength. Furthermore, the mapping results are used as the basis for the innovation of laminated bamboo.

2. BACKGROUND

2.1. Understanding Bamboo

Bamboo in the world is recorded to grow in more than 75 countries and there are 1250 species of bamboo, then the quantity of bamboo in South and Southeast Asia is approximately 80% of the total bamboo in the world. The genus Bambusa has the largest number of species, mainly distributed in tropical areas, including Indonesia [3].

Unlike the test results in the previous Internodia section, on the part Nodia has a very brittle behavior. The bamboo in Nodia's part does not experience melting after reaching its critical strain [4]. Most of the bamboo species are hollow but a solid bamboo is not too far from hollow one in terms of mechanical properties and can equally be utilized for construction work [5].

Bamboo is the fastest growing plant in the world having growth up to 60 cm or more in a day. Bamboo has social, economic and cultural significance and is used extensively for building materials along with thousands of uses [4]. Example of a bamboo forest is a bamboo forest on the slopes of Mount Raung, as shown in Figure 1.

![Figure 1 Rampal bamboo forest](image)

2.2. Bamboo Characteristics

Bamboo fibre mechanical properties have been studied showing values of strength up to 800 MPa and E-Modulus up to 40 GPa, proving their excellent tensile properties. Therefore, we focus on making this fibre suitable as reinforcement in composite materials [5].

Bamboo is the main competitor for wood besides reinforced concrete, masonry and steel, which are artificial materials considered to be of superior quality. Many regions in the world in the 21st century have competed to use bamboo. The use of bamboo changes perceptions and allows the use of bamboo to reduce carbon emissions, environmental safety and quality of life in the future [9].

Bamboo has many advantages with a character that good quality for construction. The use of bamboo is one step of nature conservation. Examples of bamboo with superior mechanical properties include the Bambusa Vulgaris (Ampel bamboo), Dendrocalamus Asper (Petung bamboo), and Gigantochloa Scortechinii [8].

The values of Modulus of Rupture (MOR) and Modulus of Elasticity (MOE) of Dendrocalamus Asper (Petung bamboo) increased from bottom to top of the stem. There is a correlation between the microstructure and the material properties of bamboo. Density and bending strength increase linearly with fiber volume fraction. The volume fraction of fibers increases from the bottom to the top of the stem [13].

Besides Ampel and Petung bamboos, Andong bamboo (Gigantochloa pseudoarundinacea) is a bamboo species with good quality for construction material. Andong bamboo (Gigantochloa pseudoarundinacea) is widely grown in West Java, Indonesia, and has an important role in the rural economy. The lower and middle section of Andong bamboo rods are suitable for laminated bamboo and the upper part is used as raw material for making strandboard [10]. Bamboo is a rapidly renewable material that is widely used as a construction material. Engineering
bamboo products are obtained from processing raw bamboo into composite and laminated bamboo. Further research is needed in perfecting laminated bamboo products [11]. Bamboo is an abundant and sustainable natural material that grows in tropical and subtropical areas. Fast growth, short life cycle, and higher mechanical strength than wood, bamboo, developed as a complement and substitute for wood. The bamboo rods are cylindrical with holes, so it is impossible to get beam and plank directly [12]. Bamboo density was directly correlated with all the mechanical properties of bamboo, while moisture content only correlated with the modulus of rupture (MOR). The value of stem wall thickness is related to the mechanical properties of bamboo, while the diameter of the stem is only related to the modulus of rupture and modulus of elasticity [14]. Generally, bamboo species grow for 5-7 years. This is the maximum age of the clump if not felled. Above 7 years of age there is no significant growth including the addition of clumps [15]. Density has a significant effect on the mechanical properties of scrimber bamboo. Long-term water absorption was also carried out to analyze the weight obtained by scrimber bamboos of different densities and the results indicated that the density of the specimens affected water absorption [17].

3. METHODOLOGY

The bamboo material testing method is very important used in experimental studies that are well-defined and allow the isolation of factors affecting the performance and behavior of bamboo materials [16]. Physical properties test according to ISO 22157-1: 2004 [18] with sample size 2.5 x 2.5 x 1 cm. An example of a test object is shown in Figure 1. The moisture content test (KA) was carried out by measuring initial weight of the bamboo (BA) and then placing it in an oven with a temperature of 103 ± 2°C for 24 hours then calculating its weight (BO). The amount of water content can be calculated using Equation 1. The density of bamboo is the mass (ρ) of bamboo, which is the weight of bamboo in air dry conditions (BKU) compared to the volume of bamboo in air dry conditions (VKU). The value of density can be obtained using Equation 2.

\[ KA = \frac{BA - BO}{BO} \times 100\% \]  

(1)

\[ \rho = \frac{BKU}{VKU} \]  

(2)

The tensile and compressive tests were conducted according to ISO 22157-1: 2004 [18]. To accommodate the time to failure requirement, loading speeds were adjusted to 1 mm/min for tensile testing, and 2 mm/min for compressive testing.

![Figure 3 Tensile strength test sample](image)

![Figure 4 Compression strength test sample](image)

Where σ represents the tensile strength or compressive strength, \(F_{\text{max}}\) is the maximum force applied to the specimens during the test (N), b, is the width of the specimens (mm), and t is the thickness of the specimens (mm). Tensile strength test sample is shown in Figure 3 and compression strength test sample is shown in Figure 4.

4. RESULTS

There are 23 types of endemic bamboo in Banyuwangi that have been mapped and scattered in the southwestern region of Banyuwangi. The results of mapping carried out on types and sizes are presented in Table 1.
The long distance nodia have the Manggong bamboo, Tutul bamboo, Andong bamboo, Jawa bamboo and Batu bamboo. Meanwhile, the farthest distance between the nodia are Manggong bamboo, Tutul bamboo, Andong bamboo, Jawa bamboo and Batu bamboo.

Table 1 Summary of bamboo dimension endemic Banyuwangi

| No | Material                              | Diameter (cm) | Thickness (cm) | Internodia Distance (cm) |
|----|---------------------------------------|---------------|----------------|--------------------------|
| 1. | Tutul Bamboo (Bambusa maculata)       | ± 9.00 - 9.35 | ± 0.90 - 1.50  | ± 45.50 - 55.52          |
| 2. | Petung/Betung Bamboo (Dendrocalamus asper) | ± 11.0 - 12.05 | ± 1.00 - 3.50  | ± 30.00 - 50.00          |
| 3. | Ori/Duri Bamboo (Bambusa arundinacea) | ± 8.50 - 8.90 | ± 0.70 - 3.00  | ± 20.00 - 31.00          |
| 4. | Hitam/Wulung Bamboo (Gigantochloa atroviolacea) | ± 8.20 - 9.00 | ± 0.70 - 2.00  | ± 37.00 - 42.00          |
| 5. | Ater Bamboo (Gigantochloa atter)      | ± 8.25 - 9.30 | ± 0.80 - 2.00  | ± 30.00 - 38.00          |
| 6. | Ampel Bamboo (Bambusa vulgaris)       | ± 8.70 - 9.10 | ± 0.70 - 1.20  | ± 34.00 - 42.30          |
| 7. | Apus/Tali Bamboo (Gigantochloa apus)  | ± 6.20 - 6.50 | ± 0.50 - 1.00  | ± 20.00 - 30.70          |
| 8. | Jawa/Jajang Bamboo (Gigantochloa hasskarliana) | ± 6.75 - 8.00 | ± 0.60 - 1.60  | ± 46.00 - 50.20          |
| 9. | Legi Bamboo (Gigantochloa verticilata) | ± 7.50 - 8.35 | ± 0.70 - 1.30  | ± 32.00 - 40.05          |
| 10. | Pagar Bamboo (Bambusa Multiplex Raeusech) | ± 2.00 - 2.48 | ± 1.00 - 1.20  | ± 20.00 - 25.00          |
| 11. | Kuning Bamboo (Bambusa vulgaris var. striata) | ± 8.45 - 9.00 | ± 0.85 - 1.50  | ± 29.00 - 40.15          |
| 12. | Gesing Bamboo (Bambusa spinosa)       | ± 9.00 - 9.70 | ± 0.75 - 1.40  | ± 35.20 - 50.00          |
| 13. | Benel Bamboo                          | ± 6.00 - 6.80 | ± 0.70 - 1.20  | ± 23.25 - 37.00          |
| 14. | Wuluh Bamboo (Schizostachyum iratien) | ± 4.50 - 5.67 | ± 0.65 - 1.00  | ± 33.00 - 40.50          |
| 15. | Batu Bamboo (Dendrocalamus strictur)  | ± 4.55 - 6.10 | ± 0.50 - 0.90  | ± 40.20 - 50.00          |
| 16. | Mayan Bamboo (Gigantochloa Robusta)   | ± 6.25 - 7.15 | ± 0.60 - 1.15  | ± 36.00 - 49.20          |
| 17. | Rampal Bamboo (Schizostachyum zollingeri) | ± 6.45 - 7.35 | ± 0.40 - 0.70  | ± 38.00 - 45.25          |
| 18. | Andong Bamboo (Gigantochloa psedoarundinaceae) | ± 7.50 - 8.27 | ± 0.70 - 1.10  | ± 45.00 - 53.50          |
| 19. | Pecut Bamboo                          | ± 4.15 - 5.00 | ± 0.50 - 0.90  | ± 30.00 - 35.20          |
| 20. | Olet Bamboo                           | ± 6.80 - 7.45 | ± 0.50 - 1.00  | ± 38.00 - 47.50          |
| 21. | Manggong Bamboo (Bambusa jacobssii)   | ± 7.20 - 8.05 | ± 0.70 - 1.20  | ± 48.25 - 56.15          |
| 22. | Gading Bamboo (Schizostachyum brachycladum) | ± 3.80 - 5.25 | ± 0.90 - 1.35  | ± 21.00 - 27.25          |
| 23. | Jepang Bamboo (Pseudosasa japonica)   | ± 3.00 - 5.25 | ± 0.50 - 0.85  | ± 30.35 - 55.60          |

Figure 5 Physical examination of bamboo

Figure 5 shown physical examination of bamboo and result of physical examination summarized on

Table 1. Table 1 shown that Petung/Betung bamboo have the largest dimensions and thickest culm thickness. The culm thickness bamboo showed that Petung bamboo had the thickest culm bamboo followed by Ori bamboo, Ater bamboo, Hitam bamboo and Tutul bamboo.

The culm diameter showed that Petung bamboo had the highest diameter followed by Gesing bamboo, Tutul bamboo, Ampel bamboo, Ater bamboo and Kuning bamboo. Meanwhile, the farthest distance between the nodia are Manggong bamboo, Tutul bamboo, Andong bamboo, Jawa bamboo and Batu bamboo. The long distance nodia have the advantage of the strength of bamboo. This is because the nature of the nodia weakens the strength of bamboo [3]. With a long distance from the nodia, this type of bamboo can be used for building construction. In addition, diameter and thickness contribute to the efficiency of the number of culm layers of bamboo.

Figure 6 shown specimen of tensile strength test with length of specimen 26 cm and grip portion of 7 cm on each side of the specimen. Figure 7 shows specimen compression test with sample height 20 cm and distance of nodia 10 cm each side.
The properties of the Banyuwangi endemic bamboo material are shown in Table 2. The results of tensile strength and compressive strength were obtained from testing using the Universal Testing Machine. The tensile strength results showed that Ater bamboo had the highest tensile strength followed by Ori bamboo, Tutul bamboo, Manggong bamboo and Andong bamboo. 

The results of compressive strength shown that Batu bamboo has the highest compressive strength followed by Pecut bamboo, Ater bamboo, Legi bamboo, Hitam bamboo and Jawa bamboo. Grouping of bamboo based tensile strength properties are shown in Table 3-Table 6.

Table 2 Summary of bamboo properties endemic Banyuwangi

| No | Material                                      | Density (gr/cm$^3$) | Water Content (%) | Tensile Strength (MPa) | Compressive Strength (MPa) |
|----|---------------------------------------------|---------------------|-------------------|------------------------|--------------------------|
| 1. | Tutul Bamboo (Bambusa maculata)             | 0.99                | 77.22             | 340.26                 | 39.73                    |
| 2. | Petung/Betung Bamboo (Dendrocalamus asper)  | 0.99                | 33.12             | 284.69                 | 38.42                    |
| 3. | Ori/Duri Bamboo (Bambusa arundinacea)       | 0.98                | 78.12             | 342.87                 | 42.18                    |
| 4. | Hitam/Wulung Bamboo (Gigantochloa atroviolacea) | 0.99           | 83.57             | 306.00                 | 45.85                    |
| 5. | Ater Bamboo (Gigantochloa atter)            | 0.99                | 55.00             | 370.34                 | 47.60                    |
| 6. | Ampel Bamboo (Bambusa vulgaris)             | 0.74                | 49.05             | 278.05                 | 41.49                    |
| 7. | Apus/Tali Bamboo (Gigantochloa apus)        | 0.97                | 94.14             | 291.27                 | 37.28                    |
| 8. | Jawa/Jajang Bamboo (Gigantochloa hasskarliana) | 0.98            | 52.82             | 284.19                 | 45.60                    |
| 9. | Legi Bamboo (Gigantochloa verticilata)      | 0.54                | 54.33             | 287.75                 | 46.67                    |
| 10. | Pagar Bamboo (Bambusa Multiplex Raeusech)   | 0.98                | 95.88             | -                      | -                        |
| 11. | Kuning Bamboo (Bambusa vulgaris var. striata) | 0.69              | 29.40             | 284.24                 | 28.42                    |
| 12. | Gesing Bamboo (Bambusa spinosa)             | 0.75                | 48.33             | 251.30                 | 34.31                    |
| 13. | Benel Bamboo                                | 0.77                | 97.58             | 315.87                 | 45.44                    |
| 14. | Wuluh Bamboo (Schizostachyum iraten)        | 0.66                | 85.59             | 268.20                 | 36.98                    |
| 15. | Batu Bamboo (Dendrocalamus strictur)        | 0.83                | 68.10             | 261.27                 | 53.16                    |
| 16. | Mayan Bamboo (Gigantochloa Robusta)         | 0.82                | 90.00             | 269.60                 | 33.97                    |
| 17. | Rampal Bamboo (Schizostachyum zollingeri)   | 0.85                | 94.27             | 266.21                 | 44.72                    |
| 18. | Andong Bamboo (Gigantochloa psedoarundinaceae) | 0.59            | 94.60             | 319.36                 | 31.12                    |
| 19. | Pecut Bamboo                                | 0.99                | 64.72             | 257.95                 | 52.44                    |
| 20. | Olet Bamboo                                 | 0.94                | 97.28             | 302.74                 | 42.17                    |
| 21. | Manggong Bamboo (Bambusa jacobsii)          | 0.72                | 80.00             | 321.66                 | 35.05                    |
| 22. | Gading Bamboo (Schizostachyum brachycladum) | 0.97                | 86.39             | -                      | 35.99                    |
| 23. | Jepang Bamboo (Pseudosasa japonica)         | -                  | -                 | -                      | -                        |

Group 1 is a bamboo group with ranged tensile strength values 341-370 MPa.

Table 3 Group 1 bamboo

| No | Material                                      | Group 1/G1 (341-370 MPa) |
|----|---------------------------------------------|---------------------------|
| 1. | Ater Bamboo (Gigantochloa atter)             |                           |
| 2. | Ori/Duri Bamboo (Bambusa arundinacea)       |                           |
| 3. | Tutul Bamboo (Bambusa maculata)             |                           |

Group 2 is a bamboo group with ranged tensile strength values 311-340 MPa.

Table 4 Group 2 bamboo

| No | Material                                      |
|----|---------------------------------------------|
| 1. | Benel Bamboo                                |
| 2. | Andong Bamboo (Gigantochloa psedoarundinaceae) |
| 3. | Manggong Bamboo (Bambusa jacobsii)          |

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Figure 7 Compression test on bamboo (a) compression test process (b) compression test specimen
Group 3 is a bamboo group with ranged tensile strength values 281-310 MPa.

| No | Group 3/G3 (281-310 MPa) |
|----|-------------------------|
| 1. | Ampel Bamboo (Bambusa vulgaris) |
| 2. | Jawa/Jajang Bamboo (Gigantochloa atter) |
| 3. | Kuning Bamboo (Bambusa vulgaris var. striata) |
| 4. | Petung/Betung Bamboo (Dendrocalamus asper) |
| 5. | Legi Bamboo (Gigantochloa verticilata) |
| 6. | Apus/Tali Bamboo (Gigantochloa apus) |
| 7. | Olet Bamboo |
| 8. | Hitam/Wulung Bamboo (Gigantochloa atroviolacea) |

Table 5 Group 3 bamboo

Group 4 is a bamboo group with ranged tensile strength values 250-280 MPa. Bamboo visualisation shown in Figure 8 and Error! Reference source not found.

| No | Group 4/G4 (250-280 MPa) |
|----|-------------------------|
| 1. | Gesing Bamboo (Bambusa spinosa) |
| 2. | Pecut Bamboo |
| 3. | Batu Bamboo (Dendrocalamus strictur) |
| 4. | Rampal Bamboo (Schizostachyum zollingeri) |
| 5. | Wuluh Bamboo (Schizostachyum iratenn) |
| 6. | Mayan Bamboo (Gigantochloa Robusta) |

Table 6 Group 4 bamboo

Figure 8 Bamboo cross section
5. CONCLUSION

Mapping results for Banyuwangi endemic bamboos obtained 23 types of bamboo spread from south to west Banyuwangi. Based on the mapping, information was obtained about the strength of each type of bamboo. Based on the results of tensile strength, Ater bamboo has the highest tensile strength followed by Ori bamboo, Tutul bamboo, Manggong bamboo, Andong bamboo, Hitam bamboo, Olet bamboo, Apus bamboo, Legi bamboo, Petung bamboo, Ampel bamboo and Jawa bamboo. Based on the tensile strength data and combined with the thickness and bamboo diameter, Petung bamboo, Tutul bamboo, Ampel bamboo, Ater bamboo, Kuning bamboo, Ori bamboo, Hitam bamboo, Legi bamboo, Andong bamboo, Manggong bamboo, Jawa bamboo and Olet bamboo, it becomes a priority in determining construction materials and making laminated bamboo.

For the selection of construction materials that withstand pressure, Batu bamboo, Pecut bamboo, Ater bamboo, Legi bamboo, Hitam bamboo and Jawa bamboo are priority choices. This is based on the compressive strength value of the material. Based on the preliminary test results, it has obtained material priority that can be used as a choice of construction materials and materials for laminated bamboo. Furthermore, further testing is needed, especially testing the characteristics of bamboo after undergoing the curing process.

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