A Study of the Physical-Mechanical Properties of Bamboo in Indonesia

Efa Suriani
Science and Technology Faculty, Sunan Ampel Islamic State University, Surabaya, Indonesia

Keywords: Physical Properties, Mechanical Properties, Bamboo

Abstract: An architect or engineer, before making a design, must understand the characteristics, as well as the strength, workability, and cost efficiency, of the materials to be used. An ecological material such as bamboo is a sustainable and environmentally friendly material. Therefore, a study of the physical-mechanical properties of bamboo, especially the bamboo in Indonesia, needs to be done. This research used a qualitative approach and field observations. The data were collected through literature studies. The data were analyzed descriptively, and conclusions were drawn from the analysis results. The results of the study show varied properties depending on the type, length of drying of the sample tested, position of the sample of bamboo stems taken, and location of the bamboo harvesting. The results also show a significant relationship between the physical properties and the mechanical properties. The physical properties determine the mechanical properties of bamboo. The type of bamboo that has a high strength, based on the surveys in the field, is Petung bamboo. This is in line with the results of the research conducted. In addition, the mechanical properties of bamboo will increase with the increase in the density of sclerenchyma fibers. In other words, sclerenchyma fibers affect the strength of bamboo. Therefore, it is necessary to do further research on the chemical properties of various types of bamboo existing in Indonesia.

1 INTRODUCTION

An architect or engineer, before making a design, must understand the characteristics, as well as the strength, workability, and cost efficiency, of the material to be used. The construction materials used in Indonesia vary, for example, metal or iron, concrete or reinforced concrete, and wood (Tanubrata, 2015).

The decrease in natural resources and the deteriorating environmental impacts necessitate the existence of sustainable and inexpensive materials (Mustakim et al., 2009). Bamboo is a material that falls into this category. It is an alternative ecological material to wood and has its potential and challenges (Suriani, 2017). Ecology is the study of the interconnection between living things such as animals, plants, and humans and their environment. An ecological material is a material that has a positive impact on the environment. A challenge is present, namely bamboo material will disappear from the community if it is not utilized in the culture or daily life of the community. Therefore, examining the physical-mechanical properties of bamboo, with and without preservation, especially the bamboo in Indonesia, in order to better recognize the characteristics of bamboo is important. Thus, bamboo is suitable to use as a building construction material.

The purpose of this article was to obtain an overview of the physical-mechanical properties of bamboo, especially the bamboo in Indonesia, with and without preservation, through a laboratory study. It also aimed to compare the uses of bamboo by bamboo entrepreneurs for building construction works. The findings are expected to increase the understanding of the characteristics of bamboo in Indonesia.

According to J. J. Janssen (1981), the factors affecting the strength of bamboo are as follows:

Suriani, E.
A Study of the Physical-Mechanical Properties of Bamboo in Indonesia.
DOI: 10.5220/0008904600002481
In *Proceedings of the Built Environment, Science and Technology International Conference (BEST ICON 2018)*, pages 154-162
ISBN: 978-989-758-414-5

a. water content, with the tensile strength of bamboo decreasing if the water content increases;
b. the transverse direction of bamboo, with the maximum tensile strength of the outer part of the bamboo stem being higher than that of the other parts—the maximum high tensile strength is proportional to the high percentage of sclerenchyma fibers; and
c. the presence or absence of nodia of bamboo. The inter-nodia section of bamboo is oriented towards the axial axis, while the nodia of the cells leads to the transverse axis. The section of the segment has a lower strength than that of non-segmented bamboo stems.

According to Morisco (1999), nodia is the weakest part of the tensile force parallel to the axis of the bamboo stem because some bamboo fibers turn, and in nodia the direction of the force is no longer parallel to all fibers. In general, nodia has the capacity to bear ineffective loads for strength or deformation. However, nodia prevents local buckling, which is important in designing bamboo as a compressive element or column.

1.1 Physical Properties

According to Wulandari (2014), knowing the physical properties such as moisture content, density, and shrinkage is important to overcome defects due to cracks when bamboo is used. Bamboo processing must be performed when the bamboo has low moisture content and high density, so that it does not undergo any dimensional change due to high shrinkage. Bamboo is a hygroscopic material, that is, it has an affinity for water and is able to absorb and remove water depending on the temperature and humidity.

According to Liese in Wulandari (2014), the moisture content in the stem differs between longitudinal and transverse direction. For transverse direction, the inside is higher than the outside. It depends on age, time of felling, and type of bamboo. One-year-old bamboo's moisture content is relatively high (approximately 120–130% of the base or tip). Bamboo aged 3–4 years has moisture content in base part higher than that in the end. When logging in a dry season, the moisture content can be at its minimum.
The internode or inter-bamboo section has lower moisture content than the nodia part. The higher the density of bamboo, the smaller the moisture content.

Moisture is the amount of water contained in a piece of bamboo, expressed as a percentage of its dry weight. Based on (ISO 22157-2, 2004) regarding laboratory manuals: *Bamboo-Determination of Physical and Mechanical Properties-Part1: Laboratory Manual*", the moisture content (MC) obtained from a test object that is 25 mm high and 25 mm wide and has wall thickness of t mm (according to the thickness of the bamboo) can be calculated by the formula below:

$$MC = [(m - m_0) / m_0] \times 100, \qquad (1)$$

where

MC	=	moisture content (%),
m	=	the mass of the test piece before drying (gram), and
m_0	=	the mass of the test piece after drying (gram).

The water content required under (ISO 22157-1, 2004) is quite high, reaching 12%. This is difficult because Indonesia has very high relative humidity. To achieve moisture content of 12%, special treatment such as drying (not in direct sunlight) or using oven (with an oven or heat from a lamp) is needed.

Bamboo density is the ratio of the dry mass of a furnace to an object with a standard mass or volume of water in the same volume. The standard object used is water at 4 °C with a density of 1 gr/cm^3. According to Liese in (Wulandari, 2014), bamboo density ranges from 0.5 to 0.9 grams per cubic centimeter. The outer part of bamboo has higher density than the inside. In the longitudinal direction the density increases from the base to the end. Bamboo density can be calculated by the formula below:

$$\rho = (m / v) \times 10^6, \qquad (2)$$

where

P	=	density, mass divided by volume, in kg/m^3,
M	=	mass, in g, of the test piece, oven-dry, in kg, and
V	=	green volume of the test piece, in mm^3.

1.2 Mechanical Properties

According to Sumarni (2010), mechanical properties are the ability of a material to hold forces or loads from the outside. Mechanical properties include the tensile strength; compressive strength; shear strength; flexural strength; stiffness; violence; and strength split.

According to Hazra (2017), a mechanical property is a property that deals with changes in the shape of an object when there is an object resistance due to the influence of the external forces acting on it. This property is important to know the strength of bamboo when used as a construction material.

Mechanical properties of bamboo include the following.

1. Tensile Strength Parallel to Grain

According to Pathurahman (1998) in (Hazra, 2017), tensile strength parallel to fiber is a measure of bamboo's strength in resisting forces that tend to cause the bamboo to separate from one another.

(Morisco, 1999), in his research from 1994 to 1999, examined the tensile strength of Ori and Petung bamboo compared to the stress reinforcement in the surrounding market of around 2400 kg/cm^2. Specimens were taken from the skin of Ori bamboo and the inside skin of Petung bamboo. Parts were taken in parts without internodes. The results are listed in Tables 1 and 2 below.

Table 1. Tensile Strength of Average Bamboo

Parts	Types of Bamboo				
	Tensile Strength (kg/cm^2)				
	Petung	Tutul	Galah	Tali	Dendeng
Base	2278	2394	1920	1442	2214
Middle	1770	2917	3350	1368	2513
End	2080	4488	2324	1735	3411

Source: (Morisco, 1999)

Table 2. Tensile Strength of Average Bamboo (Dry Oven)

Types of Bamboo	Tensile Strength in Internode (kg/cm^2)	Tensile Strength in node (kg/cm^2)
Ori	2910	1280
Petung	1900	1160
Hitam	1660	1470
Legi	2880	1260
Tutul	2160	740
Galah	2530	1240
Tali	1515	552

The tensile strength of Ori bamboo skin is quite high, reaching 5000 kg/cm^2 or 470 MPa, about twice the tensile stress of steel reinforcement, 240 MPa, while the average tensile strength of Petung bamboo is also higher, with only one specimen being lower. Round-shaped like a pipe, bamboo has a moment of high humidity, making it to be good for holding the bending moment. This was evident in the Yogyakarta earthquake on May 26, 2006, where a house with a bamboo or wood frame system was found to remain intact.

According to the 1995 International Network for Bamboo and Rattan (INBAR) in (Permana, 2017), the tensile strength of the cross-section is divided into two parts, namely

a. the inside, which is approximately 70% of the thickness of the stem, with tensile strength of 70.6 MPa and
b. the outside, which is approximately 30% of the thickness of the stem, with tensile strength of 205.2 MPa.

2. Compressive Strength Parallel to Grain

According to Hazra (2017), compressive strength parallel to fiber is the strength of bamboo to retain the force from the outside in the direction parallel to the fiber which tends to shorten or compress the bamboo part together. Janssen (1981) stated that factors that affect the compressive strength of parallel fibers include the following:

a. moisture content—low moisture content increases the compressive strength of parallel fibers in bamboo;
b. the position of the specimen in the bamboo—the closer to the end the specimen position in the bamboo stem is, the greater the compressive strength parallel to the fiber;
c. specific gravity—the greater the specific gravity, the greater the compressive strength level, because the cellulose content is higher; and
d. the percentage of sclerenchyma fibers—these fibers tend to increase from the base of the stem to the tip of the stem.

Morisco (1999), in his study, tested bamboo compressive strength using bamboo inter-nodia with a length of twice its diameter, so that buckling was deemed absent (Table 3).

Table 3. Compressive Strength of Average Round Bamboo.

Parts	Types of Bamboo				
	Compressive Strength (kg/cm^2)				
	Petung	Tutul	Galah	Tali	Dendeng
Base	2769	5319	3266	2152	4641
Middle	4089	5428	3992	2880	3609
End	5479	4639	4048	3354	3238

3. Shear Strength Parallel to Grain

The shear strength parallel to fibers is bamboo's ability to resist forces which tend to cause some parts of the bamboo to shift with other adjacent parts. The higher the specific gravity, the higher the shear strength. Janssen (1981) also stated that factors that influence the parallel shear strength of fibers include the following:

a. moisture content—shear strength decreases with the increase in moisture content;
b. whether or not there are nodia (segments)—examples of bamboo specimens have nodia with higher shear strength due to the bamboo fibers of the nodia that adhere to one another; and
c. position of the test sample—the shear strength decreases from the base position to the end.

4. Flexural Strength of Bamboo

Hazra (2017) stated that flexural strength is the ability of a load-bearing material to work perpendicular to the axis extending the fiber in the middle of the material supported by both. According to Janssen (1981), knowing the flexibility or flexural strength of bamboo is very important because the use of bamboo as a construction material is only limited to curvature. Flexural strength is influenced by several factors, including moisture content; nodia (segments) availaibility; axial position in the stem; and the shape and size of the test object.

According to Tular and Sutidjan (1961) in (Morisco, 1999), the results of bamboo testing for flexural strength obtained show a strong range from 686 kg/cm^2 to 2940 kg/cm^2 and permitted voltage of 98.07 kg/cm^2.

5. Dowel-Bearing Strength

Eratodi (2014) defined dowel-bearing strength as a strong mechanical bolt property of a material determined based on the results of a test that illustrates the strong limits of the material around the hole which is pressurized by the bolt.

2 RESEARCH METHODS

This study aimed to obtain an overview of the physical-mechanical properties of bamboo, specifically the bamboo in Indonesia. This research used a qualitative approach. The data were collected through literature studies and field observations. The data were analyzed descriptively, then conclusions were obtained from the results of the study.

The chosen locations were CV Nusantara Bamboo Company, Yogyakarta, and CV. Adi Galery Bamboo, Wonosobo. The sources for the literature study included books, final assignments, and journals related to the physical-mechanical properties of bamboo or bamboo material. The data were analyzed, and the analysis results were concluded to achieve the research objectives.

3 RESULTS AND DISCUSSION

3.1 Literature Study

The results of a study related to the physical-mechanical properties of various types of bamboo are discussed first in this chapter. This information was obtained from journals, final assignments, and books. Research was first conducted on the mechanical properties of Petung bamboo, including the parallel compressive strength, the perpendicular compressive strength, the parallel shear strength, and the flexural strength of the fiber (Made Oka, 2005). The mechanical properties of Petung bamboo at average moisture content of 12.63% are described in Table 4.

Table 4. Mechanical Properties of Petung Bamboo

Sample No	Mechanical Properties (MPa)		
	Compressive Strength //	Compressive Strength ⊥	Tensile Strength //
1	50.11	45.11	421.44
2	41.80	46.74	409.51
3	58.06	61.33	375.58
	49.99	51.06	402.18
	Shear Strength //	Flexural Strength //	Elasticity
1	8.06	110.79	15,099.40
2	6.98	98.38	11,394.58
3	7.83	177.23	14,744.99
	7.62	128.80	13,746.33

Source: Oka (2005) in (Hazra, 2017).

Research on Petung bamboo's mechanical properties over the past 10 years by UGM DTSL students was conducted by Irawati and Saputra (2012) in (Hazra, 2017). The average moisture content was 15.38%, the density was 0.72 grams/cm^3, and the bamboo age was 3–5 years. The analysis statistics obtained are described in Table 5.

Table 5. Mechanical Properties of Petung Bamboo.

Mechanical Properties	MPa
Flexural Strength	134.97
Tensile Strength //	288.00
Compressive Strength //	49.20

Compressive Strength ⊥	24.19
Shear Strength //	9.51
Modulus of Flexural Elasticity	12,888.47

Source: Irawati dan Saputra in Hazra (2017).

According to the research by Widjaja (2000), Apus bamboo has mechanical properties as follows: for bamboo aged 3 years, the average moisture content on green stems is 54.3%, and the average moisture content on dry stems is 15.1%. The results are described in Table 6.

Table 6. Mechanical Properties of Apus Bamboo

Apus Bamboo	MOR N/mm^2	Compressive Strengh N/mm^2	Shear Strength N/mm^2	Tensile Strength N/mm^2
Green with nodes	102	24	7.68	294
Green with internodes	71.5	23.5	5.99	
Dry air with nodes	87.5	37.5	7.47	299
Dry air with internodes	74.9	33.9	7.65	

Source: (Widjaja, 2000)

Triwiyono and Morisco in Permana (2017) conducted research on the moisture content of Petung bamboo in wet and dry air conditions. Measurement of the moisture content of wet bamboo was carried out one day after logging, and measurement of air-dried bamboo's moisture content was carried out after 1.5 months. Moisture content research was also carried out by Yasin (2009) in Permana (2017). The results of the study are in Tables 7 and 8.

Table 7. Moisture Content of Average Petung Bamboo

Parts	Wet	Dry air
Base	36.076%	5.227%
Middle	37.832%	6.678%
End	36.765%	7.203%

Source: Triwiyono and Morisco in Permana (2017)

Table 8. Moisture Content of Average Petung Bamboo.

Number Culm	Number Sample	Moisture Content (%)
Culm 1	1	13.23
	2	12.93
	3	12.45
Culm 2	1	13.08
	2	12.71
	3	12.70
Culm 3	1	12.74
	2	12.46
	3	13.16

Source: Yasin in Permana (2017).

Wulandari (2014) on her research has shown as it seen in Table 9, the physical properties of local bamboo species in West Sumbawa Regency are that the higher the water content, the higher the value of development and shrinkage, and the higher the density, the higher the value of development and depreciation.

Table 9. Physical Properties of Bamboo from West Sumbawa.

Information	Bamboo	Value
Highest Moisture Content	Tali	11.666%
Highest Density	Tutul	0.613 g/cm^3
Highest Shrinking and Swelling	Duri and Betak	0.637% and 0.618%

Source: Wulandari (2014)

The physical and mechanical properties of Apus bamboo in Turgo (Yogyakarta), according to Permana (2017), are listed in Table 10. The specimens were dried for 1 month (30 days) after being treated with preservation in the laboratory. Mechanical properties of Apus bamboo are inversely proportional to water content but directly proportional to density.

Table 10. Physical-Mechanical Properties of Apus Bamboo.

Physical Properties	**Value**
Moisture Content	13.93%
Density	717.96 kg/m^3
Mechanical Properties	**Value**
Tensile Strength	270.94 MPa
Compressive	48.97 MPa

Strength	
Flexural Strength	70.46 MPa
Shear Strength (Node)	5.14 MPa
Shear Strength (Internode)	4.02 MPa
Dowel Bearing Strength	37.38 MPa
Modulus of Tensile Elasticity	18.058 MPa
Modulus of Compressive Elasticity	25.582 MPa
Modulus of Flexural Elasticity	19.514 MPa

Source: Permana (2017)

The physical and mechanical properties of Apus bamboo in Sayegan (Yogyakarta), according to Hazra (2017) are shown in Table 11. Mechanical properties increase with the increase in density of bamboo and decrease with the increase in water content.

Table 11. Physical-Mechanical Properties of Apus Bamboo.

Physical Properties	**Value**
Moisture Content	14.60%
Density	546.28 kg/m^3
Mechanical Properties	**Value**
Tensile Strength	223.36 MPa
Compressive Strength	40.89 MPa
Flexural Strength	60.07 MPa
Shear Strength (Node)	5.46 MPa
Shear Strength (Internode)	4.84 MPa
Dowel bearing strength	$f_{e\ maks}$ 17.07 MPa $f_{e5\%}$ 16.56 MPa
Modulus of Tensile Elasticity	20.893 MPa
Modulus of Compressive Elasticity	12.102 MPa
Modulus of Flexural Elasticity	15.464 MPa

Source: Hazra (2017)

According to Basri & Pari (2017), physical properties are identified to determine the stability of bamboo. Knowing the drying properties is the basis for determining the optimum drying temperature. Testing of physical properties is carried out in the direction of diameter and thickness of bamboo stems. To determine the drying temperature, the wood drying method is adopted. Defects such as deformation (gripping & wrinkling) and broken ends are observed. The result is a close relationship between the fresh moisture content of bamboo and the density and shrinkage of bamboo stems. The research results are listed in Table 12.

Table 12. Optimum drying temperature.

Bamboo	Optimum Temperature (Initial and Final Temperature)
Temen and Ori	45–70 °C
Ampel and Ater	40–60 °C
Petung	33–50 °C

Source: Basri and Pari (2017)

Triwiyono and Morisco in Basri and Pari (2017), also conducted research on density or specific gravity in wet and dry conditions. The results are listed in Table 13 as follows.

Table 13. Average Density of Petung Bamboo.

Parts	Wet	Dry air
Base	0.639	0.664
Middle	0.703	0.727
End	0.717	0.760

Source: Triwiyono dan Morisco in Permana (2017)

Furthermore, according to Awaludin in Hazra (2017), in relation to the bolt strength based on the D5764 standard, the mechanical properties of bamboo are similar to those of wood because both are composed of fibers. The compressive force used is the compressive force of the test results which intersect with the off-set line method 5% D (D is the diameter of the bolt). Strong results of Wulung bamboo are shown in Table 14.

Table 14. Dowel-Bearing Strength of Wulung Bamboo.

Group Name	Wulung Bamboo	
	$f_{5\%}$ (MPa)	$f_{e\ maks}$ (MPa)
A	27.15–39.17	40.49–45.88
B	28.38–41.22	34.83–49.36
C	32.24–38.94	37.93–43.26
D	35.43–40.00	36.06–42.63

Source: Awaludin in Hazra (2017).
Note:

- A = D12.2 mm with guide holes
- B = D15.6 mm without guide holes
- C = D12.2 mm with guide holes
- D = D15.6 mm without guide holes

Research on the mechanical properties of bamboo Betung aged ±4 years to obtain the maximum value of stiffness and flexural strength in different positions and with different tensile strength parallel to the bamboo fiber expressed in MOE and MOR has been carried out by Yoresta (2013).

The standard used is ASTM D143-05. The results show a significant difference, namely, the position of the upper fiber leather bamboo (press area) has a higher value of MOE (Modulus of elasticity) and MOR (Modulus of rupture) than does the bottom (tensile area). The values can be seen in the following table.

Table 15. Value of MOE and MOR of Betung Bamboo.

Bamboo Position	MOE (*Modulus of elasticity*) kg/cm^2	MOR (*Modulus of rupture*) kg/cm^2
Position of the top grain skin (compression area)	62,118.90	826.36
Position of the bottom grain skin (tension area)	51,563.20	633.38
	Shear Strength Parallel to Grain	
Betung Bamboo	2309.00 kg/cm^2	

Source: Yoresta (2013)

According to Mustafa (2009), Petung bamboo that is aged 3–5 years has good strength. However, building shops usually mix between young, mature and old bamboo (due to the method of clearing in one clump), so there is no clear distinction to know the quality of bamboo. For this reason, a study of the physical and mechanical properties of young, mature, and old Petung bamboo was carried out (case study: base section). The results of the study are listed as follows.

Table 16. Physical-Mechanical Properties of Petung Bamboo.

Character	Young	Adult	Old
Density (gr/cm^3)	0.695	0.809	0.742
Density of Sclerenchymal fibers(mm^2/mm^2)	0.4257	0.4290	0.4284
Compressive Strengh (Mpa)	37.52	46.59	43.13
Stress Limit Proportion (Mpa)	33.10	42.33	38.40
Modulus of Elasticity (Mpa)	3773.15	4719.13	3783.93
Shear Strength (Mpa)	6.86	9.94	8.95
Tensile Strength (Mpa)	151.54	217.89	186.09

Source: Mustafa (2009)

Based on the table, the density of bamboo and the density of sclerenchymal fibers have an influence on the quality or strength of bamboo. Other results show that the highest strength is found in adult bamboo, while the lowest is found in young bamboo. Thus, adult bamboo can be utilized. Another advantage of using adult bamboo is that it enables preservation of bamboo clumps. In addition, the mechanical properties of bamboo will increase with the increase in the density of sclerenchymal fibers. In other words, sclerenchymal fibers affect the strength of bamboo.

3.2 Observations and Interview

Observations or surveys in the field were carried out by the researchers. There were two locations reviewed by bamboo entrepreneurs or craftsmen, namely, Purwomartani, Yogyakarta, and Kaliwiro, Wonosobo. The researcher looked directly into the process of bamboo production from the beginning of bamboo processing until it is used either as a construction material or others. The researchers also conducted an interview with one of the employees or workers who oversaw the bamboo production.

In Yogyakarta, the bamboo production starts with cutting down bamboo, then placing it in a workshop to be preserved. Bamboo is cleaned and washed so that mold and mildew disappear from the surface of the bamboo. This is done so that fungus, which can cause a decrease in the quality of bamboo, have no potential to develop.

The preservation process lasts for a maximum of 10 days before the bamboo is laid and placed in good air circulation (by allowing space between bamboo pieces) for 2 days. Then, the bamboo can be sent to the location with an estimated travel time (loading) of 1 day. Thus, the total time from the preservation and drying until the bamboo can be used is 13 days.

The bamboo type that is continuously produced is Petung bamboo. The prices for non-preserved and preserved bamboo are distinguished. The price of durable bamboo can be 3 times the price of non-preserved bamboo. In addition, the base of the bamboo fares at a higher price than do the middle and end parts. This is because it is considered the strongest or the thickest (has high strength), so it is a good choice if used as a building construction material, which has been proven in the field.

The bamboo production process is different in the Wonosobo area. After being bought from the market or from a bamboo farmer, bamboo is immediately cleaned then soaked for 3 days for a preservation purpose. Next, the bamboo is dried for about a week. The bamboo is ready to be processed or produced for construction or crafting purposes.

The bamboo which is considered to have high strength, similar to the bamboo production in Yogyakarta, is Petung bamboo in the base area because it is thick and hard.

3.3 Discussion

The results of the research on the physical-mechanical properties of bamboo, especially the bamboo in Indonesia, vary depending on the type, length of drying of the sample object to be tested, position of the sample of bamboo stems taken, and location of the bamboo harvesting. The results show a significant relationship between physical properties and mechanical properties. The results are recorded as follows.

Table 17. Physical-Mechanical Properties of Betung Bamboo

Information	Range
Dry Moisture Content	12.63–15.38%
Density	0.72–0.809 gram/cm^3
Flexural Strength	128.80–134.97 MPa
Tensile Strength //	151.54–402.18 MPa
Compressive Strength //	37.52–49.99 MPa
Compressive Strength ⊥	24.19–51.06 MPa
Shear Strength //	6.86–9.94 MPa
Modulus of Flexural Elasticity	12,888.47–13,746.33 MPa
MOE	62,118.90 kg/cm^2
MOR	826.36 kg/cm^2
Density of Sclerenchyma fibers	0.4257–0.4290 (mm^2/mm^2)
Stress Limit Proportion	33.10–42.33 (MPa)

Source: Researcher's analysis (2018)

Table 18. Physical-Mechanical Properties of Apus Bamboo.

Information	Range
Dry Moisture Content	13.93–15.1%
Wet Moisture Content	54.3%
Density	546.28–717.96 kg/m^3
Flexural Strength	60.07–70.46 MPa
Tensile Strength //	223.36–299 MPa
Compressive Strength //	33.9–48.97 MPa
Shear Strength //	4.02–7.65 MPa
MOR	74.9 MPa
Modulus of Tensile Elasticity	18,058–20,893 MPa
Modulus of Compressive Elasticity	12,102–25,582 MPa
Modulus of Flexural Elasticity	15,464–19,514 MPa
Dowel Bearing Strength	17.07–37.38 MPa

Source: analysis result (2018)

4 CONCLUSIONS

The results of this study vary depending on the type, length of drying of the sample object to be tested, position of the sample of bamboo stems taken, and location of the bamboo harvesting. However, the results show a significant relationship between physical properties and mechanical properties. The physical properties and mechanical properties of bamboo produced significantly influence each other. The physical properties determine the mechanical properties of bamboo. The findings of this study include the following. The type of bamboo that has high strength based on surveys in the field is Petung bamboo. This is in line with the results of the research conducted. In addition, the mechanical properties of bamboo will increase with the increase in the density of sclerenchyma fibers. In other words, sclerenchyma fibers affect the strength of bamboo. Therefore, it is necessary to do further research on the chemical properties of various types of bamboo in Indonesia.

REFERENCES

Basri, E., Pari, R., 2017. Sifat Fisis Dan Pengeringan Lima Jenis Bambu (Physical and Drying Properties of five bamboo Species). Jurnal Penelitian Hasil Hutan 35, 1–13.

Eratodi, I.G.L.B., 2014. Sambungan Balok-Kolom Bambu Laminasi Menggunakan Pelat Baja Dikarter Dan Baut (Disertasi). Program Pascasarjana Fakultas Teknik UGM, Yogyakarta.

Hazra, S., 2017. Sifat Fisika Dan Mekanika Bambu Apus (Studi Kasus: Sayegan) (TUGAS AKHIR). Departemen Teknik Sipil Dan Lingkungan Fakultas Teknik UGM, Yogyakarta.

ISO 22157-1, 2004. Bamboo-Determination of physical and mechanical properties-part1:Requirement.

ISO 22157-2, 2004. Bamboo-Determination of physical and mechanical properties-part1:Laboratory Manual.

Janssen, 1981. Bamboo in Building Structures. Eindhoven University of Technology, Netherlands.

Janssen, J.J., 1981. Bamboo in building structures. https://doi.org/10.6100/ir11834

Made Oka, G., 2005. Cara Penentuan Kelas Kuat Acuan Bambu Petung. Majalah Ilmiah Mektek Vol. VI, pp 99-105.

Morisco, 1999. Rekayasa Bambu. Nafiri Offset, Yogyakarta.

Mustafa, S., 2009. Karakteristik Sifat Fisika dan Mekanika Bambu Petung pada Bambu Muda, Dewasa, dan Tua (Studi Kasus: Bagian Pangkal).

Mustakim, Tanuwidjaja, T., Andry, W., Budi, F., 2009. Bambu sebagai Material yang Berkelanjutan dan Affordable untuk Perumahan.

Permana, I., 2017. Sifat Fisika Dan Mekanika Bambu Apus (Studi Kasus: Bambu Daerah Turgo) (TUGAS AKHIR). Program Studi Teknik Sipil Departemen Teknik Sipil dan Lingkungan, Yogyakarta.

Sumarni, S., 2010. Struktur Kayu. Yuma Pustaka.

Suriani, E., 2017. Bambu Sebagai Alternatif Penerapan Material Ekologis: Potensi dan Tantangannya. EMARA Indonesian Journal of Architecture Vol 3 Nomor 1 – Agustus 2017, 33–42.

Tanubrata, M., 2015. Bahan-Bahan Konstruksi Dalam Konteks Teknik Sipil. JURNAL TEKNIK SIPIL 11, 76–168.

Widjaja, E.A., 2000. Bamboo Diversity And Its Future prospect in Indonesia. Sustainable Utilization of Forest Products.

Wulandari, F.T., 2014. Sifat Fisika Empat Jenis Bambu Lokal Di Kabupaten Sumbawa Barat. MEDIA BINA ILMIAH 8, 1–5.

Yoresta, F.S., 2013. Sifat Mekanis Bambu Betung (Dendrocalamus asper) 1, 5.