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Analysis of Salinity from Seawater on Physical and Mechanical Properties of Laminated Bamboo Fiber Composites with an Epoxy Resin Matrix for Ship Skin Materials

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Abstract – *The use of bamboo fiber as a natural composite material has been widely studied. The results of previous research indicate that Apus bamboo fiber is highly recommended as an alternative material to replace wood as ship's skin. This study examines the effect of seawater salinity on changes in the physical and mechanical properties of laminated bamboo composites, considering that ships are generally operated at sea. Apus bamboo fibers (Gigantochloa Apus) used in this study came from the Getasan Salatiga area, Central Java. The variables studied in this study have been variations in the number of layers totaling 3, 5, and 7 layers and blade thickness of 1 mm, 1.5 mm, and 2 mm, with the direction of the fibers crossing each other at an angle of $0^o/90^o$, and the average width of the bamboo slats has been 20 mm. Apus bamboo fibers are formed into boards reinforced with an epoxy resin with the hand lay-up lamination technique and are given a compressing pressure of 2 MPa, so that a board with a thickness of 6.5 mm with a fiber weight fraction 0.65%–0.75% is formed. The boards have been immersed in the sea for a period of 3, 6, 9, and 12 weeks. In order to determine the effect of seawater salinity on the physical and the mechanical properties of laminated bamboo, the specimen has been characterized by mechanical tests that include moisture content, specific gravity, shrinkage, tensile test, bending test, and impact test. The test results indicate that as the duration of immersion in seawater increases, there will be a decrease in tensile stress by 1.46%-2.61%, in the modulus of tensile elasticity by 1.14%-3.67%, in bending stress by 1.02%–2.28%, in the modulus of bending elasticity by 1.36%-3.45%, and in impact strength by 7.63%-11.51%. The test results on the physical properties of the test object have occurred based on an increase in water content, specific gravity, and changes in thickness dimensions on the test object.*

***Keywords**: Bamboo Fiber, Epoxy Resin, Laminate, Composite, Gigantochloa Apus, Salinity, Physical Properties, Mechanical Properties*

I. Introduction

Bamboo plants still grow naturally in many countries as grass plants [1]. In addition, bamboo has specific mechanical properties that are superior to the ones of other types of natural fibers, mainly because the fibers are arranged longitudinally [2]. The use of bamboo fibers as polymer reinforcement materials provides many benefits from various aspects, for example, the reduced material costs, the increased strength and durability, and the environmental friendliness. By contrast, thermoplastics or thermosets, such as polypropylene, polyethylene, polyvinyl chloride, polystyrene, epoxy, and polyester, have been commonly used as bamboo fiber composites [3]. Thermosetting polymers are needed to ensure several aspects that will occur, such as heat and high dimensional stability. This is closely related to its use, for example, as a composite adhesive that requires high adhesion and the use for electrical and thermal insulation materials that require very high strength and modulus. In another study, the composite has been tested with different dosages of polypropylene and sisal fibers (0.05%, 0.10%, 0.30%, and 0.50%). The results have indicated that adding polypropylene fibers in a cement matrix gives better results in terms of flexural tensile strength and an improvement in its ductile property compared to sisal fibers [4]. The test results of other studies also indicate that strengthening of the slabs with jute fiber strips significantly enhances the impact load strength [5]. In other study, two types of plant fibers (sisal and hemp) have been added to pure gypsum in order to study their effects on some gypsum properties. Different volumetric percentages (0.3, 0.6, 0.9, 1.2%) of each fiber type have been added to gypsum in order to produce several mixes. Moreover, silica fume has been added alone to gypsum with percentages of 1, 1.5, 3, 5% by weight of gypsum, and it has been added to the mixes with the sisal fibers in order to study their common effect. A 5 cm cube specimen and prisms with dimensions of 5×5×30 cm have been used for testing the compressive strength and modulus of rupture

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respectively and for various curing periods of 2, 7, 30, 90 days. The results show that the addition of hemp and sisal fibers with percentages of no more than 0.3% for hemp and 0.6% for sisal can improve the compressive strength and the modulus of rupture of gypsum products [6]. Another research result presents a new composite brick made of cellulose fiber packaged in a thin, hermetically sealed plastic block made from a set of recycled PET bottles, and coated with a layer of mortar.

The results of this study indicate that there are several advantages of this brick, including cost optimization, environmental sustainability, and ease of assembly in construction. These advantages have also been discussed in order to demonstrate their attractive use in building construction as well as their compliance with thermal and acoustical building code recommendations [7]. Research on the effect of synthetic short fibers on the mechanical properties of non-structural and structural fiber reinforced ultra-light aggregate (ULWAC) concrete is developed. The statistical parameters of fiber reinforced structural ULWAC have been determined, and the high cost has been associated with this type of concrete.

Ductility indices for plates and beams, which have the capability to exhibit strain-hardening prior to failure, have been calculated using energy-based method, and they have been above the minimum required value of 3 [8]. An experimental investigation has been conducted to assess the behavior of solid concrete bricks when subjected to compressive loading. Expanded Polystyrene (EPS) concrete has been added along with steel fibers in order to produce solid concrete brick units. Using EPS beads have been found to reduce the compressive strength of the solid concrete brick. This reduction has increased with the replacement ratio of EPS beads with coarse aggregate. The added steel fibers increase the compressive strength with increasing steel fibers content [9].

II. Literature Review and Problem Statement

Bamboo fiber is starting to get the attention of more researchers mainly because it has unique characteristics and regenerative character. In addition, its appearance looks more attractive when it is used as a reinforcing fiber in composite polymers. Because of that, apart from being relatively cheap, bamboo fiber composites also have natural advantages, namely good physical properties. The low cellulose content and the small microfibrillar angle of the bamboo fiber will result in high volume resistivity and excellent mechanical properties. Therefore, there is no doubt that bamboo fiber is a superior competitor as reinforcement in composite materials [10]. Bamboo Apus (Gigantochloa Apus) is commonly found in Indonesia, where it is commonly known as rope bamboo. At this time, Apus bamboo is widely used for handicraft materials such as bamboo fans, bamboo baskets, house plapon/asbestos, woven crafts, and others. Apus bamboo in the value of air content 12%-15% has a specific gravity value of 0.59 g/cm^3, a bending strength of 502.3-1,240.3 kgf/cm^2, a modulus of elasticity of 57.515-121.334 kgf/cm^2, and a tensile strength of 1.231-2,859 kgf/cm^2 [11]. Soaking using a sodium hydroxide (NaOH) or methanol solution has resulted in an increase and a decrease in the strength of the laminated bamboo. NaOH decreases the strength value of laminated bamboo because the fibers on the bamboo blade become course, making the epoxy resin damaged/faded [12]. Another researcher [13] has also stated that the use of lye in bamboo fibers will reduce the density of the bamboo fibers, thereby decreasing the tensile strength and modulus of elasticity. By contrast, the use of alkali will also increase the adhesive strength of the fibers to polyester type adhesives, because the bamboo fibers will become coarser so that the interface bond is stronger and the shear strength is higher.

The prototype of a ship using bamboo as a base material is offered as an alternative to wooden vessels, which are increasingly becoming rare nowadays. The results of the research that has been carried out indicate that vessels made of bamboo have higher strength, more security, and prices that are up to 50% lower [14] than those of than vessels made of wood. The use of laminated bamboo in vessel construction can reduce vessel skin thickness by 27% on 30 GT fishing boats when compared to the use of teak wood. This indicates that laminated bamboo has high strength and elasticity when given tensile and compressive loads. The manufacturing process is also easier and more flexible because there is no standard size, but it adapts to shipbuilding needs. Bamboo used in construction has the advantage of being able to be exposed to water, especially salt water, because bamboo fibers are considered stronger when exposed to salt water [15].

The glue interface on each cm^2 affects the bond strength of the laminated bamboo interfaces. With the same total composite volume in the test specimen, it indicates that the laminated composite type of Petung with the perpendicular fiber direction has the highest adhesive interface value per cm^2 so that its strength is the highest, compared to parallel, brick, and woven arrangements [16]. This is because the level of homogeneity increases and the strength of Petung bamboo is higher than the one of the epoxy resin glue used. The decrease in strength is also due to the presence of voids/holes in the specimen that from which damage initiates. In addition, the influence of the direction of the fibers that are not related to each other causes the specimen to crack easily. The smaller the thickness of the Petung bamboo blade is, the greater the value of the bond strength of laminated bamboo interfaces is [17]. The composite material from laminated bamboo and meranti wood can be used as construction material on wooden ships [18]. In previous studies, it has been stated that when it has been submerged for 0-9 weeks in seawater, the values of stress, modulus of elasticity, bending strength of the Petung-type bamboo laminate composite have decreased by 40% [19]. The average compressive strength of Petung bamboo laminates after being immersed in seawater for 9 weeks can be classified into Class II and Class III Strong in the BKI Timber Ship regulations. Requirements in the regulations of the Indonesian Classification Bureau (BKI) stated that Fiberglass Reinforced Plastics (FRP) ships are obligated to have a tensile strength of 98 N/mm^2, a modulus of tensile elasticity of 6.86 × 10^3 N/mm^2, a bending strength of 150 N/mm^2, and a modulus of bending elasticity of 6.86 × 10^3 N/mm^2 [20].

This study investigates the effect of seawater salinity on the quality of laminated bamboo composites. The type of bamboo studied has been rope bamboo or apus bamboo (Gigantochloa Apus). Apus bamboo has been chosen because it has flexible properties and it is easy to make into thin sheets. The variables studied in this paper have been variations in the number of layers, which have been 3, 5, and 7 layers, and blade thickness of 1 mm, 1.5 mm, 2 mm, with the direction of the fibers crossing between 0°/90°, whereas the width of the bamboo blades averaged 20 mm. The duration of the immersion time has been for 3 weeks, 6 weeks, 9 weeks, and 12 weeks in seawater.

III. The Aim and Objectives of the Study

The aim of this study is to investigate the effect of seawater salinity on the quality of laminated bamboo composites (gigantochloa apus laminae reinforced epoxy resin). In order to achieve the set aim, the following objectives have been formulated:

- Investigating the effect of soaking time duration on the physical properties of laminated bamboo composites;
- Investigating the effect of soaking time duration on the mechanical properties of laminated bamboo composites.

IV. Materials and Methods

This study uses two important materials, namely epoxy resin as a matrix material and Apus bamboo fiber (Gigantochloa Apus) as reinforcement.

Fig. 1. Epoxy Resin and Hardener

IV.1. Epoxy Resin

The adhesive material used for the bamboo lamination process is epoxy resin glue, which is commonly used in the maintenance of wooden ships and the manufacture of fiberglass boats. Epoxy resin adhesives consist of two components, namely epoxy resin and hardener that contain fillers. Epoxy resin is a type of adhesive that is thermosetting. This epoxy consists of two components, namely epoxy resin and hardener that are mixed at 50% each when used. Epoxy is used as putty as well as to cover damage to wood and metal. Epoxies are water resistant and in certain chemicals include oil, gasoline, some acids, and alkalis. The resin contains Bisphenol A (80%-90%), Modified Epoxy Resin (5%-15%), Alkyl Glyeidyl Ether (5%-15%), Mercapton Polymers (50%-60%), Tertiary Amine (5%-10%), Polyamide Resin (30%-35%), Triethylene Tetramine (<3%), and Alifatic Amine (1%-10%) with a compressive strength value of 56.94 MPa and a compressive elastic modulus of 570.37 GPa.

IV.2. Bamboo

Bamboo used in this study is the Apus bamboo (Gigantochloa Apus) that comes from the Getasan area, Salatiga Regency, Central Java. The age of bamboo used is 3-4 years, with an average diameter of 10-15 cm.

IV.3. Laminated Bamboo Board Manufacturing Process

Apus bamboo (Gigantochloa Apus) is formed into bamboo strips with three blade sizes with different thicknesses, namely 1, 1.5, 2 mm. The process of making laminated bamboo boards is as follows:

1. Apus bamboo is cut from the Getasan area, Salatiga Regency, Central Java. Bamboo stalks are cut above 1 meter from the ground. The part of the stem used for the research is above 1 meter to 4.5 meters from the ground;
2. The bamboo is cut according to the length of the segment crosswise (cross cutting) with the same length, namely following the length of the bamboo segment (La), ±40 cm;
3. The bamboo swabs are cut into several sections with a width of ±2 cm are then made into laminae using a blade saw machine. Lamina saws are used to make laminae with a width (Wa) of ±2 cm; then, the bamboo blades are cleaned;

Fig. 2. Apus Bamboo (Gigantochloa Apus)

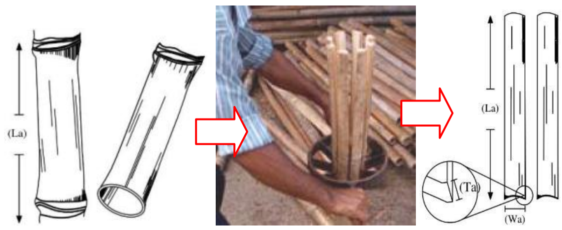

Fig. 3. How to cut the Bamboo Apus segment

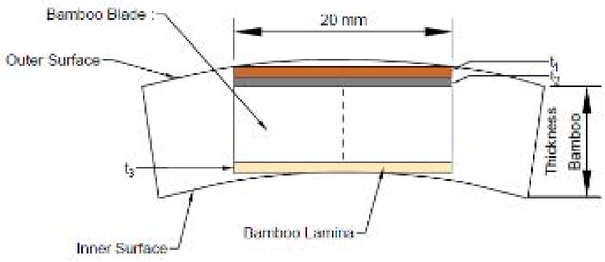

Fig. 4. The shape of the laminae
of the Apus bamboo (*Gigantochloa Apus*)

4. Formation of bamboo slats (four-side planning). This process is carried out to get the desired lamina thickness. In this study, the thicknesses of the laminae (Ta) have been 1, 1.5, and 2 mm;
5. Preservation of bamboo slats. The slats of bamboo lear that have been cut are then preserved by dousing them with a preservative solution in the form of borax, a preservative with a composition of 2.5% borax (Sodium Tetraborate) dissolved in water. The bamboo slats are doused with a borax solution while resting on the curing area;
6. The process of drying bamboo slats and measuring moisture content. The process of drying bamboo slats is carried out using an oven for 4-6 hours until the moisture content reaches 10%-20%. In this process, all the bamboo blades are measured for the level of moisture content so that, according to the test standards and specifications of the material, the moisture content of the material should be less than 13%;
7. The sorting process. Bamboo slats are grouped based on the thicknesses that are planned to make the laminate board;
8. The process of sanding (smoothing) bamboo slats. The bamboo slats, which have been grouped based on variations in thickness, are sanded using a sandpaper machine so that the surface is smooth and reaches a thickness in accordance with the planned blade thicknesses;
9. The process of forming a sheet (layers). In this process, bamboo strips are formed into sheets with the help of epoxy wood glue.
   Glue is applied to the left and right of the bamboo slats and then are glued together with other bamboo slats to form a sheet or layer with a size of 40 cm × 40 cm with the direction of the fibers parallel to (0°)/(90°);

Fig. 5. Apus Bamboo laminae

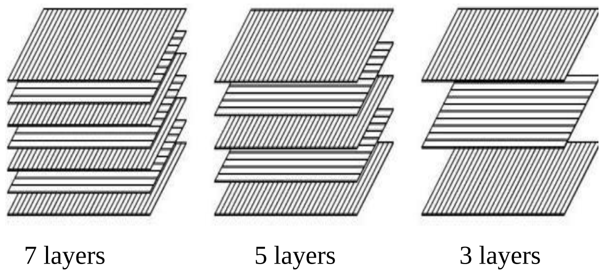

Fig. 6. Bamboo fiber sheets in the crossing degree direction of 0°/90°

10. Lamination process. The lamination process is carried out using the hand lay-up method to make laminate boards from bamboo fiber sheets. The mold surface is smeared with a release layer (silicon) to facilitate the removal of the laminated composite. Epoxy resin (component A) and hardener (component B) are mixed at a ratio of 1:1 and stirred until the physical color turns clear yellow. Then the mixture is applied evenly to the entire surface of the bamboo layer, and then, the layers are arranged by stacking on top of the molds that have been provided according to the planned variations in the arrangement and direction of the fibers;
11. Pressing. Pressing is done using a cold press machine at a pressure of 2 MPa or the equivalent of 30 bar. When the press pressure has reached the desired pressure, the bolts on the iron clamp in the mold are tightened. Laminated bamboo planks that have been pressed are left for 24 hours before being removed from the clamp so that the adhesion between the layers is maximized. This research has been conducted in a room with a temperature of 25 °C ± 3 °C and relative humidity of 60%-70%. The planned weight fraction of bamboo fiber is 65%-75%, with a weight fraction of epoxy resin of 25%-35%. The laminated bamboo board that has been formed will look like the image shown in Fig. 7;
12. Preparation of test specimens. Test specimens for testing physical properties. The physical properties test refers to the Indonesian National Standard (SNI) 01-5008.2-2000 concerning general use plywood, which was a revision of SNI 01-5008.2-1999 concerning general use of plywood and blockboard and SNI 01-7211-2006 concerning plywood for ships.

Fig. 7. Bamboo composite board
in the crossing degrees direction of 0°/90°

The physical characteristics of the research carried out in this study are as follows:

a. Water/moisture content test. The size of the test specimen (length × width × thickness) of 100 mm × 100 mm × 6.5 mm has measured the level of moisture content so that the initial water content value has been obtained according to the test standards and specifications of the MC for the required material; therefore, the moisture content of the material should be less than 13%;
b. Density test (ρ). The specimen used is the same size as the moisture content test sample; its size (length × width × thickness) is 100 mm × 100 mm × 6.5 mm. The test specimens are measured for length, width, and thickness using a caliper gage. Furthermore, the test sample is weighed to get the value of its air weight (BKU);
c. Shrinkage test. The size of the test specimen (length × width × thickness) of 50 mm × 25 mm × 6.5 mm has been measured using calipers for thickness to obtain initial dimensions in air-dry conditions.

Test specimen for testing mechanical properties:

a. Tensile test specimen. The tensile test has been carried out using ASTM standard D3039 at a specimen size of 250 mm × 25 mm × 6.5 mm;
b. Bending test specimen. The bending test has been carried out using ASTM standard D7264 at a specimen size of 130 mm × 13 mm × 6.5 mm;
c. Impact test specimen. The impact test has been performed using ASTM D256 at a specimen size of 63.5 mm × 10 mm × 6.5 mm.

IV.4. Treatment of Test Specimens

In order to analyze the effect of water salinity on changes in physical and mechanical properties of bamboo laminate composites, immersion in seawater has been carried out at intervals of 3, 6, 9, and 12 weeks in sea water. The location used for soaking test specimens in seawater is located at the shipyard of PT. Marina Indah services, the port area of Tanjung Mas Semarang.

The water conditions at the specimen immersion site have been water salinity ranging from 30 to 32 ppt, sea water specific gravity of 1.022 kg/liter, with outdoor temperatures of 34 °C-38 °C during the day and 21 °C-25 °C at night.

IV.5. The Process of Testing Laminated Bamboo Specimens

In order to analyze the physical and the mechanical properties of laminated bamboo, a mechanical test has been carried out at the Material and Construction Laboratory of the Department of Naval Architecture and Shipbuilding Engineering, Diponegoro University, Semarang. The test standards used are as follows:

1. Testing moisture content. The test specimen measuring 100 mm × 100 mm × 6.5 mm that has undergone a process of immersion in seawater is measured the level of water content (moisture content) so that the final water content value of the test specimen is obtained;
2. Density testing (ρ). The specimens of 100 mm × 100 mm × 6.5 mm, which have undergone a process of immersion in seawater, are weighed to determine the final weight. Furthermore, the test specimen is measured for length, width, and thickness using a caliper measuring device. The ratio between the final weight and the final volume will give the density of the test specimen;
3. Shrinkage and expansion test. The test specimen measuring 50 mm × 25 mm × 6.5 mm that has undergone a process of immersion in seawater is measured for thickness, length, and width using calipers in order to obtain the initial dimensions in wet conditions. The test specimens have been dried in an oven at 103 °C ± 2 °C for 4-6 hours until the moisture content reached less than 10%. Furthermore, the test specimen is measured again with the dimensions of length, width, and thickness with a caliper gage to obtain the final dimensions. Changes in the dimensions of the specimens before immersion, after immersion, and after drying will show their shrinkage.

Fig. 8. Water content and density test specimens

Fig. 9. Shrinkage test specimen

4. Tensile test. The tensile test has been performed using ASTM standard D3039 with a specimen size of 250 mm × 25 mm × *t* mm (*t* is the variation in specimen thickness). Tensile testing uses a Universal Testing Machine (UTM) type WE-1000B, with a maximum capacity of 1,000 kN. Each variation of the specimen has been repeated for five specimens. The shape and the size of the tensile test specimens are shown in Fig. 10;
5. Bending test. The bending test has been carried out using ASTM standard D7264 with a specimen size of 130 mm × 13 mm × *t* mm (*t* is the variation in specimen thickness). Tensile testing uses a UTM type WE-1000B, with a maximum capacity of 1,000 kN. Each variation of the specimen has been repeated for 5 specimens. The shape and the size of the bending test specimens are shown in Fig. 11;
6. Impact test. Impact testing aims to determine the clay or brittle properties of the laminated bamboo material against an impact. The impact test is located at the Materials and Construction Laboratory of the Department of Naval Architecture and Shipbuilding Engineering, Diponegoro University, Semarang, and the specifications for the tools are as follows: the impact energy is 300 J (big hammer) 150 J (small hammer), the impact speed is 522 m/s, and the pendulum angle is 150°. The standard impact test used is ASTM: D256. Each variation of the specimen is repeated for five specimens; the shape and the size of the impact test specimens are shown in Fig. 12.

Fig. 10. Tensile test specimens

Fig. 11. Bending test specimens

Fig. 12. Impact test specimens

V. Results and Discussion

V.1. Physical Properties Testing Results

1. Moisture Content test. Water content is the amount of water contained in the laminated bamboo composite, which is expressed in percent. The initial percentage of moisture content of the tested laminated bamboo composites has been 9.62% for three-layer composites, 9.72% for five-layer composites, and 9.86% for seven-layer composites. The results of testing the moisture content of the laminated bamboo composites after immersing them in seawater for a period of 12 weeks are shown in Figure 13. It shows the results of testing the percentage of moisture content of laminated bamboo composites after immersion in sea water for a duration of 12 weeks. There has been a change from 9.62% to 93.34% for three-layer composites, from 9.72% to 94.98% for five-layer composites, and from 9.86% to 96.84% for seven-layer composites. This shows that the longer the immersion time is, the higher the percentage of water content in the composite is. The effect of the variation in the number of layers on the percentage of water content does not really show a significant number, because the difference in the value of the water content that occurs is still below 5%. However, the variation of the seven-layer composite (96.84%) has showed the greatest change compared to the five-layer (94.98%) and three-layer (93.34%) composites.
2. Specific gravity (density) test. Density is the ratio between the mass of the composite and its volume. The composite density value will affect the mechanical properties of laminated bamboo composites. The initial density value of laminated bamboo composites based on the test has been 0.84 g/cm^3 for the three-layer variation, 0.86 g/cm^3 for the five-layer variation, and 0.88 g/cm^3 for the seven-layer variation. The results of testing the moisture content of the laminated bamboo composites after immersing in seawater for a period of 12 weeks are illustrated in Figure 14.

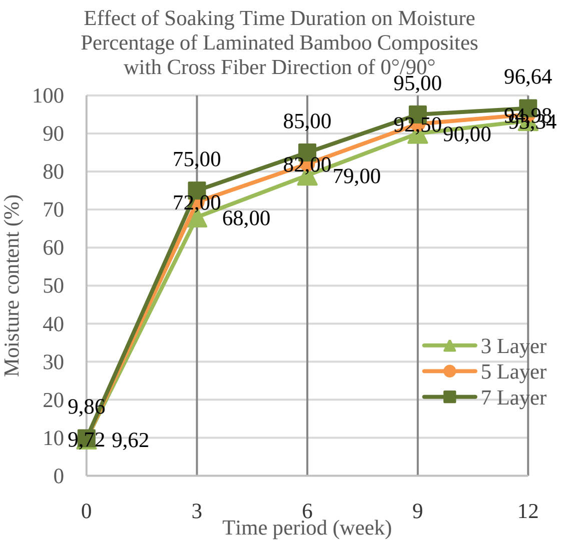

Fig. 13. Moisture value of laminated bamboo composites

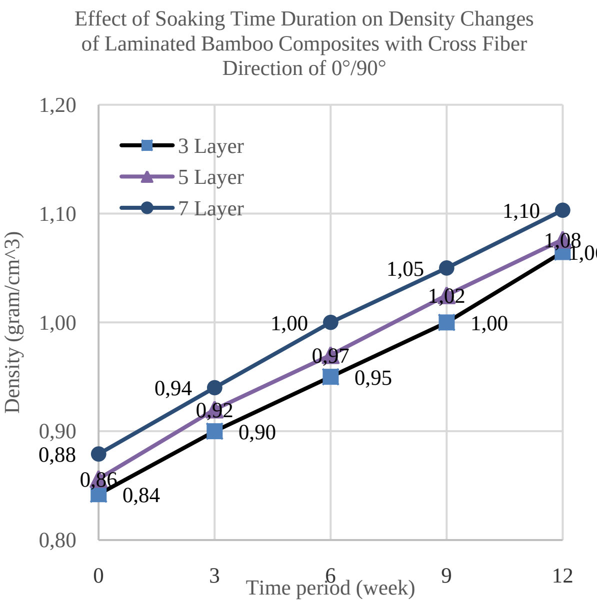

Fig. 14. Density value of laminated bamboo composites

3. Figure 14 illustrates the results of testing the density value of laminated bamboo composites after immersion in seawater for a duration of 12 weeks. There has been a change from 0.84 g/cm^3 to 1.06 g/cm^3 for three-layer composites, from 0.86 g/cm^3 to 1.08 g/cm^3 for the five-layer composite, and from 0.88 g/cm^3 to 1.10 g/cm^3 for the seven-layer composite. This shows that the longer the immersion time is, the higher the density value of the composite is. The effect of the variation in the number of layers on the density value of laminated bamboo composites does not really show a significant difference, because the changes that occur are still below 5%. The test results have also indicated that the variation of the seven-layer composite (1.10 g/cm^3) has showed the greatest change compared to the five-layer (1.08 g/cm^3) and three-layer (1.06 g/cm^3) composites.

4. Dimensional expansion and shrinkage test. Bamboo has hygroscopic properties that can absorb or release moisture in accordance with the moisture content in its environment, so the bamboo will experience dimensional changes, especially if there is a change in water content below the saturation point of the fiber. Dimensional changes can occur in the form of expanding or shrinking the dimensions of the test object. Testing of shrinkage has been carried out in order to determine the resistance of bamboo laminate composites to sea water and environmental weather.
   a. Dimensional expansion. The expansion of bamboo laminate composite dimensions consists of length, width, and thickness. The value of dimensional development can be obtained by comparing the dimensions of the laminated bamboo composite in air-dry conditions against the dimensions after being immersed in seawater for a duration of 3, 6, 9, and 12 weeks as shown in Figure 15. It shows the expansion of thickness dimensions in laminated bamboo composites along with the immersion time of up to 12 weeks, namely 10.56% for three-layer composites, 12.89% for five-layer composites, and 15.09% for seven-layer composites. The test results also indicate that the greater the number of layers that make up the composite is, the greater the thickness dimension expansion that results is, where the seven-layer composite has a greater thickness development compared to five-layer and three-layer composites. The expansion of the length and width dimensions of the composite has not experienced a significant change, because the test results have indicated that the change in the length and width dimensions has been still below 2% of the initial dimensions of the laminated bamboo composite specimen.

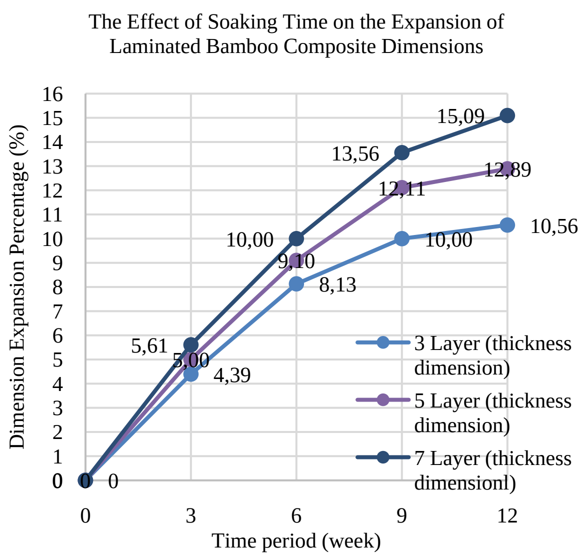

Fig. 15. Dimensional expansion values of laminated bamboo composites

b. Dimensional shrinkage. The shrinkage of bamboo laminate composite dimensions consists of shrinkage in length, width, and thickness. Dimensional shrinkage values can be obtained by comparing the dimensions of laminated bamboo composites in dry conditions against their dimensions after being immersed in seawater for a duration of 3, 6, 9, and 12 weeks and then being dried in an oven at a temperature of 103°C ± 2°C for 4−6 hours until the water content reaches less than 10%. Changes in the shrinkage value of laminated bamboo composites are illustrated in Figure 16.
It illustrates a reduction in thickness dimensions in laminated bamboo composites along with the immersion time duration of up to 12 weeks, namely 4.04% for three-layer composites, 5.09% for five-layer composites, and 6.18% for seven-layer composites.
The test results also indicate that the greater the number of layers that make up the composite is, the greater the shrinkage of the thickness dimension that occurs is, where the seven-layer composite experiences a thicker dimension shrinkage that is greater than the one of the five-layer and three-layer composites. The shrinkage of the length and width dimensions of the composite has not changed significantly, because the test results have indicated that the changes in length and width dimensions have been still below 2% of the initial dimensions of the laminated bamboo composite specimen.

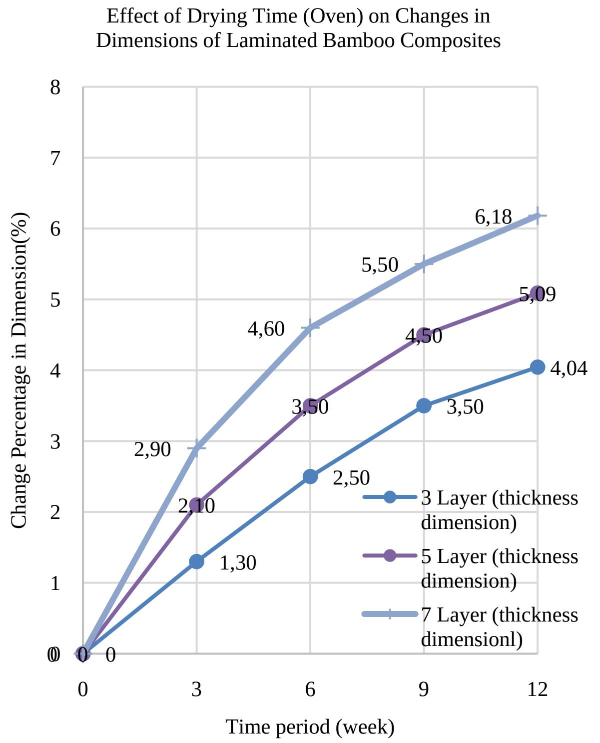

Fig. 16. Dimensional shrinkage value of laminated bamboo composites

V.2. Mechanical Properties Testing Results

1. Tensile test.
   a. Tensile stress. The value of tensile stress from the results of tensile testing on laminated bamboo composite specimens immersed in seawater for a period of 12 weeks is illustrated in Figure 17. It indicates a decrease in the tensile stress values due to the interaction of laminated bamboo composites with seawater for a duration of 0 to 12 weeks. In the three-layer specimen variation, after being immersed for 12 weeks, the tensile stress value has decreased by 1.46%. In the five-layer specimen variation, after being immersed for 12 weeks, the tensile stress value has decreased by 2.23%.
   In the seven-layer specimen variation, after being immersed for 12 weeks, the tensile stress value has decreased by 2.61%. The test results also indicate that the greater the number of layers in the composite is, the higher the percentage of drop in tensile stress is. Laminated bamboo composite with seven layers has the highest tensile stress compared to five-layer and three-layer composites.
   b. Modulus of tensile elasticity. The modulus of tensile elasticity from the results of tensile testing on laminated bamboo composite specimens immersed in seawater for 12 weeks is illustrated in Figure 18. It illustrates a decrease in the tensile elastic modulus value due to the interaction of laminated bamboo composites with seawater for a duration of 0 to 12 weeks.

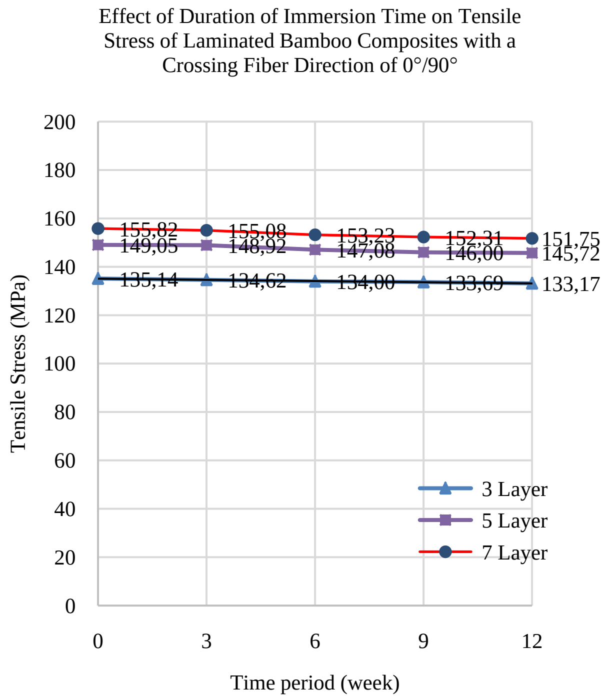

Fig. 17. The graph of the value of tensile stress against duration immersion time

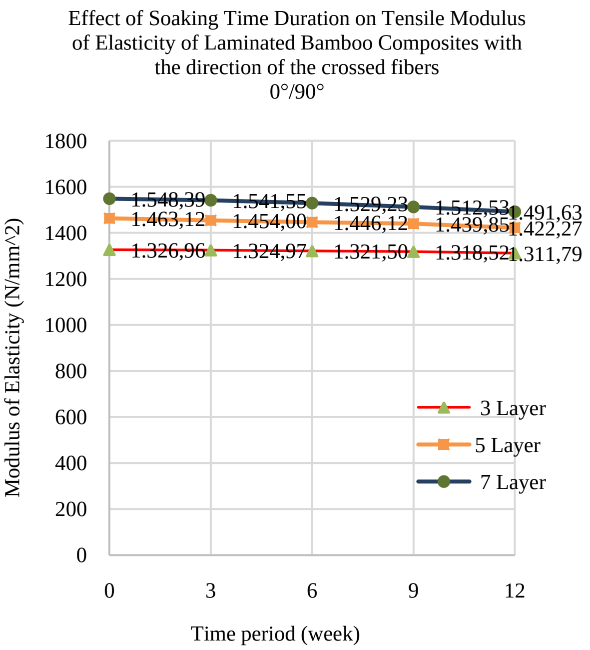

Fig. 18. Graph of the modulus of elasticity in drag with respect to immersion time

In the three-layer specimen variation, after being immersed for 12 weeks, the modulus of tensile elasticity is decreased by 1.14%. In the five-layer specimen variation, after being immersed for 12 weeks, the modulus of tensile elasticity is decreased by 2.79%.

In the seven-layer specimen variation, after being immersed for 12 weeks, the modulus of tensile elasticity is decreased by 3.67%. The test results have also indicated that the greater the number of layers in the composite is, the higher the percentage decrease in the tensile elasticity modulus of the laminated bamboo composite is.

2. Bending test.
   a. Bending stress. The bending stress value from the bending test results of the laminated bamboo composite specimens immersed in seawater for a period of 12 weeks is illustrated in Figure 19. It illustrates a decrease in the bending stress value due to the interaction of laminated bamboo composites with seawater for a duration of 0 to 12 weeks. In the three-layer specimen variation, after being immersed for 12 weeks, the bending stress value has decreased by 1.02%. In the five-layer specimen variation, after being immersed for 12 weeks, the bending stress value has decreased by 1.65%.

      In the seven-layer specimen variation, after being immersed for 12 weeks, the bending stress value has decreased by 2.28%. The test results have also indicated that the greater the number of layers in the composite is, the higher the percentage decrease in bending stress of laminated bamboo composites is.

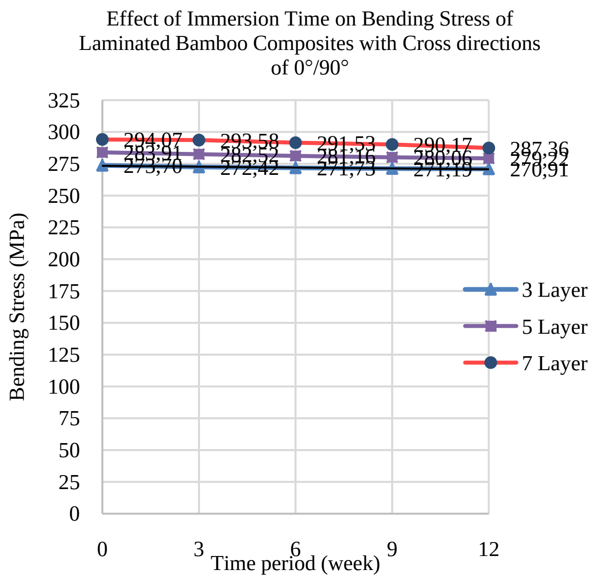

Fig. 19. Graph of the value of bending stress against immersion time

   b. Bending modulus of elasticity. The modulus of bending elasticity from the test results on a laminated bamboo composite specimen immersed in seawater for 12 weeks is illustrated in Figure 20. Figure 20 illustrates a decrease in the modulus of elasticity due to the interaction of laminated bamboo composites with seawater for a duration of 0 to 12 weeks. In the three-layer specimen variation, after being immersed for 12 weeks, there has been a decrease in the modulus of elasticity by 1.36%. In the variation of five-layer specimens, after being immersed for 12 weeks, the decrease in the modulus of elasticity has been 2.23%. In the variation of seven-layer specimens, after being immersed for 12 weeks, the decrease in the modulus of elasticity has been 3.45%. The test results have also indicated that the greater the number of layers in the composite is, the higher the percentage of decreased elasticity modulus of laminated bamboo composites is.
3. Impact test. The impact strength value of the impact test results on laminated bamboo composite specimens immersed in seawater for a period of 12 weeks is illustrated in Figure 21. Figure 21 indicates a decrease in the value of the impact strength due to the interaction of laminated bamboo composites with seawater for a duration of 0 to 12 weeks. In the three-layer specimen variation, after being immersed for 12 weeks, the impact strength value has decreased by 7.65%. In the five-layer specimen variation, after being immersed for 12 weeks, the impact strength value has decreased by 8.27%. In the variation of seven-layer specimens, after being immersed for 12 weeks, the impact strength has decreased by 11.51%. The test results have also indicated that the greater the number of layers in the composite is, the higher the percentage of the impact strength of the laminated bamboo composite is.

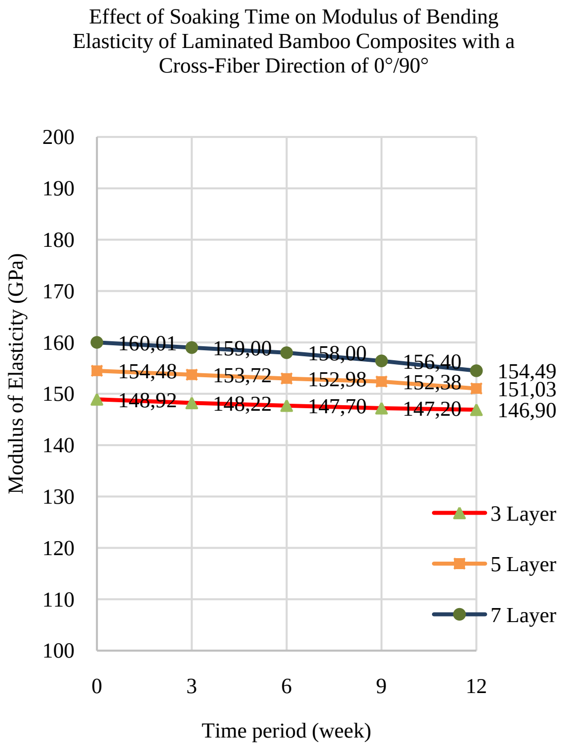

Fig. 20. Graph of the modulus of elasticity with respect to the duration of immersion

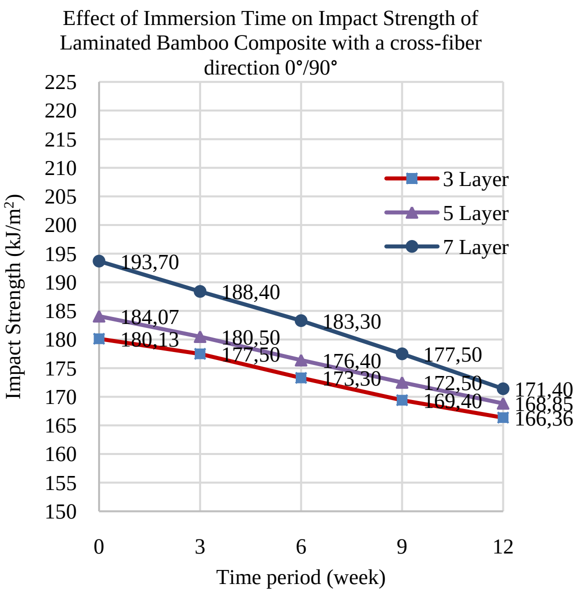

Fig. 21. Graph of impact strength against immersion time

V.3. Discussion

Soaking laminated bamboo composite specimens in seawater for duration of 3, 6, 9, and 12 weeks will affect the physical and mechanical properties of the test specimens. Longer immersion time has resulted in the increase of the percentage of water content in the test object from 9% to 96%. Epoxy resins are in the form of long molecular chains, and both their ends are reactive sites. This reaction is formed by epoxy groups, and the lack of an ester group means that this type of polymer is based on a chain epoxy that has excellent water resistance. The name "epoxy" refers to a chemical group consisting of one oxygen atom linked by two carbon atoms. An important property of any resin, especially in the marine environment, is its resistance to degradation as a result of the influence of water. The immersion time will result in an increase in the water absorption rate of the epoxy composition [21]. The test results have also indicated an increase in the weight of the test object from 0.84 g/cm^3 to 1.06 g/cm^3 for the three-layer specimen, from 0.86 g/cm^3 to 1.08 g/cm^3 for the five-layer specimen, and from 0.88 g/cm^3 to 1.10 g/cm^3 for the seven-layer test specimen. The interaction of the test object with seawater indicates a change in the dimensional shrinkage of the test object. The result of dimension measurement indicates that the thickness dimension of the test object has increased up to 15% from the original thickness and has decreased the thickness dimension after oven-drying by 6%. The change in thickness dimensions of the specimen is caused by the entry of seawater into the bamboo fiber pores through the side of the specimen, so that the bamboo fiber develops without any containment from the epoxy resin. In addition, the entry of sea water into the pores of the bamboo fiber will affect the interfacial bond of the composite fiber layer. The test results also indicate that the dimensional changes in the length and in the width of the specimens are not very significant (less than 2%). This is because the bamboo fiber layer on the specimen can be held back by epoxy resin, so the length and the width dimensions tend to be stable from the initial dimensions. The change in the percentage of water content increases with the duration of immersion and has a direct effect on the mechanical properties of laminated bamboo composite specimens. This can be seen from the results of the tensile, bending, and impact tests, which as can be seen in all the graphs above, indicate that there are decreases in tensile, bending, and impact strengths along with the increasing immersion time from 3 weeks to 12 weeks. The test results on the test object have indicated a decrease in tensile stress by 1.46%-2.61%, modulus of tensile elasticity by 1.14%-3.67%, bending stress by 1.02%-2.28%, modulus bending elasticity by 1.36%-3.45%, and impact strength by 7.63%-11.51%. The number of layers on the test object also affects the mechanical properties, since the test results show that the seven-layer laminated bamboo composite has a higher mechanical strength than the five-layer and three-layer laminated bamboo composites. According to Lettieri and Frigione [22], the entry of water causes plasticization of the adhesive and increases reactivation of cross-linking reactions, and physical aging occurs. An epoxy resin is a type of material that is less prone to degradation under the influence of water compared to other resins due to the lack of hydrolysis-sensitive ester groups in their molecular structure. The results have indicated that epoxy laminates will retain approximately 90% of their mechanical strength after being immersed in water for a year, whereas polyester laminates will hold approximately 65%. This is because polyester resins (including vinyl esters) are susceptible to degradation under the influence of water due to the molecular structure of the ester groups that are sensitive to hydrolysis.

By referring to the requirements required in the regulations of the Indonesian Classification Bureau (BKI) for ships made of FRP, they have a tensile strength of 98 MPa, a modulus of tensile elasticity of 6.86×10^3 MPa, a bending strength of 150 MPa, and a modulus of bending elasticity of 6.86×10^3 MPa [20]. The results of tensile testing and bending testing of laminated bamboo composites with cross-fiber directions in this study are still above the requirements of BKI for all the variations tested so that it is feasible to recommend the material for boat skin.

Fernades et al. [23] have found out that in a saltwater environment, the increase in crack toughness could be explained as a result of the interaction between two opposing factors. On one hand, adsorbed water causes less degradation (the glass transition temperature is reduced). On the other hand, this degradation does not adequately address the increase in ductility caused by adhesive plasticization. Heshmati et al. [24] have investigated the effects of aging adhesives on joints bonded in five different environments, including aqueous solution salt, at various temperatures (20 °C and 45 °C).

Among the reported results, tensile strength has been significantly degraded with increasing duration of immersion time. Uthan et al. [25] have also underlined that degradation adversely affects tensile strength, although the tensile modulus values do not decrease significantly. In the study presented by Heshmati et al. [26], the immersion time has been set at 210 and 840 days, whereas in this study, the longest aging time has been 90 days. Perhaps a longer period of immersion will lead to changes that are more significant. In the studied cases, the longest immersion time in water has been three months. Therefore, no significant reduction in strength parameters has been observed. According to Heshmati et al. [26], brine decreases the mechanical properties of the adhesive to a lesser extent than distilled water. Narynbek Ulu et al. [27] have underlined that the breakdown mechanisms (in the case of elastomers) in seawater are complex and not fully understood. Further research on laminated bamboo composites with an epoxy resin should be developed, since this is an interesting issue, especially in the field of using laminates and epoxy composites in ship construction, as well as superstructure for ships, which is also emphasized by Nash et al. [28].

The authors have also investigated a thermoplastic matrix infusion system that has compared the most commonly used matrix materials in marine structures under various immersion conditions and has developed a procedure to demonstrate which materials were suitable for marine ship construction.

VI. Conclusion

The interaction between the laminated bamboo composites and the sea water solution affects the quality of the physical and mechanical properties of the laminated bamboo composites. The longer the duration of immersion in the seawater solution is, the lower the mechanical properties of the laminated bamboo composites are. This is due to the increase in the percentage of water content in the composite specimen so that the interface bond between the fiber layers that hold up the composite will decrease. Increasing the percentage of moisture content in the laminated bamboo composite specimen will increase the density. The test results also indicate that there is a development in the thickness dimensions of the specimens after immersion and a decrease in the thickness dimensions after drying of the specimens in the oven. The effect of the number of layers on the formation of laminated bamboo composites indicates that there are differences in physical and mechanical properties. The test results indicate that more layers that form the composite show changes in physical properties and improved mechanical properties. The results of the mechanical testing of laminated bamboo composites in this study are still adequate to the requirements of the Indonesian Classification Bureau (BKI) for all the variations tested so that it is feasible to recommend the material for boat skin

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