

# Analysis of the Effect of Brackish Water on the Mechanical Properties of 'Gigantochloa apus' Bamboo Laminated Board for Ship Hull Material

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The maritime industry faces increasing pressure to use sustainable materials for ship construction, especially in brackish water, which is common in estuarine regions of Indonesia. As an alternative to steel, bamboo laminated board composites represent a notable innovation. This article comprehensively analyzes the mechanical properties of bamboo laminated boards made from 'Gigantochloa apus' when exposed to brackish water conditions. The research includes a series of experiments involving the number of bamboo laminate layers, immersion periods, and immersion environment conditions. The mechanical properties of the bamboo laminated boards – including impact, bending, and tensile strength – were carefully evaluated and compared to the Indonesian Classification Bureau (BKI) standard as a safety requirement. The results reveal a complex relationship among the number of layers, immersion time, brackish water temperature, and the performance of bamboo laminated boards. Our research indicates that 'Gigantochloa apus' bamboo laminated boards exhibit remarkable resistance to brackish water, maintaining structural integrity and resilience over time, in contrast to other materials. As immersion time varied, the mechanical strength properties of all layer variations decreased by approximately 5 to 9 percent. According to data analysis and comparison with BKI standard safety regulations, apus bamboo laminated board is suitable for ship hulls.

## KEY WORDS

- ~ 'Gigantochloa apus' bamboo
- ~ Brackish water
- ~ Tensile test
- ~ Bending test
- ~ Impact test
- ~ Ship hull

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## 1. INTRODUCTION

Wood and concrete are the most commonly used materials in buildings (Shah, Sharma, and Ramage, 2018). Growing global economic activity and population drive demand for wood and wood-based products. However, deforestation reduces wood supply and decreases carbon dioxide absorption (Chaowana, 2013). The bamboo tree is the fastest-growing plant, reaching maturity quickly, and is widely available due to its presence in dense forests and rapid growth rate. Additionally, bamboo is considered lightweight, stiff, and strong – often surpassing other composite materials such as wood fiber-reinforced polymers (Anokye et al., 2016; Emamverdian et al., 2020; Li et al., 2020; Nie et al., 2021). Laminated bamboo can serve as an alternative building material to steel reinforcement. Laminated panels have better dimensional stability than other bamboo products (Srivaro, 2016; Chainey, Shijagurumayum, and Thokchom, 2022).

Bamboo composites can be used to construct ship hulls (Corradi et al., 2009). Laboratory experiments in ship construction have shown that mixing bamboo fibers with supporting materials produces bamboo fiber-reinforced plastic (BRP) (Yamaguchi and Fujii, 2004). These technological advancements have increased the popularity of composite materials. Bamboo is often used directly, indirectly, or in cut form as raw material in the shipping industry. Bamboo lamination can provide the strength and stiffness required to meet critical design criteria (Li et al., 2013). Instead of traditional materials, natural plant fibers can be used for high-strength, low-weight applications (Abd El-baky and Attia, 2018).

There are some limitations to using bamboo for laminated boards, including the difficulty in identifying the connections between board segments (Mahdavi, Clouston, and Arwade, 2011; Chen et al., 2017, 2020). Previous research by Widodo et al. (2007) found that using components in laminated board production resulted in a strength decrease ratio 25% lower than expected. To reduce the high production costs of laminated bamboo, a bamboo-hybrid-slat laminate will be produced by combining bamboo with *Pterocarpus indicus*, as described by Supomo et al. (2021). This laminate will be used to build fishing boats.

Previous studies have shown that laminated bamboo exhibits high strength and elasticity under tensile and compressive stresses (Manik et al., 2022; Manik, Firdhaus, et al., 2023). Because there is no universally accepted size, production can be simplified and adapted to meet changing demands in the shipbuilding industry. Bamboo construction also offers resistance to water damage. A previous study (Manik, Rindo, and Alif Airlangga, 2020) examined the mechanical properties of laminated bamboo immersed in freshwater, finding that these properties decreased by about 6–19% with increasing immersion times. Consequently, Manik et al. (Manik, Suprihanto, Sulardjaka, et al., 2021) investigated the impact of saltwater on the physical and mechanical characteristics of laminated bamboo composites, finding that these parameters dropped by roughly 1–8% with longer immersion durations.

Research on laminated bamboo in brackish water, common in estuarine regions of Indonesia, is needed because of its potential advantages over conventional materials like steel and wood for shipbuilding (Manik, Tuswan, et al., 2023). This research will compare the tensile, bending, and impact strengths of bamboo laminated boards made with an epoxy resin mixture and exposed to brackish water for three, six, and nine weeks under controlled ship construction laboratory conditions. The laminated boards will have bamboo fiber arrangements of three, five, and seven layers crossed at 90 degrees. This study aims to develop laminated bamboo technology as a viable option for boat hulls for fishing vessels in estuaries.

## 2. MATERIALS AND METHODS

### 2.1. Material Preparation

For this experiment, we use bamboo slats made from segments of apus bamboo (*Gigantochloa Apus*) with an average diameter of 150 mm, sourced from the Salatiga area in Indonesia. The process of making laminated bamboo specimens is shown in Figure 1a–f. The boards were laid out in a single layer, each measuring 350 mm in length and 350 mm in width (1a). After applying the epoxy resin (1b), the surface of the apus bamboo is brushed with 200-grit sandpaper to ensure good adhesion (1c). The next step is to prepare the board for coating by removing any debris. Silicon gel may be applied to the mold to prevent the lamination from sticking during the pressing process. The coating is applied to the initial layer of bamboo and spread evenly. The bamboo is prepared according to the number of layers – three, five, or seven – to make laminated boards (1d). The bamboo laminate boards are pressed until the resin solidifies (1e), then left to rest for 24 hours before being removed.

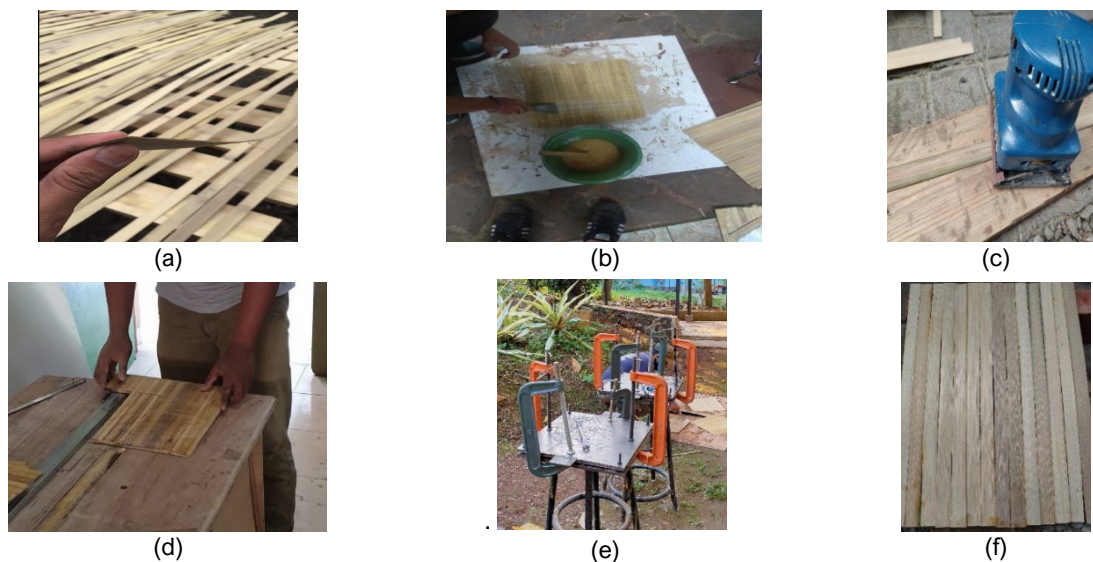


Figure 1. The process of making laminated bamboo specimens: (a) formation of laminated bamboo slats, (b) Apus bamboo gluing process, (c) brushing resin onto apus bamboo to ensure adhesion, (d) forming a laminated board using three, five, or seven layers of bamboo, (e) laminate board clamping, (f) apus bamboo laminated board.

The adhesive used is an epoxy resin commonly applied in wooden and fiberglass boat maintenance, consisting of two components: Component A, an epoxy that is cream-colored with a viscosity greater than 3000 poise at 30°C, a specific gravity of 1.1–1.4 kg/L at 30°C, a solids content of 98–100%, and a theoretical coverage of 5–8 m<sup>2</sup> per coat depending on surface porosity and coating thickness; and Component B, a hardener that is brown-colored with similar specifications to component A. This epoxy resin, listed in Table 1, serves as both a putty and an adhesive.

No	Material	Percentage
1	Bisphenol A (BPA)	80-90%
2	Altered polyepoxides	5-15%
3	Alcohol Glycidyl Ether (AGE)	5-15%
4	Mercaptans	50-60%
5	Tertiary Amine	5-10%
6	Polyamide (PA) Resin	30-35%
7	Triethylenetetramine (TETA)	< 3%
8	Aliphatic Amine	1-10%

Table 1. Epoxy resin composition

The curing process involved leaving the pressed laminated boards in the clamp for 24 hours at room temperature (25 ± 3°C) and a relative humidity of 60-70% to ensure optimal interlayer adhesion before removal. The fraction of bamboo fibers and epoxy resin matrix is influenced by the applied press pressure (2.0 MPa in this study), which reduces the resin fraction as pressure increases. For the 3, 5, and 7 layer configurations, the bamboo fiber weight fractions were 0.75, 0.70, and 0.65, respectively, with corresponding epoxy matrix fractions of 0.25, 0.30, and 0.35 as summarized in Table 2.

Number of layers	Compression Pressure (MPa)	Apus Bamboo Mass (%)	Epoxy Resin Mass (%)
3	2,0	75	25
5		70	30
7		65	35

Table 2. Bamboo fiber and epoxy resin matrix as composite components.

Specimens were created and tested for tensile, bending, and impact properties at the Ship Material and Strength and Ship Construction Laboratory, Department of Naval Architecture, Diponegoro University. The outdoor immersion specimens, shown in Figure 2b, were collected from a brackish water pond in Demak, Central Java, Indonesia, with a salinity level of 15–20 ppt measured using a refractometer (Figure 2a). Outdoor temperatures ranged from 34°C to 38°C during the day and 21°C to 25°C at night. The indoor immersion, shown in Figure 2c, was conducted at the Ship Material and Strength Laboratory, Diponegoro University, with indoor temperatures ranging from 20°C to 25°C during the day and 25°C to 28°C at night.

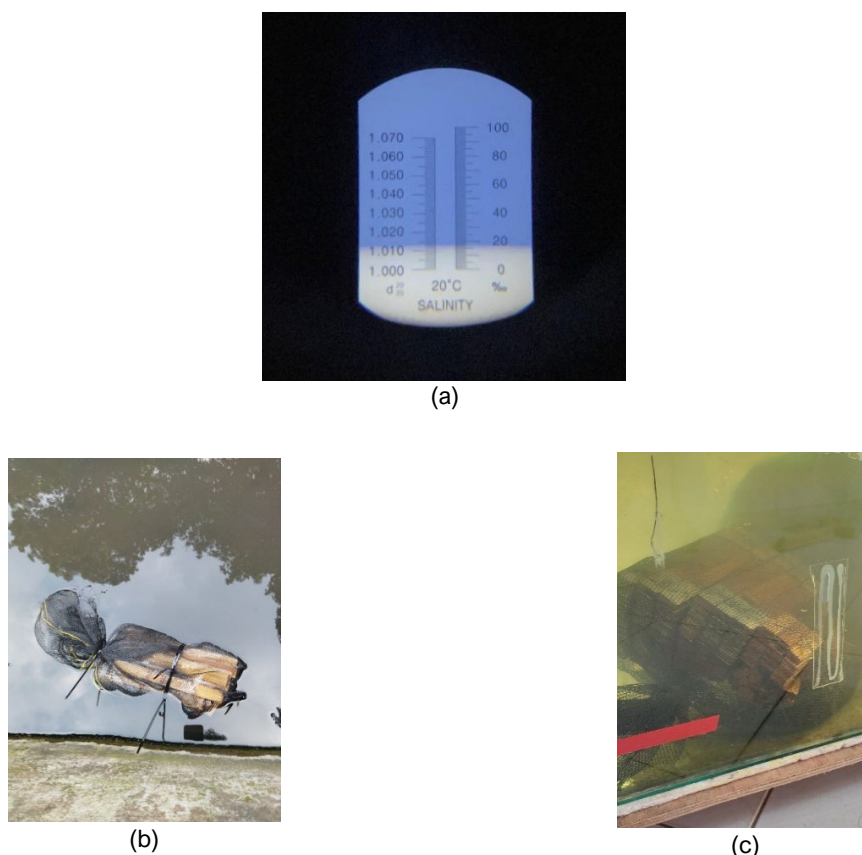


Figure 2. Salinity level of the brackish water by a refractometer (a) and process of immersing the material (b) outdoors and (c) indoors.

Table 3 presents the three variations applied to the specimens in this study: (1) the number of laminated bamboo layers (3, 5, or 7); (2) the immersion duration (3, 6, or 9 weeks); and (3) the immersion location (indoor or outdoor). For each combination of these variations (excluding the non-immersed controls), nine specimens were prepared, with three allocated to each mechanical test (tensile, bending, and impact), yielding a total of 162 tested specimens across the 18 immersed conditions (54 per test type). The control specimens (0 weeks immersion) were prepared similarly but without variation in immersion location, resulting in an additional 27 specimens (9 per test type) and a grand total of 189 specimens. Images of the tensile test specimens after indoor and outdoor immersion are provided in Figure 3.

Number of Layers	Immersion Time (weeks)	Immersion Place
3	0, 3, 6, 9	indoor
		outdoor
5	0, 3, 6, 9	indoor
		outdoor
7	0, 3, 6, 9	indoor
		outdoor

Table 3. Design of experiment



Figure 3. Tensile test specimens after (a) indoor and (b) outdoor immersion.

## 2.2. Mechanical Testing

### 2.2.1. Impact Test

As shown in Figure 4a, the impact test specimens were cut from laminated bamboo boards using a saw, with dimensions of 63 mm x 10 mm x 10 mm, in accordance with the ASTM E23-16b standard (ASTM International, 2016). Figure 4b depicts standard high-strain-rate test results from the Charpy V-notch test conducted at the Ship Construction Laboratory, Naval Architecture Department of Diponegoro University, which evaluates the fracture energy of the material. The absorbed energy measures notch toughness and aids in the study of temperature-dependent transitions between ductile and brittle states. This impact test requires sufficient energy to shatter the test object with a single strike. A mallet of a specific weight is lowered from an angle of  $150^\circ$  ( $\alpha$ ) and strikes a rectangular test object with a  $45^\circ$  notch angle. Due to the ductility of the test object, the test object fractures, and the hammer swings back to form an angle ( $\beta$ ) (ASTM International, 2002b).



Figure 4. (a) Specimen testing for JB-300B impact testing machine, and (b) Impact test result specimen.

### 2.2.2. Bending Test

Bending test specimens were cut from the laminated bamboo boards using a saw, with each specimen measuring 130 mm x 13 mm x 10 mm shown in Figure 5a and bending test depicted in Figure 5b have been conducted at the Ship Construction Laboratory, Naval Architecture Department of Diponegoro University, following the ASTM D-7264 standard to visually identify the material's quality and quantify its strength to load and elasticity (ASTM International, 2007).



Figure 5. (a) specimen testing on the WEW-1000B Universal Testing Machine (UTM) with the detailed specimen test results, and (b) Bending test specimen according to ASTM D-7264.

### 2.2.3. Tensile Test

Figure 6a depicts tensile test specimens that were cut from the laminated bamboo boards using a saw, with dimensions measuring 250 mm x 50 mm x 10 mm using the ASTM D-3039 standard to determine tensile strength (ASTM International, 2000). The test item at the Ship Construction Laboratory, Naval Architecture Department of Diponegoro University, is secured in the Universal Testing Machine, and the loading is gradually increased up to a specified load until the test object breaks, as shown in Figure 6b. The tensile force acting on the specimen will produce an increase in length as well as a decrease in cross-sectional area.



Figure 6. (a) Universal Testing Machine (UTM) WEW-1000B with the detailed on specimen test results and (b) Specimen size based on ASTM D-3039.

## 3. RESULTS

### 3.1. Impact Test Results

The ASTM E23-16b (ASTM International, 2016) standard is used for impact testing. The term "impact strength" was employed in the supplied Charpy impact test scenario to refer to the material's capacity to withstand the energy demands of a quickly imposed load. The test results determined the average impact strength value of laminated bamboo with the effect of air and brackish water inside each specimen, with a standard deviation of 5.81. Table 4-5 and Figure 7 demonstrate that the indoor immersion impact test results decreased in all versions, with an average drop of roughly 7%. The 3-layer specimen reduced by 7.29% from 190.68 KJ/m<sup>2</sup> to 176.79 KJ/m<sup>2</sup>, the 5-layer laminate by 6.71% from 195.49 KJ/m<sup>2</sup> to 182.38 KJ/m<sup>2</sup>, and the 7-layer specimen by 5.75% from 201.95 KJ/m<sup>2</sup> to 190.34 KJ/m<sup>2</sup>. The test results of the impact strength values between specimens treated with immersion in brackish water indoors and outdoors revealed that the impact strength values for models indoors were higher than outdoors for all layer variations, with a range of impact strength values greater than approximately 1-3%. The results of the tests reveal that the number of layers and the duration of immersion time affect the Impact value.

Immersed Time (Weeks)	3 Layers (KJ/m <sup>2</sup> )		5 Layers (KJ/m <sup>2</sup> )		7 Layers (KJ/m <sup>2</sup> )	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
0	190.68	190.68	195.49	195.49	201.95	201.95
3	184.52	182.46	190.65	188.97	197.44	195.88
6	179.35	175.79	185.15	182.38	194.68	192.27
9	176.79	170.11	182.38	178.55	190.34	186.76

Table 4. Impact test results

Immersed Time (Weeks)	differences between indoor and outdoor (%)			differences between immersion time (%)		
	3	5	7	3	5	7
0	0.00%	0.00%	0.00%	-	-	-
3	-1.12%	-0.88%	-0.79%	-3.23%	-2.48%	-2.24%
6	-1.98%	-1.49%	-1.24%	-5.95%	-5.29%	-3.60%
9	-3.78%	-2.10%	-1.88%	-7.29%	-6.71%	-5.75%

Table 5. Differences between specimens' variation.

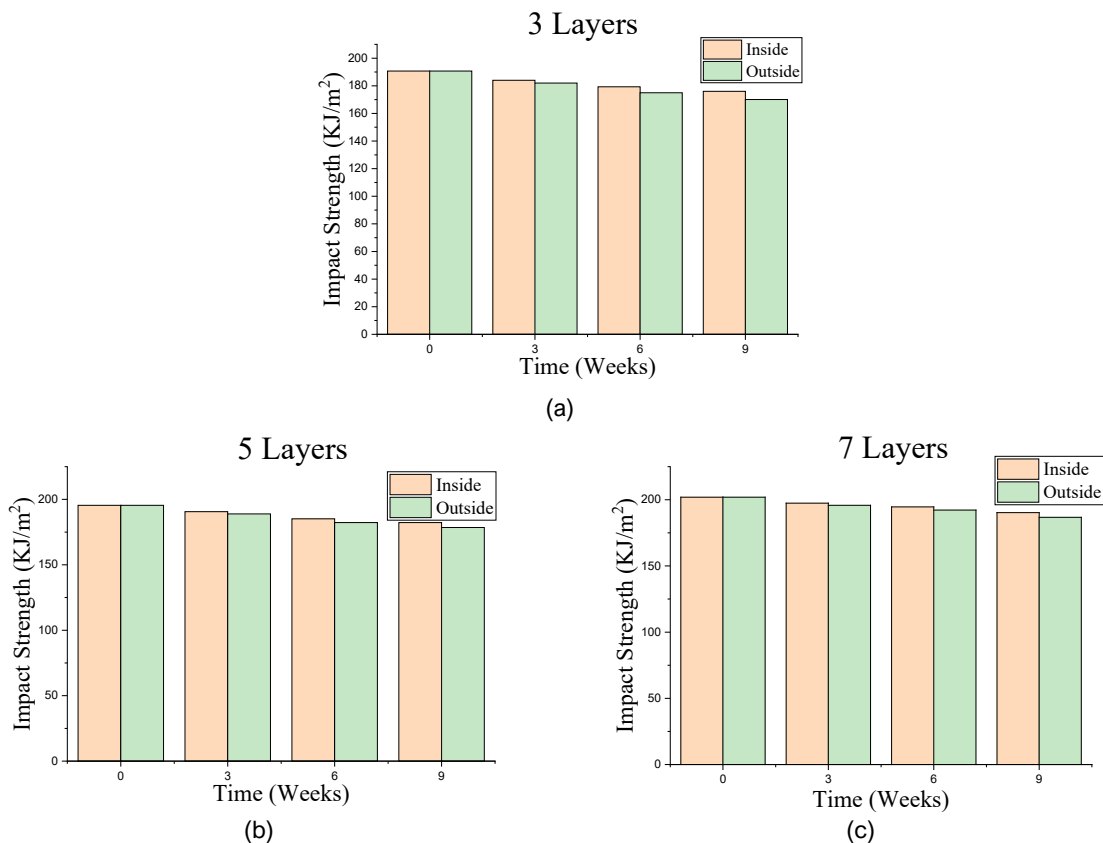


Figure 7. Comparison of Impact Strength against variations in the number of layers (a) three layers, (b) five layers, (c) seven layers and variations in immersion time and immersion location.

### 3.2. Bending Test Results

The bending test follows the ASTM D-7264 (ASTM International, 2007) standard for bending testing at the Ship Construction Laboratory in the Naval Architecture Department of Diponegoro University.

A bending test involves bending or twisting a test material until it reaches its brittleness limit point. A three-point bending test (Three-point bending) was used in this study. In the current experiment, the maximum load ( $F$ ) can be measured. Using the formula from William (William D. Callister Jr., 2003), as can be seen below:

$$\sigma = \frac{3FL}{2bd^2} \dots\dots\dots(1)$$

We calculated the bending stress in the recent investigation, where  $F$  is the maximum load,  $L$  is the length of the support span,  $b$  is the specimen width, and  $d$  is the model's thickness.

As a result, the average bending strength of each specimen is obtained with a standard deviation of 4.64, as illustrated in Tables 4-5 and Figure 8; results of the indoor immersion bending test for each variation are shown in Figure 6. There was a 9.62% drop in the 3-layer specimen variation from 273.77 MPa to 247.44 MPa, a -7.79% decrease in the 5-layer specimen from 283.91 MPa to 261.80 MPa, and a 25% decrease in the 7-layer model from 294.07 MPa to 275.55 MPa. The average reduction is -6.30%. The bending test results show that the bending value for samples immersed indoors is higher than that of samples immersed outdoors by 2-3%. This applies to all layer variations, with the highest differences, namely 3.55% in the three-layer variation immersed for nine weeks.

According to the Indonesian Classification Bureau (BKI) guideline book, BKI Vol. 5 "Guidelines for Fiberglass-Reinforced Plastic Ships" (Biro Klasifikasi Indonesia, 2021), ships with supporting fiber must have a bending strength of at least 150 MPa (see the red dashed line). Figure 6 presents a comparison of tensile strength based on bending stress (Table 6), assuming the standard BKI requirements for fiberglass-reinforced plastic ships are applied. In the tension test, samples that meet the BKI requirements come from tests with four different immersion times (0, 3, 6, and 9 weeks) and two immersion sites (inside and outside).

Immersed Time (Weeks)	3 Layers (MPa)		5 Layers (MPa)		7 Layers (MPa)	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
0	273.77	273.78	283.91	283.91	294.07	294.07
3	265.24	262.45	277.64	275.75	289.35	288.12
6	259.78	254.37	271.12	267.33	283.65	280.38
9	247.44	238.65	261.80	255.18	275.55	270.18
<b>BKI Standard (Biro Klasifikasi Indonesia, 2021)</b>	150	150	150	150	150	150

Table 6. Bending test results

Immersed Time (Weeks)	differences between indoor and outdoor (%)			differences between immersed time (%)		
	3	5	7	3	5	7
0	0.00%	0.00%	0.00%	-	-	-
3	-1.05%	-0.68%	-0.42%	-3.11%	-2.21%	-1.61%
6	-2.08%	-1.40%	-1.15%	-5.11%	-4.50%	-3.54%
9	-3.55%	-2.53%	-1.95%	-9.62%	-7.79%	-6.30%

Table 7. Tables Differences between specimens' variation.

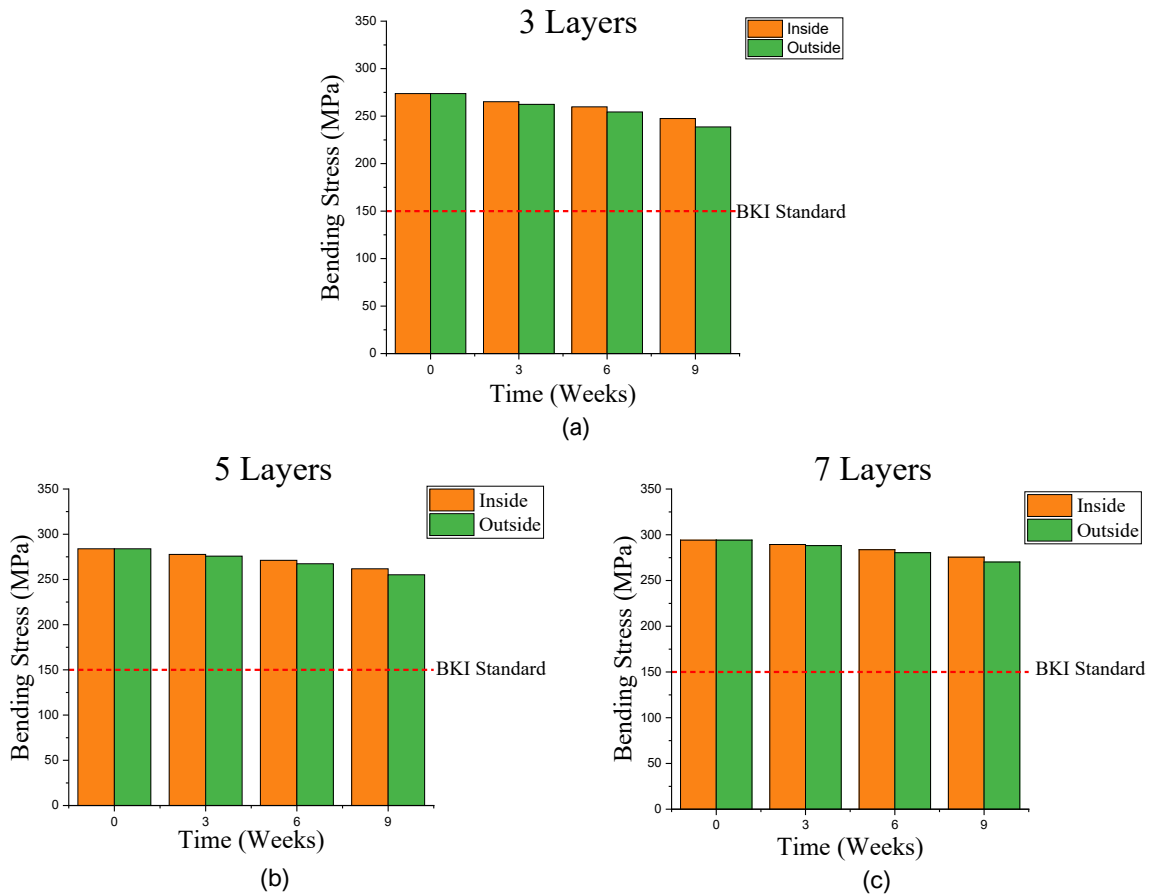


Figure 8. Comparison of Bending Strength against variations in the number of layers (a) three layers, (b) five layers, (c) seven layers and variations in immersion time and immersion location.

### 3.3. Tensile Test Results

The maximum load ( $P$ ) of tensile test specimens evaluated on the Universal Testing Machine (UTM) is determined for each model. The test results include tensile strength, strain, and modulus of elasticity. The maximum load data obtained from the machine may be computed using the maximum stress formula below from Davis (Davis, 2004).

$$\sigma = \frac{P}{A_0} \dots\dots\dots(2)$$

and the tensile strength ( $\sigma$ ) of each specimen is obtained, where  $P$  is the maximum load,  $A_0$  is the cross-sectional area of the specimen. Tensile testing is performed per the ASTM D-3039 standard (ASTM International, 2002a). Tensile testing was performed at the Laboratory at the Naval Architecture Department of Diponegoro University.

Table 8-9 presents the test average results for the tensile strength value for laminated bamboo under the impact of air and brackish water inside, with a standard deviation of 4.26. Figure 9 indicates a drop in the indoor immersion tensile test results for all variants. There was a 9.35% drop in the 3-layer specimen variation from 135.15 MPa to 122.51 MPa, the 5-layer specimen showed a 7.66% decrease from 149.05 MPa to 137.64 MPa, and a 6.08% decrease in the 7-layer model from 155.82 MPa to 146.35 MPa. The tensile test results indicate that models submerged inside had a 1-2% higher bending value than those immersed outside. This trend applies to all layer variants, with the most significant change, 2.87%, in the 9-week-immersed three-layer variety.

Ships reinforced with supporting fiber must have a specified tensile strength of at least 98 MPa (indicated by the red dashed line) according to the BKI Vol 5 guidelines for fiberglass-reinforced plastic ships (Biro Klasifikasi Indonesia, 2021). Figure 8 shows a Comparison of tensile strength based on tensile stress (Table 6), assuming the standard BKI standards for fiberglass-reinforced plastic ships are used. Variations that fulfil the BKI standard in the tensile test include specimens from testing with four different durations of immersion (0, 3, 6, and 9 weeks) and two other immersion locations (inside and outside).

Immersed Time (Weeks)	3 Layers (MPa)		5 Layers (MPa)		7 Layers (MPa)	
	Indoor	Outdoor	Indoor	Outdoor	Indoor	Outdoor
0	135.15	135.14	149.05	149.05	155.82	155.82
3	127.21	124.76	142.13	140.08	149.75	148.56
6	124.61	121.87	139.18	136.87	147.67	145.66
9	122.51	118.99	137.64	134.74	146.35	143.68
<b>BKI Standard (Biro Klasifikasi Indonesia, 2021)</b>	98	98	98	98	98	98

Table 8. Tensile test results

Immersed Time (Weeks)	differences between indoor and outdoor (%)			differences between immersed time (%)		
	3	5	7	3	5	7
0	0.00%	0.00%	0.00%	-	-	-
3	-1.05%	-0.68%	-0.42%	-3.11%	-2.21%	-1.61%
6	-2.08%	-1.40%	-1.15%	-5.11%	-4.50%	-3.54%
9	-3.55%	-2.53%	-1.95%	-9.62%	-7.79%	-6.30%

Table 9. Tables Differences between specimens' variation.

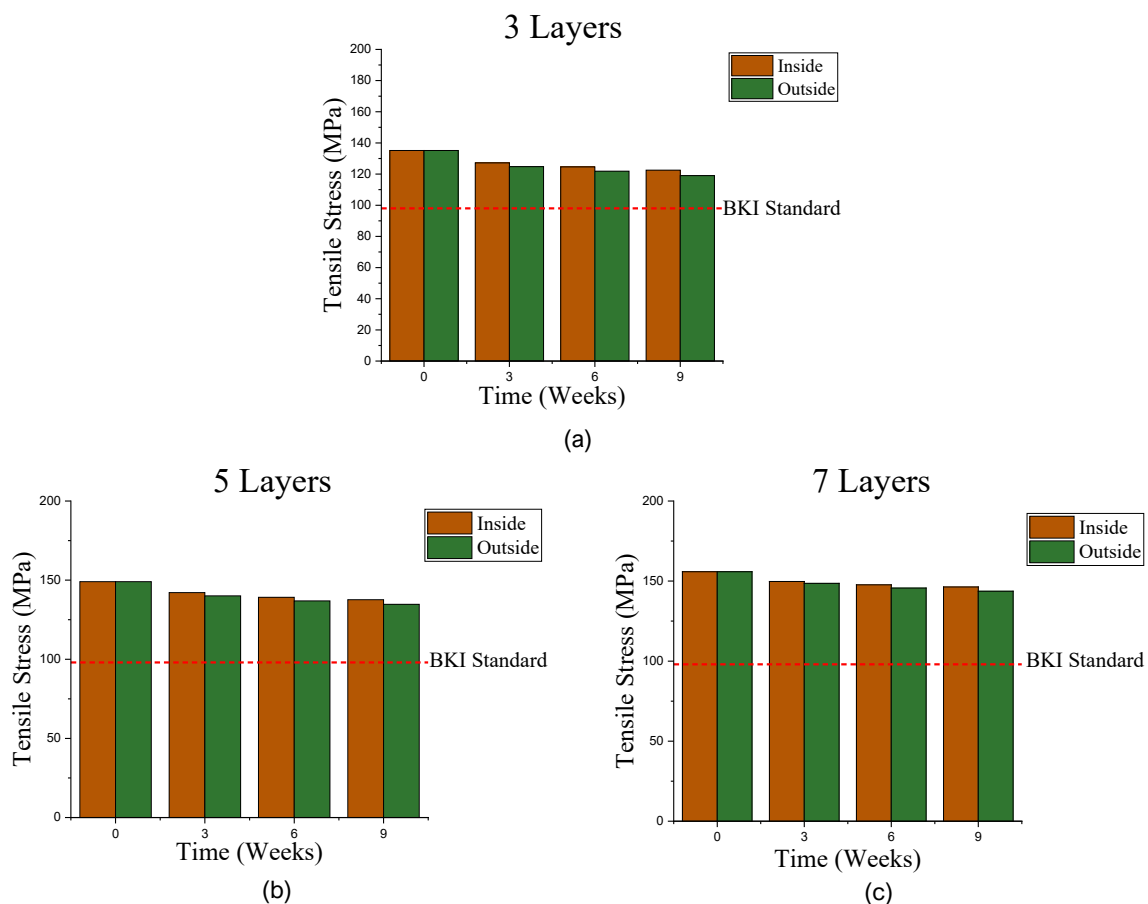


Figure 9. Comparison of Tensile Strength against variations in the number of layers (a) three layers, (b) five layers, (c) seven layers and variations in immersion time and immersion location.

## 4. DISCUSSION

The mechanical strength of laminated bamboo boards is affected by immersion time, location, and the number of layers, with lower results observed in impact, bending, and tensile tests. The most significant decreases occurred in the bending and tensile tests, with an average stress reduction of 7.90% for specimens immersed for nine weeks. This reduction is due to the bamboo laminate material absorbing water, with its moisture content increasing during prolonged immersion.

Chemically, the hygroscopic nature of bamboo fibers, which are rich in hydroxyl groups from cellulose and hemicellulose, facilitates water absorption through diffusion and capillary action, leading to swelling and increased moisture content (Wei et al., 2021; Zhao et al., 2022; Mohammed et al., 2023). This absorption can cause plasticization of the epoxy resin matrix, as water molecules penetrate the polymer chains, reactivating cross-linking reactions and weakening the interfacial bonds between the bamboo fibers and resin (Oliveira et al., 2022; Ahmad, Gowrishankar, and Shettar, 2025).

In brackish conditions, salts at salinity levels of 15–20 ppt exacerbate these effects by promoting ion exchange and osmotic pressure, potentially accelerating the degradation of hemicellulose and lignin. This results in debonding, void formation, and reduced tensile, bending, and impact strengths over prolonged immersion periods such as 6–9 weeks (Manik, Suprihanto, Nugroho, et al., 2021; Garzón et al., 2022; Gao et al., 2025). However, shorter immersion periods, such as 3 weeks, may initially enhance fiber-matrix adhesion by altering surface chemistry, removing extractives, and improving compatibility, leading to temporary improvements in mechanical properties before degradation occurs (Wang et al., 2019; Prashanth et al., 2025).

Additionally, mechanical properties differ between indoor and outdoor immersion, with values for specimens immersed indoors being higher by around 1–3% for all variations in layers and immersion times. This is because bamboo laminate material immersed indoors is more protected than outdoors, where it is directly exposed to air and sunlight.

Despite the decrease in mechanical strength for impact, bending, and tension, the Indonesian Classification Bureau regulations for tensile and bending testing require all specimens, regardless of layer variations, immersion time, and location, to meet minimum standards of 98 MPa for tensile strength and 150 MPa for bending strength (Biro Klasifikasi Indonesia, 2021).

Previous research (Manik, Rindo, and Alif Airlangga, 2020; Manik, Suprihanto, Sulardjaka, et al., 2021) tested the technical properties of laminated bamboo by immersing specimens in seawater and freshwater for various durations, showing the same trend. The mechanical strength of laminated bamboo decreases with longer immersion periods. According to this research, the loss in mechanical properties of laminated bamboo submerged in brackish water (5–9%) was less than in seawater (6–19%) but greater than in freshwater (1–8%).

## 5. CONCLUSIONS

The impact of brackish water on apus bamboo laminates intended for use as shipbuilding material has been successfully tested. The findings from this research include the following aspects:

The mechanical property values of the bamboo laminate with seven layers are the highest among the different layer configurations. The mechanical strength properties of all layer variations were reduced by 5–9% as the immersion time increased.

The seven-layer laminated board exhibits the highest impact strength when not immersed. In contrast, the laminated apus bamboo board with three layers shows the lowest impact strength after nine months of outdoor immersion. Specifically, the impact strength of the latter is measured at 170.11 KJ/m<sup>2</sup>, which is 7.29% lower than that of the non-immersed laminated apus bamboo board.

The bending strength of the laminated bamboo boards ranges from 238.65 MPa to 294.07 MPa. The seven-layer laminated bamboo board without immersion demonstrates the highest bending strength, while the three-layer variation subjected to nine months of outdoor immersion exhibits the lowest. This scenario results in a reduction of bending strength by 9.62%.

The tensile strength observed in the study ranges from 118.99 MPa to 155.82 MPa. The highest tensile strength was found in the seven-layer board without immersion, while the lowest was observed in the three-layer board after nine months of outdoor immersion, showing a reduction in tensile strength of 9.35%.

Although there is a reduction in the mechanical properties of the apus bamboo laminated board composites with three, five, and seven layers after 0–9 weeks of immersion, the data analysis and comparison with BKI standard rules as a safety requirement indicate that these laminates can be used as alternative ship hull materials, as they meet the minimum BKI standards.

For future work, investigating the microstructure of composite materials – including the effects of the number of layers in apus bamboo laminated boards, immersion period in brackish water, and temperature conditions – is particularly interesting. This could lead to a better understanding of how microstructural transformations influence the mechanical properties and long-term performance of apus bamboo laminated boards.

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