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# Degradation of Epoxy Composites Reinforced with Hybridized Ramie Fibers and Glass Fibers When Exposed to Aggressive Environments

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***Abstract***— *This study aimed to examine the performance, durability, and long-term sustainability of composite materials. It is crucial to understand the effect of combining polyester composites with ramie fibers and glass fibers. This research utilized a range of experiments, including water absorption testing, tensile testing, bending, and observation of fault morphology using SEM. The tests were conducted on polyester composites reinforced with ramie fiber and glass laminate, both with and without immersion, in a 3.5% NaCl solution. The research employed the experimental method, as well as observation tests and literature studies based on relevant books and research journals. The focus was on material handling equipment, particularly ramie fiber, to gather necessary information on water absorption strength and the degradation of tensile and flexural properties caused by using artificial seawater. The objective was to develop a composite that could maintain its properties for applications in building structures. The analysis revealed that the aggressive environment had a significant effect on the tensile strength of the polyester composite reinforced with ramie fiber laminate when it was not soaked, as compared to the same composite after being soaked for 15 days in a 3.5% NaCl solution at a temperature of 50 °C. The initial tensile strength of the polyester composite reinforced with ramie fiber laminate was 15.097 MPa. However, after soaking, the tensile strength decreased to 8.733 MPa. The decrease was attributed to the water content in the composite, which adversely affected the interfacial adhesion between the ramie fiber and polyester matrix. Natural plant fibers, in this case, ramie laminate fibers, will swell due to the absorption of moisture or water so that they form a cavity at the fiber interface with the matrix, which eventually causes cracks in the polymer matrix. This makes it harder for the composite to transfer loads from the polyester matrix to the ramie laminate fibers, which lowers its mechanical and dimensional stability. On average, the composites experienced this condition, which showed a sharp decline due to horizontal cracks in the interlayer.*

***Keywords***— *Degradation, ramie fiber, hybridization, epoxy.*

## I. INTRODUCTION

The field of engineering materials is advancing at a rapid pace. Humans constantly strive to discover breakthroughs that surpass their predecessors. Composite materials are extensively utilized due to their exceptional properties, outstanding qualities, lightweight nature, high strength, stiffness, corrosion resistance, and ability to withstand fatigue loads (Hadi et al.). Composite materials are increasingly being adopted by industries to manufacture cars, airplanes, and other equipment components. Therefore, this composite material needs to be studied and developed.

The use of composites is progressively growing across several sectors of life in the present manufacturing and construction industry. Composites are materials formed by combining two or more basic materials with distinct chemical and physical properties. Composites can be classified into three categories: particle-reinforced, fiber-reinforced, and structural composites (Kaw, 2005). Their applications are highly varied, including car bumpers, vehicle bodies, airplane bodies, boat bodies, and more. Fiber-reinforced composites are extensively utilized in devices that necessitate materials possessing a dual combination of strength and lightweightness. Fibers used in composites can be categorized into two types: natural fibers and synthetic fibers.

Presently, natural fiber composites are being increasingly utilized in various areas, particularly in the field of civil engineering. Composites reinforced with natural fibers have the benefits of being lightweight, biodegradable, and cost-effective. However, they also have certain weaknesses, one of which is their lack of durability. People enhance the durability of natural fibers by integrating synthetic fibers like glass fibers in various ways. Simply put, enhancing durability can be achieved by combining natural fibers with synthetic fibers.

No previous studies have been carried out on natural fiber composites by exposing them to aggressive environments. At the same time, the natural properties are not constant. The drawback of non-constant conditions is the risk that the parameters or treatment may not be consistent. Thus, this research aimed to expose the subject to artificially aggressive environments.

*Composites* are normally defined as the combination of multiple distinct materials, resulting in a unified entity with distinctive properties that differ from those of the original material. Considering composites' broad and diverse nature, the definition provided above only covers one aspect and point of view. Experts have proposed numerous more definitions of the understanding of composites. According to Nijssen (2015), a composite is a material structure comprising at least two macroscopically distinguishable materials that work together to achieve improved outcomes. Riswijk et al. (2021) define composites as hybrid materials consisting of polymer resins reinforced with fibers. These materials combine the excellent mechanical and physical properties of fibers with the appearance, bonding and physical properties of a polymer.

Composite materials are typically categorized according to the type of matrix employed, including polymer composites, cement composites, and metal composites. *Natural fiber composites* combine natural fibers as reinforcement and polymers as binders. Natural fiber composites are composite materials in which the reinforcing fibers are sourced from natural origins, making them renewable resources and carbon dioxide neutral. Alternatively, it can be described as a composite material consisting of natural fibers as the reinforcing material and a bio-based or synthetic material as the bonding material.

Ramie fiber is derived from the bark of the *Boehmeria nivea* plant. It is considered one of the world's strongest natural fine textile fibers. This fiber is commonly referred to as Chinese grass. The ramie plant is a perennial with a grass-like appearance that thrives and matures effortlessly in tropical regions. Ramie, belonging to the *Urtecaceae* family, is a perennial plant that generates a significant quantity of unbranched stems from subterranean rhizomes. Ramie fiber possesses exceptional strength, exhibits a glossy appearance, can absorb water, is resistant to tangling, and demonstrates resistance to bacterial growth. Due to these characteristics, ramie fibers are frequently employed with other fibers, such as cotton or silk.

Fiberglass is a form of fiber composite material that possesses the advantage of high strength while maintaining a low weight. Fiberglass is not as stiff and light as carbon fiber, but it is more durable and relatively cheaper in the market. Fiberglass is a frequently employed material in the construction of aircraft, boats, automobile exteriors or interiors, bathroom fixtures, swimming pools, septic tanks, water tanks, roofs, pipes, insulation for walls, surfboards, trash cans, and various other applications.

Unsaturated polyester resin, also known as polyester, serves as the composite's matrix material. This resin is also a constituent of thermoset resins. Thermoset polymers undergo a process in which liquid resins are transformed into hard and brittle solids by chemical cross-links, resulting in the formation of strong polymer chains.

This study examined the degradation of epoxy composites reinforced with hybridized ramie fibers and glass fibers when subjected to aggressive environments. The study emphasizes the work, stability, and long-term maintenance of composite materials, emphasizing their urgency. Understanding the effect of ramie fiber and glass fiber reinforcement on polyester composites is highly significant.

## II. RESEARCH METHODS AND MATERIALS

The research employed the experimental approach (true experimental research), specifically through direct observation and research tests conducted on the subject of study. To gather data, the researcher conducted a comprehensive literature review of books and research journals focused on material handling equipment, specifically ramie fiber. This effort was made to acquire the necessary information for the research. Given this data, the researcher intended to examine both the water absorption strength and the degradation of tensile and flexural properties due to the application of artificial seawater. The goal is to develop a composite material that can retain its properties for use in building structures.

The materials employed in this study include:

Before commencing research activities, it is essential to establish a research site that is conducive to and tailored to the requirements of composite manufacturing. Composite manufacturing can be conducted in a dry environment with enough ventilation. The next stage involves preparing composite materials, specifically resin, catalyst, and sisal fiber. Before purchasing resins and catalysts, it is crucial to verify that the brochure clearly indicates the expiration date, that the container is free from any leakage, and that the seal remains intact. Preparing personal protection equipment (PPE), including gloves, masks, and safety glasses, is equally crucial.

This study began by determining the necessary materials and establishing an appropriate and convenient site to create composites. Composite production can be conducted in a low-humidity environment with adequate air circulation. The next stage involves preparing composite materials, specifically resin, catalyst, hemp fiber, and glass fiber. Before purchasing resins and catalysts, verifying that the brochure clearly indicates the expiration date, that the container is free from any leakage, and that the seal remains intact is crucial. It is equally crucial to set up preparations for personal protection equipment (PPE), such as gloves, masks, and safety glasses. The required ingredients are as follows:

1. Natural fibers: The natural fibers utilized are ramie fibers derived from natural sources.
2. Glass fibers: The glass fibers utilized in this study is random glass fiber.
3. Epoxy resin: The matrix employed is epoxy resin, which is combined with a catalyst to serve as a hardening agent for the resin. Another essential component is acetone, which is required to effectively remove any residual resin that may be adhered to the tools utilized throughout the composite manufacturing procedure. Acetone is exclusively used on undried resins. Aside from acetone, the use of release agents is necessary to aid in the separation of composites produced with glass molds. The research utilized Miracle Gloos as a specific sort of releasing agent.

This study utilized Bakelite® EPR174 epoxy resin, specifically the type derived from epichlorohydrin bisphenol A. This resin has been extensively studied and is commonly used as a binder for natural fibers. Its viscosity falls within the medium-to-high range and exhibits a high heat distortion temperature.

## III. RESULTS AND DISCUSSION

This study provides data obtained from several tests, including water absorption testing, tensile testing, bending, and observation of fault morphology using scanning electron microscope (SEM). The tests were conducted on polyester composites reinforced with ramie/glass fiber laminates. The composites were tested with and without immersion in a 3.5%

NaCl solution. The data were then processed and discussed as follows:

## *3.1 Aggressive Environment Influences*

### *3.1.1 The Effect of Aggressive Environment on Tensile Strength*

An experiment was conducted to examine the tensile characteristics of polyester composites reinforced with ramie fiber laminates. Test specimens were subjected to two conditions: one without soaking or immersion and the other with immersion in a 3.5% NaCl solution for 15 days. The results of the tensile test are presented in Table 3.1 below. A graph is made based on the data provided in Table 3.1, as shown in Figure 3.1.

TABLE 3.1 the numerical values for the tensile strength, elongation, and elastic modulus of composites.

| Sample | Tensile strength (MPa) | Elastic modulus (MPa) | Elongation (%) |
|---|---|---|---|
| Normal (Ramie-Ramie-Ramie) Without Immersion | 15.097 | 678.04 | 5.028 |
| K1 (Ramie-Ramie-Ramie) | 8.733 | 304.91 | 5.357 |

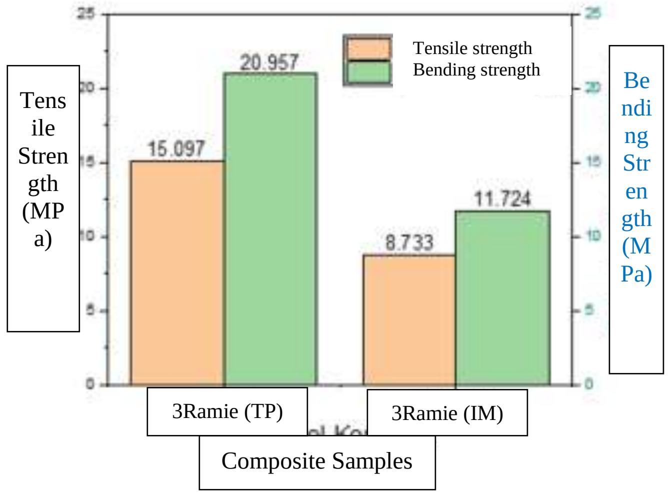

Figure 3.1 comparison of tensile strength of normal samples with 50°C immersion temperature.

According to Figure 3.1, the tensile strength of the polyester composite reinforced with ramie fiber laminate is higher before soaking than after soaking for 15 days in a 3.5% NaCl solution at 50 °C. The initial tensile strength of the polyester composite reinforced with ramie fiber laminate is 15.097 MPa. However, after soaking, the tensile strength decreases to 8.733 MPa. The drop results from water being absorbed into the polyester-laminate ramie composite. The presence of water in the composite will have a detrimental impact on the bonding between the ramie fiber and polyester matrix interfaces in the composite. Moisture absorption causes ramie laminate fiber, a type of natural plant fiber, to expand and create empty spaces at the interface between the fibers and the matrix. These empty spaces eventually lead to the formation of cracks in the polymer matrix. These processes, such as reduced load transfer between the polyester matrix and the ramie laminate fibers, lead to a decrease in the composite's mechanical properties and dimensional stability. This condition typically occurs in composites that exhibit a significant decrease in strength due to horizontal cracks in the interlayer.

These findings align with the research findings of Uner (2015), who reported similar results in their study on ramie fiber/epoxy composites. The composite's strength will decrease when water molecules infiltrate the material via the channels and capillary tubes of the fibers. They exert their influence at the boundary between epoxy and ramie fiber, resulting in the expansion of the sample. Therefore, the bond between the resin and fiber will be broken. The composite's mechanical properties may be enhanced due to a large amount of water, leading to fiber swelling that fills the void between the fiber and the polymer matrix. This can also explain why the tensile strength and Young's modulus of the composites decreased following a 15-day immersion in a 3.5% NaCl solution. Figure 3.2 below displays an image depicting the swelling mechanism and damage to the bonding interface between ramie fiber and polyester matrix.

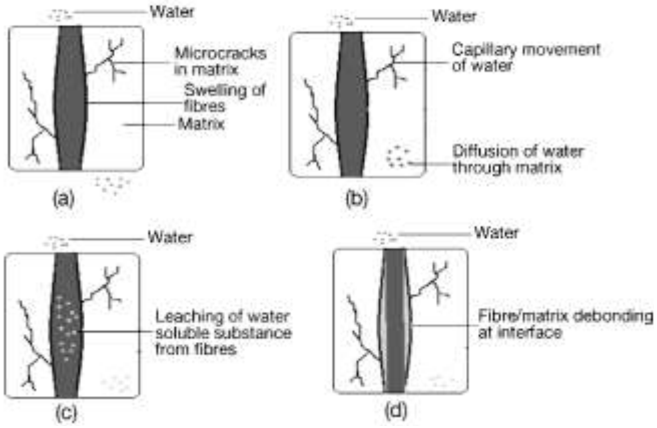

Figure 3.2 Water absorption mechanism of polyester composite reinforced ramie fiber laminate and its effect on fiber/matrix interface.

There are several reasons for this particular composite, which consists of polyester-reinforced ramie fiber, that contribute to the negative impact of water on its properties. The ramie fibers undergo swelling due to water absorption, increasing the likelihood of micro-cracks in the ramie-polyester laminate matrix. Water absorption can have a detrimental effect on the matrix due to processes including chain reorientation and shrinkage (Singh & Palsule, 2013). The presence of cracks and damage caused by cracks in the ramie-polyester laminate's matrix facilitates the capillary transport of water, which involves the movement of water molecules along the interface between the fiber and the matrix. The presence of water penetrates the interface, which can cause the bond to loosen during fiber-matrix interaction.

### *3.1.2 The Effect of Aggressive Environment on Modulus of Elasticity*

The value of the elastic modulus of the composite exhibits a similar declining pattern as the tensile strength of the composite. Figure shows that the 3Ramie (TP) composite has an elastic modulus value of 678.04 MPa. Following that, the sample 3Ramie (IM) had a reduction of 28.56% in its properties after being immersed in a 3.5% NaCl solution at a temperature of 50 °C for a duration of 15 days. The interfacial bond between ramie fiber and polyester is an essential element in attaining favorable mechanical properties. The strength of the interface significantly influences the mechanical properties of the composite. A weak interface will make the composite susceptible to damage. The fiber's moisture absorption and wettability affect the interfacial bond between the fiber and matrix. Debonding is more likely to occur when the fiber exhibits significant moisture absorption, poor wettability, and weak binding between the natural fiber and polymer matrix.

### *3.1.3 The Effect of Aggressive Environment on Flexural Strength*

This section also discusses bending experiments conducted on the same specimens and treatments. Table and Figure display the bending test results of a polyester composite reinforced with ramie laminate immersed in a 3.5% NaCl solution for 15 days at 50 °C.

TABLE 3.2 Bending strength of normal test specimens without immersion and immersion

| Sample | Bending strength (MPa) | Bending modulus (MPa) |
|---|---|---|
| Normal (Ramie-Ramie-Ramie) Without Immersion | 20.957 | 709.54 |
| K1 (Ramie-Ramie-Ramie) | 11.724 | 506.83 |

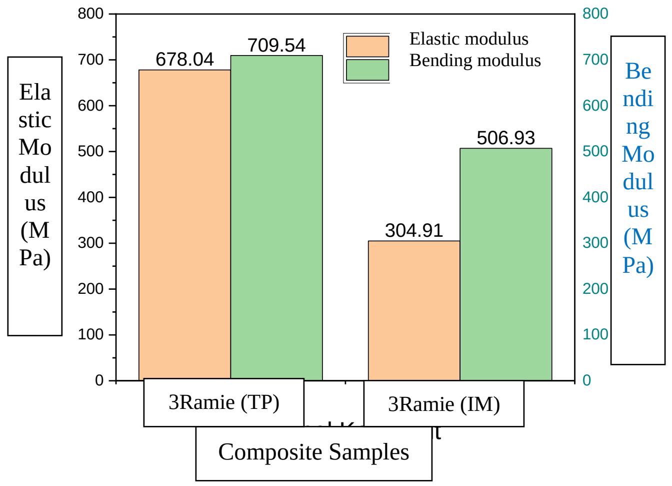

Figure 3.3. Comparison of modulus of elasticity of normal samples with immersion samples

According to the data presented in Table 3.2 and Figure, the bending strength results exhibit a similar pattern to the tensile strength of the ramie laminate-reinforced polyester composite. The bending strength of the polyester composite reinforced ramie laminate is significantly higher when it is not immersed compared to when it is immersed in seawater at 50 °C for 15 days. Specifically, the bending strength is 20.957 MPa without immersion and 11.742 MPa after immersion. The diffusion of a 3.5% NaCl solution into the composite causes the interfacial binding between the polyester and ramie fiber laminate to weaken. Water absorption causes a significant reduction in the composite's mechanical properties. The water absorption process leads to fiber swelling, which in turn triggers shear stress at the interface. Consequently, the fiber bonds are released from the epoxy matrix, resulting in a decrease in mechanical properties.

The mechanical properties of natural fiber composites in wet environments are influenced by various factors, such as the type of fiber, the fiber volume fraction in the composite, the temperature at which the composite is immersed, and the duration of immersion. Numerous previous studies have been conducted in relation to this one. Other studies using various composites have also documented the influence of different types of fibers on the water absorption properties and mechanical properties of sisal and ramie fiber composites when used as reinforcement with epoxy and polyester. According to Sahu and Gupta (2022), the ramie composites exhibited lower susceptibility to water absorption compared to the sisal composites. Additionally, they disclosed that the ramie/phenolic composites had a reduction in strength when moisture levels increased over varying time periods, affecting their physical and mechanical properties. In their study, Seki et al. (2011) investigated the behavior of ramie/polyester composites while exposed to distilled or fresh water and seawater. They discovered that the composites' interlaminar shear strength decreased as the immersion period in both types of water increased. JA et al. (2016) conducted a study where they created composites using Napier fiber and polyester. They found that the tensile and flexural strengths of these composites decreased with increasing immersion time. With an increase in the fiber volume fraction, there is a corresponding increase in the percentage of water absorption. This can be attributed to the elevated concentration of cellulose fibers present in the polymer composite. Therefore, the composite's tensile and flexural properties were found to decrease due to water absorption.

The bending modulus of the polyester composite-reinforced ramie fiber laminate is provided in Table 3.2 and Figure 3.2. The reduction in elastic modulus is significantly larger than the reduction in composite bending modulus, as depicted in Figure 3.2. The bending modulus of the polyester composite reinforced with ramie fiber laminate fell from 709.54 MPa to 506.83 MPa after being soaked in seawater at a temperature of 50 °C for a duration of 15 days. The inclusion of water in the polymer chain networks increases the chains' mobility, resulting in an increase in flexibility. This makes the polymer plastic and reduces its stiffness and mechanical strength., resulting in a decrease in its rigidity and mechanical durability. Although extended immersion can still result in significant water absorption, leading to potential irreversible damage, the material's tensile strength and elastic modulus can still be restored. The presence of a significant number of hydrogen bonds between the remaining water and the polymer chains may contribute to the rise in the elastic modulus (Zhou & Lucas, 1999b).

### *3.2 The Effect Of Composite Material Configuration*

#### *3.2.1. The Effect of Configuration on Tensile Strength*

The study involved testing the tensile strength of four samples: K1 (Ramie-Ramie-Ramie), K2 (Glass-Glass-Glass), K3 (Glass-Ramie-Glass), and K4 (Ramie-Glass-Ramie). Table 3.3 and Figure 3.4 below show the tensile testing data, specifically focusing on the effect of the laminate configuration.

TABLE 3.3. Tensile strength, elongation and modulus elasticity values of composites.

| Sample | Tensile strength (MPa) | Elastic modulus (MPa) | Elongation (%) |
|---|---|---|---|
| K1 (Ramie-Ramie-Ramie) | 8.733 | 304.91 | 5.357 |
| K2 (Glass-Glass-Glass) | 11.906 | 676.76 | 2.630 |
| K3 (Glass-Ramie-Glass) | 13.241 | 844.02 | 2.777 |
| K4 (Ramie-Glass-Ramie) | 14.013 | 834.03 | 3.765 |

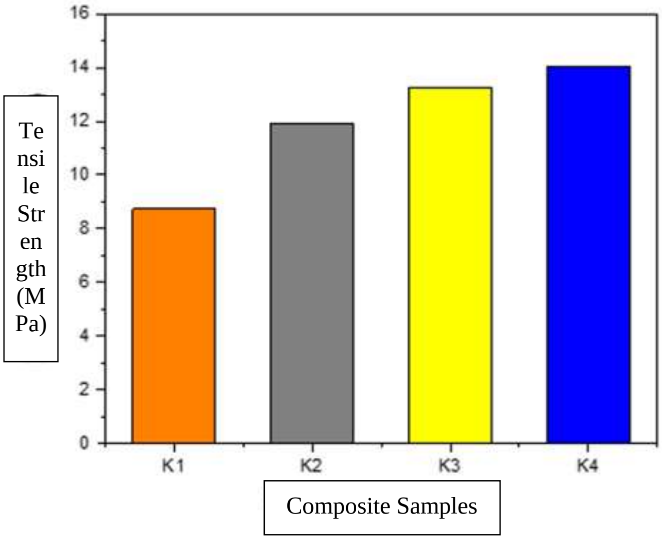

Figure 3.4 Comparison of tensile strength of composite samples with different configurations at 50°C immersion.

According to Figure 3.4, the tensile strength of sample K1 (Ramie-Ramie-Ramie) is 8.733 MPa, the lowest. Afterward, strength was significantly improved when the material was combined with fiberglass (sample K4, ramie-glass-ramie), reaching a value of 14.013 MPa. This is mostly attributed to the matrix's capacity to establish mechanical bonding with various fibers. The tensile strength of the K2 (fiberglass-fiberglass-fiberglass) composite remains lower than that of K3 (fiberglass-ramie-fiberglass) and K4 (ramie-fiberglass-ramie), which have strengths of 11.906 MPa, 13.241 MPa, and 14.013 MPa, respectively. This shows that the hybrid laminate process of ramie-fiberglass polyester composite makes it much stronger in tension, especially by cutting down on the need for fiberglass as a reinforcement composite. The increased tensile strength seen in sample K4 (ramie-fiberglass-ramie) is likely attributed to the change in bonding strength between layers resulting from the modification of the hybrid process sequence. Joseph et al.'s (2008) study on banana fiber/fiberglass hybrid composites found that increasing the thickness of layers composed of the same materials led to a greater occurrence of interlayer delamination. Hence, the alternating stacking sequence, which reduces the thickness of layers composed of similar materials, slows down crack propagation due to reduced interlayer delamination.

The results of this study are consistent with the research findings provided by Karimzadeh et al. (2020). They developed a hybrid reinforced polyester composite consisting of pineapple leaf fibers and fiberglass soaked in water. The tensile testing findings indicate that the arrangement of pineapple leaf fibers and fiberglass significantly influences the tensile strength of laminate composites. The tensile strength of the four pineapple leaf laminate composites was 47.07 MPa; the pineapple leaf-fiberglass-pineapple leaf laminate composite was 62.58 MPa; the pineapple leaf-fiberglass-pineapple leaf laminate composite had a tensile strength of 67.98 MPa; and the pineapple leaf-fiberglass-pineapple leaf laminate composite had a tensile strength of 119.21 MPa. Despite the uniform fiber volume fraction across all samples, the interlayer bond strength varied depending on the stacking sequences. Composites with alternating stacking order yielded optimal interlayer bond strength, resulting in higher mechanical properties. When composites have too strong bonds between layers, damage will not happen, but localized cracks will develop. Conversely, insufficient interlayer bond strength results in the rapid propagation of damage inside the composite. While the fiber volume percentage remains constant across all samples, the interlayer bond strength varies depending on the stacking sequences. Composites with an alternating stacking sequence yield optimal interlayer bond strength, resulting in higher mechanical properties. When composites have too strong interlayer bonds, damage will not happen; instead, local breaking will occur. Conversely, insufficient interlayer bond strength leads to rapid damage propagation inside the composite.

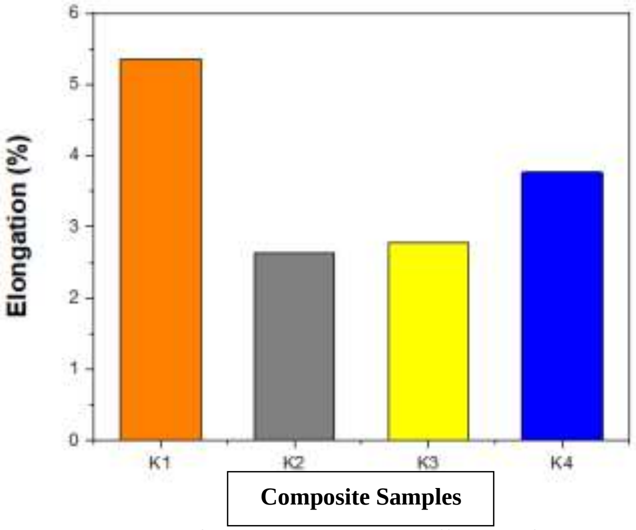

Figure 3.5 Elongation of composite samples with different configurations at 50°C immersion.

Figure 3.6 displays the tensile elongation of the composites from each developed variation. The elongation value of the composites is mostly determined by the composition and configuration of fiberglass and ramie. Composite K1 (ramie-

ramie-ramie) exhibits the highest elongation at 5.357%. Following this, composites K4 (ramie-fiberglass-ramie) and K3 (fiberglass-ramie-fiberglass) have elongation values of 3.765% and 2.777%, respectively. The lowest elongation is observed in composite K2 (fiberglass-ramie-fiberglass), with a value of 2.63%. The high elongation in sample K1 can be attributed to the inherent properties of natural fibers, which have a greater capacity for stretching than glass fibers (Septiyanto & Abdullah, 2019). A study by Septiyanto and Abdullahi (2019) investigated the properties of jute and e-glass fiber reinforced epoxy composites. The elongation values obtained for epoxy-jute and epoxy-glass composites were 8.9278% and 8.2299%, respectively, indicating a minimal difference. Furthermore, ramie fibers have a higher water absorption capacity (Figure 3.9). Consequently, when subjected to a tensile force, the fiber is prone to shifting or even pulling out before the composite material breaks. This factor is responsible for the increased elongation of composites with a greater amount of ramie fibers.

Figure 3.6 below displays the elastic modulus value for each variant of the composite reinforcing laminate.

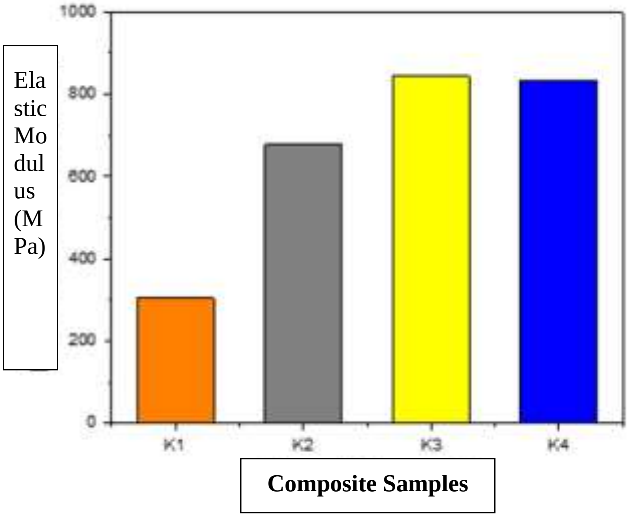

Figure 3.6 comparison of sample configuration elastic modulus

The illustration in Figure 3.6 shows how the configuration of layers in the laminate affects the elastic modulus of the composite material. The modulus of elasticity value of the composite has the same trend as the tensile strength of the composite. Among the samples, the K3 composite (fiberglass-ramie-fiberglass) has the highest elastic modulus value of 844.02 MPa. It is followed by samples K4 and K2, with values of 834.03 MPa and 676.76 MPa, respectively. The lowest elastic modulus value is observed in sample K1, which measures 304.91 MPa. The positive effect of the lamination process on composite reinforcement can be inferred from the modulus of elasticity or tensile strength of this composite, especially by reducing the use of glass fiber, which is less environmentally friendly.

The K3 composite contains a higher concentration of glass fibers, resulting in a more rigid bond at the ramie fiber interface than other composites. The effect of moisture attack on K3 specimens is stronger due to the waterproof nature of the fiberglass, which prevents moisture absorption. Hence, composites with a higher proportion of ramie fibers and exposed to a wet environment have reduced stiffness and tensile strength compared to other composites. Nevertheless, the K3 and K4 specimens exhibited superior tensile strength values compared to the other specimens, both in dry and wet environments.

### *3.2.2. The Effect of Configuration on Bending Strength*

Table 3.4 and Figure 3.8 present the bending strengths of polyester composite-reinforced ramie-fiberglass laminate variations. The average values of bending strength and bending modulus for all samples are calculated and reported in Table 3.4.

TABLE 3.4 Bending strength of polyester composite reinforced fiberglass-ramie laminate

| Sample | Bending strength (MPa) | Bending moduluss (MPa) |
|---|---|---|
| K1 (Ramie-Ramie-Ramie) | 11.724 | 506.83 |
| K2 (Glass-Glass-Glass) | 12.243 | 495.42 |
| K3 (Glass-Ramie-Glass) | 27.388 | 1600.4 |
| K4 (Ramie–Glass-Ramie) | 20.621 | 748.8 |

According to Figure, the ramie-fiberglass fiber laminate sample soaked in a 3.5% NaCl solution at a temperature of 50 °C for 15 days yielded the highest bending strengths. The sample with the highest bending strength was in the K3 (glass-ramie-glass) configuration, measuring 27,388 MPa. This was followed by sample K4 with a bending strength of 20,621 MPa, K2 with a bending strength of 12,243 MPa, and sample K1 with the lowest bending strength of 11,724 MPa.

The number of laminates between ramie fiber and fiberglass is consistent across all samples. However, the bonding strength between layers in the composite differs depending on the stacking sequence of the composite reinforcement. The composites with ideal interlayer bond strength specifically sample K3 and K4, exhibited superior mechanical properties. In composites with a sufficiently strong interlayer bond, damage will be prevented, yet flaws may still arise in certain local parts. On the other hand, low interlayer bond strength causes the damage to spread very quickly throughout the composite. Therefore, K2 (fiberglass-fiberglass-fiberglass) and K1 (ramie-ramie-ramie) composites have fairly low bending strength due to the low bonding interface between laminate layers.

The water absorption process is also increased for the K1 composite (ramie-ramie-ramie), leading to a decrease in mechanical strength. According to Septiyanto and Abdullah (2019), the bond between the fiber and the matrix impacts the bending strength of composites reinforced with synthetic or natural fibers. Jute fiber-reinforced epoxy composites have a lower average tensile strength than e-glass fiber-reinforced epoxy composites. The tensile strength of jute fiber-reinforced epoxy composites has not achieved equality with that of glass fiber-reinforced epoxy composites utilized in the industrial sector. Consequently, alternative natural fiber reinforcements are required that may attain a similar strength to glass fiber. Nevertheless, the mechanical strength of the fiberglass laminate composites in this study remains quite high.

Figure illustrates the bending modulus of each polyester composite reinforced with fiberglass-ramie laminate fibers. The K3 composite (fiberglass-ramie-fiberglass) possesses the highest bending modulus and strength, reaching a value of 1600.4 MPa. On the other hand, the K2 composite (fiberglass-fiberglass-fiberglass) has the lowest bending modulus of 495.42 MPa. It is noteworthy that the K1 (ramie-ramie-ramie) composite sample exhibits a slightly higher stiffness modulus of 506.83 MPa.

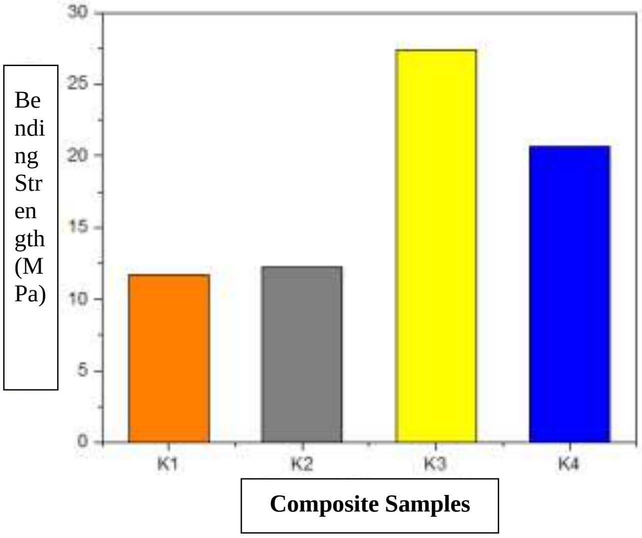

Figure 3.7. Comparison Chart of Bending Strength (MPa).

The observed occurrence is likely attributed to the larger size of the ramie fiber compared to fiberglass. This size difference hinders the binding or penetration of the polyester resin into the fiberglass lumps. This conclusion is supported by the scanning electron microscope (SEM) images, which reveal fiber pull-out. Similar to the tensile properties of the polyester composite reinforced fiberglass-ramie laminate, the K4 (ramie-fiberglass-ramie) composite is still quite dominant, like the K3 composite, with a bending modulus of 748.8 MPa (for the K4 composite). These bending modulus values once again confirm that to obtain the best composite mechanical characteristics, it is necessary to laminate natural fibers (ramie) with synthetic fibers (fiberglass), of which natural fibers (ramie) have weaknesses such as low moisture resistance, water absorption, and less resistance to heat.

In this study, immersion in a 3.5% NaCl solution at a temperature of 50 °C was conducted. Raising the temperature at which the polymer composite is immersed will result in a higher water absorption rate. In addition to fiber swelling caused by exposure to a wet environment, it generates internal stress within the composite, which can lead to failure at the interface between the fiber and matrix. Hence, a rise in moisture content can enhance the plastic deformation of composites made from natural fibers. Consequently, composites that combine natural fiber reinforcement on the outer layer of glass fiber will likely disrupt the network when they absorb water. The bamboo fiber and matrix absorb most of the water at the fiber interface. The water then proceeds to attack the interface between the fiber and the matrix, resulting in a decrease in the interface's strength. Water also leads to a decrease in the strength of both fiber and matrix. For the matrix, water causes plasticization, resulting in a decrease in the bending modulus of the composite.

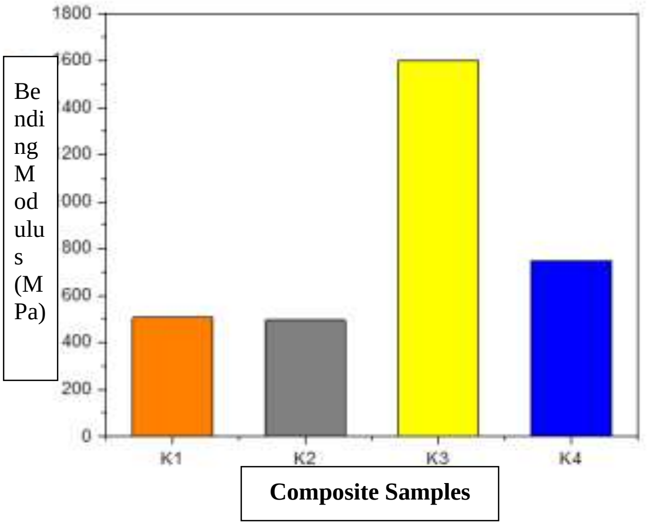

Figure 3.8 Bending modulus of composite samples with different configurations at 50°C immersion.

### *3.2.3. The Effect of Configuration on Water Absorption*

The water absorption behavior of a polyester composite reinforced with a fiberglass-ramie laminate fiber arrangement was tested in a 3.5% NaCl solution for a duration of 384 hours (15 days) at a temperature of 50 °C. The results of this test are presented in Figure 4.9. This test was conducted to measure the composite material's water absorption capacity under specific conditions and for a specific period. It helps determine the amount of water that the composite absorbs. According to Figure, the immersion configuration samples were exposed to water for 384 hours at a temperature of 50 °C. The results show that sample K2 (fiberglass-fiberglass-fiberglass) had the lowest water absorption rate, measuring 1.03%. This was followed by sample K3 (fiberglass-ramie-fiberglass) with a water absorption rate of 2.60% and sample K4 (ramie-fiberglass-ramie) with a water absorption rate of 4.39%. The sample with the highest water absorption is the K1 (ramie-ramie-ramie) configuration sample, which has a water absorption rate of 4.62%. Composites made of natural fibers exhibit water sensitivity because of their hydrophilic nature. During the early stages, all samples exhibited a significant increase in water absorption after approximately 48 hours of immersion at a consistent temperature of 50 °C.

The water absorption in these samples is a result of the natural fibers' ability to absorb water or moisture. The sample exhibits a higher water absorption capacity than the polyester resin. Natural fibers typically exhibit a water absorption capacity of approximately 11%–12% (Lokantara et al., 2009). As a result, the *ramie-ramie-ramie* laminate fiber-reinforced polyester composite demonstrates a water absorption rate four times higher than that of the *fiberglass-fiberglass-fiberglass* laminate-reinforced polyester composite. Increasing the volume percentage of ramie fiber in the composite leads to a higher absorption rate. Additionally, the bond between the matrix and ramie fiber creates a gap that facilitates water entry by capillarization (Dhakal et al., 2006). Furthermore, the remaining lignocellulose content and other impurities present in natural fibers have a tendency to exhibit increased water absorption.

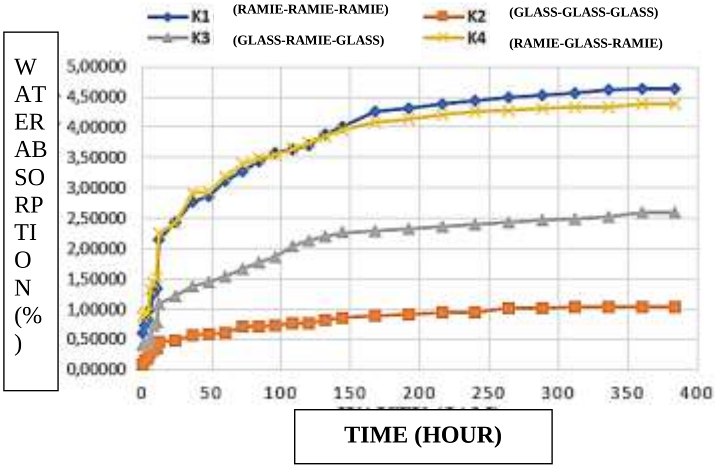

Figure 3.9 Comparison of water absorption of samples in the immersion configuration for 384 hours with a temperature of 50 °C.

Sugiman et al. (2019) have also discovered similar research findings utilizing different composites. According to their research, water absorption showed a linear increase during the initial soaking period of less than 100 hours. After that, the rate of water absorption decreased until it reached equilibrium. The water absorption also rose in proportion to the volume fraction of natural fiber. It has been noted that water absorption in the polyester composite reinforced *fiberglass-fiberglass-fiberglass* laminate fiber deviates significantly from the Fickian diffusion law, but for other volume fractions, water absorption follows this law. In addition, Sari et al. (2020) documented the water absorption characteristics of polyester composites reinforced with corn husk fiber, with a range of volume variations from 20% to 60%. According to their findings, after being soaked for 30 days, the composite sample of polyester-corn husk composite (40:60) absorbed the highest amount of water, which was 9.5%. As the amount of corn husk fiber increased, all composites showed increased water absorption capability. The polyester-corn husk (20:80) composite exhibited the lowest water absorption of 2.39% after being soaked for six days. Initially, the water absorption rate was higher, but it gradually dropped as the soaking duration grew. The composite's water absorption capacity and thickness development are directly influenced by its density. The presence of numerous voids and a weaker bond between the fiber and the matrix result in more water accumulation in the voids, leading to an increase in the composite's weight. According to the Indonesian National Standard (SNI) for particleboard quality, the permissible water absorption percentage should not exceed 14%. The water absorption value of the ramie and fiberglass composites still passes the SNI criteria.

### *3.3 Microstructure Analysis Based On Sem Test Results*

#### *3.3.1. SEM Images of Fiber Composition Fracture Morphology*

Figure 3.10 displays the fracture micrographs of the ramie fiber laminate-reinforced polyester composite samples before and after being immersed for 15 days during the tensile test. Scanning electron microscope (SEM) exams show signs of great post-cracking strength, demonstrating high ductility and energy absorption capacity. However, due to its composition as a polyester composite with ramie fiber laminate reinforcement, it may only be suitable for use in low-voltage structural buildings.

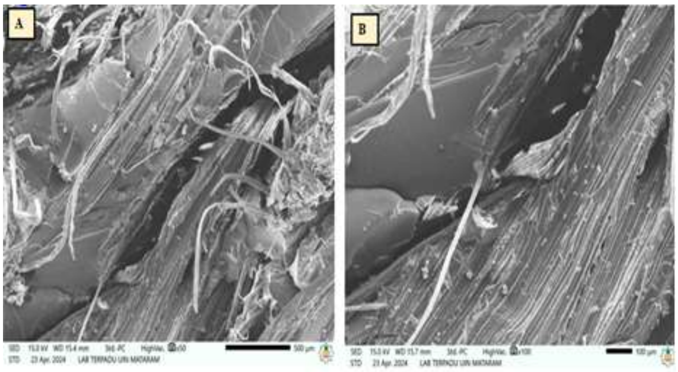

Figure 3.10. SEM images of the fracture morphology of sample K1 (ramie-ramie-ramie) without immersion.

As illustrated in Figure 3.10, the samples display a slightly rough surface before immersing in the NaCl solution, revealing noticeable voids on the polyester with Ramie fiber laminate. The infiltration of water into the interface diminishes its strength and leads to failure due to bond release and *fiber pull-out*. The primary reason for the prevalence of *fiber pull-out* in these composites is likely the presence of woven fibers, specifically the warp and weft made up of fiber bundles. These threads hinder the polyester resin's ability to fully permeate and bond with them, resulting in reduced adhesion.

Figure 3.11 displays scanning electron microscope (SEM) images depicting the fracture of sample K1 (ramie-ramie-ramie) during a 15-day immersion in a 3.5% sodium chloride (NaCl) solution. Based on the observations in Figure 3.10, it can be inferred that the composite's fracture surface becomes more uneven when it contains a higher number of voids. Additionally, micro-crack formations are clearly visible, and the openings appear large after immersion in NaCl solution. When comparing the surface morphology with that of the composites without soaking, the deformation of the polyester matrix is considerable through the formation of larger micro-crack openings, especially where the ramie fibers are dislodged. This observation is an additional indicator that water absorbed by the ramie fibers has a higher sensitivity to the occurrence of failures in the polyester matrix as well as *fiber pull-out.*

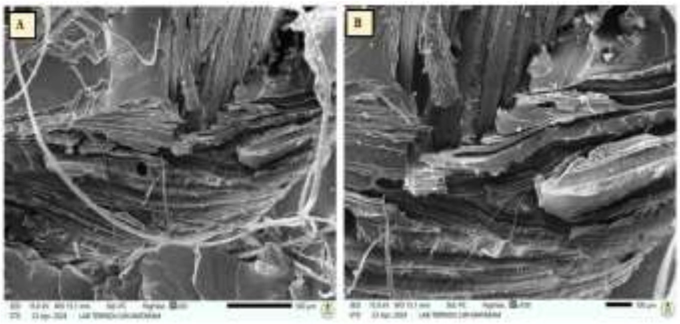

Figure 3.11. SEM images of the fracture morphology of sample K1 (ramie-ramie-ramie) with a 15-day immersion in 3.5% NaCl solution.

The figure displayed depicts a scanning electron microscope (SEM) image of the surface fracture of a K3 composite (fiberglass-ramie-fiberglass) after being immersed in a 3.5% sodium chloride (NaCl) solution for a duration of 15 days. It is clearly seen in Figure 3.10b that the interface bond between fiberglass-ramie fiber and polyester is less tight, and there is a cavity between the interfaces. This verifies that the NaCl solution has penetrated the surface, resulting in a decrease in density at the fiber-resin interface. Water absorption leads to evaporation, causing the fiber to shrink. This shrinkage ultimately weakens the interfacial binding, resulting in suboptimal mechanical strength.

### *3.3.2. Images of Fiber Configuration Composition*

The SEM test results comparing test specimens with different material arrangements or configurations are presented in Figure 3.12.

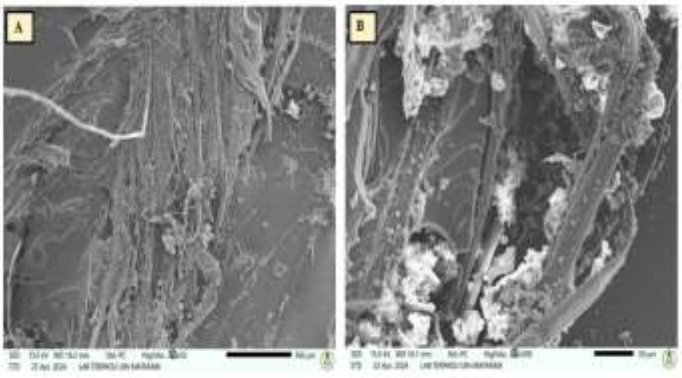

Figure 3.12 SEM images of fracture morphology of polyester composite K3 configuration (fiberglass-ramie-fiberglass) with 15 days of immersion.

It is clearly seen that pipe-shaped fiber pieces are pulled out (fiber pull-out). This phenomenon is observed in the composite area, indicating defects that occur during the composites' production process. The manual technique of combining fibers and matrix results in a less homogeneous mixture, leading to certain fiber surfaces not fully coated by the matrix. Another potential explanation is attributed to the composite soaking process, which facilitates water infiltration into the fiber pores, resulting in fiber expansion. This causes the fibers to be easily detached when given a load, ultimately reducing their ability to carry it.

## IV. CONCLUSIONS

According to the discussion section of the conducted research, the following conclusions can be drawn:

1. An aggressive environment significantly reduces the load-bearing capacity of the composite material. The unexposed composite had an average tensile strength of 15.097 MPa, whereas the exposed composite had an average tensile strength of 8.733 MPa. In addition, the unexposed composite material had an average flexural strength of 20.957 MPa, whereas the exposed composite material had a mean flexural strength of 11.742 MPa. The most probable cause of this is the diffusion of the 3.5% NaCl solution into the composite, which weakens the binding between the epoxy and the ramie/glass hybrid fiber at the interface. As a result of water absorption, the composite saw a significant reduction in its mechanical properties. The process of water absorption leads to the expansion of fibers, which in turn triggers shear stress at the interface. This ultimately causes the fiber bonds to detach from the epoxy matrix, resulting in a decline in mechanical properties.
2. The observations of various sample configurations suggest that the way the material is arranged has a significant effect on the composite's performance when it is exposed to aggressive environments. Sample K1 (Ramie-Ramie-Ramie) exhibited the lowest tensile strength, at 8.733 MPa. Following that, there was a significant increase in the value when the process of hybridization with fiberglass was carried out on sample K4. The value increased significantly, resulting in a tensile strength of 14,013 MPa. This is mostly attributed to the matrix's capacity to form mechanical bonds with different fibers. The bending strength test results, from highest to lowest, were as follows: sample K3 (glass-ramie-glass) with a strength of 27.388 MPa; sample K4 with a strength of 20.621 MPa; sample K2 with a strength of 12.243 MPa; and sample K1 with the lowest bending strength of 11.724 MPa. While the number of laminates between ramie fiber and fiberglass remains consistent in all samples, the bond strength between layers in the composite may change throughout various stacking series of composite reinforcement. There are other natural fibers that provide comparable strength to glass fiber.
3. SEM observation results indicate that immersion in a NaCl solution results in a surface that is slightly rough, with visible voids on the surface of epoxy reinforced with ramie or glass fibers. Moreover, the infiltration of water into the composite material diminishes the strength of the interface and leads to failure as a result of bond detachment and fiber extraction. The dominance of fiber pull-out in these composites can be attributed to the presence of woven fibers, specifically the warp and weft, which are composed of fiber bundles. This characteristic hinders the polyester resin's ability to fully penetrate and bind to the fibers. Water absorption leads to evaporation, causing the fiber to shrink. This shrinkage weakens the interfacial bond, resulting in suboptimal mechanical strength.

## REFERENCES

[1] Huner, U. 2015. Effect of water absorption on the mechanical properties of flax fiber reinforced epoxy composites, Adv. Sci. Technol. Res. J. 9 (26) (2015) 1–6, https://doi.org/10.12913/22998624/2357.

[2] Seki Y, Sever K, Sarıkanat M, et al. Aral, jute/polyester composites: the effect of water aging on the interlaminar shear strength (ILSS). In: 6th International Advanced Technologies Symposium (IATS’11), Elazı¬g, Turkey, 16–18 May 2011, pp. 368–371.

[3] JA, MH, Majid MA, Afendi M, et al. Effects of water absorption on Napier grass fibre/polyester composites. Compos Struct 2016; 144: 138–146.

[4] S. Joseph, M. S. Sreekala, P. Koshy, and S. Thomas, 2008. Mechanical properties and water sorption behavior of phenol–formaldehyde hybrid composites reinforced with banana fiber and glass fiber. J. Appl. Polym. Sci., 109, 1439 (2008).

[5] Karimzadeh, A., Yahya, M. Y., Abdullah, M. N., & Wong, K. J. (2020). Effect of Stacking Sequence on Mechanical Properties and Moisture Absorption Characteristic of Hybrid PALF/Glass Fiber Composites. Fibers and Polymers, 21(7), 1583–1593. doi:10.1007/s12221-020-9640-2.

[6] Rahmat Firman Septiyanto, Akbar Hanif Dawam Abdullah, 2019. Perbandingan Komposit Serat Alam dan Serat Sintetis melalui Uji Tarik dengan Bahan Serat jute dan E-glas. in Gravity Jurnal Ilmiah Penelitian dan Pembelajaran Fisika. November 2019. DOI:10.30870/gravity.v1i1.2536.

[7] Sari, N. H., Pruncu, C. I., Sapuan, S. M., Ilyas, R. A., Catur, A. D., Suteja, S., … Pullen, G. (2020). The effect of water immersion and fibre content on properties of corn husk fibres reinforced thermoset polyester composite. Polymer Testing, 106751. doi:10.1016/j.polymertesting.2020.106751.

[8] S Sugiman, P D Setyawan, B Anshari. 2019. Effect of fiber length on the mechanical properties and water absorption of bamboo fiber/polystyrene-modified unsaturated polyester composites. IOP Conf. Series: Materials Science and Engineering 532 (2019) 012008. doi:10.1088/1757-899X/532/1/012008.

[9] Diharjo, K. (2006). Pengaruh Perlakuan Alkali terhadap Sifat Tarik Bahan Komposit Serat Rami-Polyester. Jurnal Teknik Mesin , 8-13.

[10] Djamil, S., Lubis, S. Y., & Hartono, d. (2014). Kekuatan Tarik Komposit Matrik Polimer Berpenguat Serat Alam Bambu Gigantochloa Apus Jenis Anyaman Diamond Braid dan Plain Weave. Jurnal Energi dan Manufaktur , 5-8.

[11] Lies Banowati, H. H. (2020). Analisis Perbandingan Kekuatan Tarik Komposit Rami/Epoksi Dan Hibrid Ramie-Glass/Epoksi. ISSN 2087 – 9245, 50-89.

[12] Lokantara, I. P., Suandana, N. P., & Karohika, &. I. (2009). Jurnal Ilmiah Teknik Mesin CakraM . Efek Fraksi Volume Serat dan Penyerapan Air Tawar Terhadap Kekuatan Bending Komposit Tapis Kelapa/Polyester, 138-143.

[13] Rahardjo, T. (2008). Study Eksperimental Pemanfaatan Serat Rami (Boemeria Nivea) Sebagai Bahan Penguat Komposit Polimer Matrik Polistiren. Jurnal Flywheel, ISSN : 1979-5858, 20-33.

[14] Sabri, W. H., Fajrin, J., & Anshari, &. B. (2020). Perilaku Lentur Komposit Poliester Yang Diperkuat Dengan Limbah Serat Rami Dari Industri Tekstil. ISSN 1978-3787 .

[15] Suryawan, I. G., Suardana, N., Suarsana, I. K., Lokantara, I. P., & Lagawa, I. K. (2019). Kekuatan Tarik dan Lentur pada Material Komposit Berpenguat Serat Jelatang. Jurnal Energi dan Manufaktur, 7-12.

[16] Zakiyyah, F. Y. (2016). MEKANIKA. Pengaruh Variasi Arah Serat Komposit Berpenguat Hibrida Fiberhybrid Terhadap Kekuatan Tarik dan Densitas Material Dalam Aplikasi Body Mobil, 50-68.

[17] Boimau, K. (2020). Pengaruh Orientasi Serat Terhadap Sifat Tarik Komposit Poliester Berpenguat Serat Pisang. Lontar Jurnal Teknik Mesin Undana (LJTMU), 7(01), 23-27.