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Performance of Epoxy Composites Reinforced with of Hybridization Abaca Fiber and Glass Fiber in Aggressive Environment

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Abstract—*The use of polymer composite materials is currently increasing due to their perceived advantages over other alternative materials. Several benefits of this material include rigidity, strength, corrosion resistance, lightweightness, and cost-effectiveness. This study aimed to examine the performance of epoxy composites reinforced with hybridized abaca fibers and glass fibers in aggressive environments. This study examined the overall performance and configuration of the composite material. A total of 30 hybrid composite specimens were prepared, consisting of 15 specimens for tensile testing and 15 for flexural testing. The specimens were categorized into four configurations, each with two treatments. The first treatment served as a control and involved no exposure or soaking, consisting of six samples. The second treatment involved immersing the specimens in a chamber containing artificial seawater with a NaCl concentration of 3.5% for a duration of 15 days at a temperature of 50°C. This treatment included 24 samples. The composite material arrangement was configured as follows: (K_1) Abaca-Abaca-Abaca; (K_2) Glass-Glass-Glass; (K_3) Glass-Abaca-Glass; (K_4) Abaca-Glass-Abaca. Each configuration consists of six samples. These samples underwent tensile and flexural tests in accordance with the ASTM D3039 and ASTM D790 standards. The results showed that the aggressive environment affected the performance of the composites. The exposed (soaked) composites had lower tensile strength, flexural strength, and modulus of elasticity than the unexposed composites. There was a decrease in tensile strength of 12.43% and a decrease in flexural strength of 29.97% in the exposed specimens. This is because the water environment can cause the composite's strength to decrease due to the diffusion of water into the composite, thereby weakening the interfacial bond between the matrix and the fiber. The configuration of the composite material arrangement carried out in this study also showed that the tensile strength and flexural strength of the K_1 (Abaca-Abaca-Abaca) composite were higher than the other configurations. It is due to the characteristics of natural fibers that have high tensile strength, folding ability, buoyancy, resilience, bending, length, high porosity, and resistance to salt water.*

Keywords— *Epoxy composite, hybridized abaca fiber and glass fiber, aggressive environment, tensile test, and flexural test.*

I. INTRODUCTION

Utilizing natural fibers as reinforcement for polymer composites is a smart decision since they offer numerous advantages compared to synthetic fibers. The benefits of utilizing natural fibers include being easy to obtain at low prices, easy to process, environmentally friendly, harmless, renewable, and biodegradable. Some natural fibers, such as abaca, sisal, kenaf, and jute, are frequently utilized as composite reinforcement materials. The abaca plant (Musa textilis Nee) is a variety of banana plants whose fruit is not made use of; the fiber is extracted from its pseudostem, also known as the false stem. Abaca fibers provide high tensile strength, folding ability, buoyancy, bounciness, flexibility, length, high porosity, and resistance to salt water. Synthetic fibers are produced through chemical processes, in contrast to natural fibers, which are derived from living organisms. Glass fiber, a commonly utilized synthetic fiber, exhibits higher specific strength and rigidity compared to other materials, making it highly promising as reinforcement.

Hybridization is an approach to improving the mechanical or physical properties of composite-based materials by combining the weaknesses of one material with the strengths of another material through a specific bond. Over time, it has been known that the performance of natural fiber composites has decreased compared to synthetic fibers. Researchers have employed a process known as fiber hybridization to overcome this situation, mixing natural and synthetic fibers in a specific ratio to enhance the strength of the composite material. On a macroscopic scale, researchers combine composite materials to form a third material with new and improved properties. Composite materials basically consist of reinforcement and matrix. Reinforcement materials often consist of plastic or polymer materials, and matrix materials are generally fibers made of strong materials with each having different properties.

II. RESEARCH METHOD

This research aimed to examine the effect of an aggressive environment on composite performance and investigate the effect of composite material arrangement configuration on composite performance. In order to accomplish the objectives of this study, test specimens were created using two different layouts: Layout I, which is a simple comparative experiment, and Layout II, which is a single-factor experiment. Layout I included a control sample in the form of a normal test specimen that did not undergo soaking. The control sample consisted of three layers of abaca fiber. In Layout II, a comparison was made between the configuration of the composite material arrangement and the effects of aggressive treatment through immersion in artificial saltwater containing 3.5% NaCl for a duration of 15 days at a temperature of 50 °C in a chamber. The composite material arrangement was made in 4 configurations, namely K_1 (Abaca-Abaca-Abaca), K_2 (Glass-Glass-Glass) K_3 (Glass-Abaca-Glass), and K_4 (Abaca-

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Glass-Abaca). Tensile strength and flexural strength tests were carried out according to ASTM standards to assess the impact of aggressive environmental conditions on the performance of the composite material.

A. Materials

The research utilized abaca fibers, glass fibers, epoxy resin, and catalysts as its materials. The abaca fiber was purchased from PT Retota Sakti Magelang Production Unit, while the glass fiber was obtained from a provider located in West Jakarta. The abaca fibers utilized were long fibers cleaned and woven at a 90-degree angle with a fiber proportion of 25%. The epoxy resin and catalyst with a ratio of 1:1 utilized in this study were obtained from a supplier in the Sweta area, West Nusa Tenggara.

B. Samples

The composite manufacturing mixture is determined by the volume fraction proportion of natural fiber, synthetic fiber, and epoxy resin. The hand lay-up method is the most simple and practical way of producing composites in this study. The process commences by pouring resin into a container filled with hybridized fibers, followed by the application of pressure while simultaneously leveling it using rollers or brushes. The process is repeated until the desired thickness is attained, and then the composite surface is covered with glass. The mold can be made from materials such as plaster, wood, glass, sheet plate, and others.

Layout I samples were made from a total of 6 samples consisting of 3 layers of abaca fibers, placed in open air without being soaked or exposed, serving as a control. Layout II test specimens were made from a total of 24 samples consisting of 4 configurations of hybrid composite material arrays that were soaked or exposed for testing tensile strength and flexural strength.

C. Tensile Strength Testing

This test was conducted to analyze the extent of the resistance of the abaca fiber and glass fiber composite to the static loading given. The test principle involves applying a continuous, uniaxial (one-way) tensile load to test specimens of a specific size and shape until they break. Along with the tensile, observations were made of the length increase. Figure 1 illustrates the composite specimen's dimensions for the tensile test in accordance with the ASTM D3039 standard.

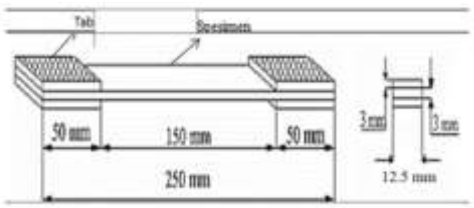

Figure 1. Tensile Samples

A schematic of the tensile testing be seen in Figure 2 below.

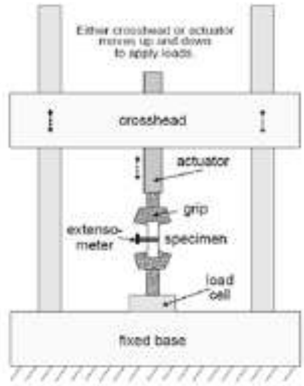

Figure 2. Schematic of tensile testing

D. Flexural Strength Testing

Flexural strength testing is carried out to determine the extent of composite resistance to flexural loads. It is conducted using the three-point bending method, which involves three loading points: two fulcrum points located at the edges of the test specimen and one loading point positioned at the center of the test specimen. The flexural testing was performed utilizing a Flexural Testing Machine (FTM) in accordance with the ASTM D790 standard, which regulates the flexural testing of plastic materials. Figure 3 illustrates the composite specimen's dimensions for the flexural test.

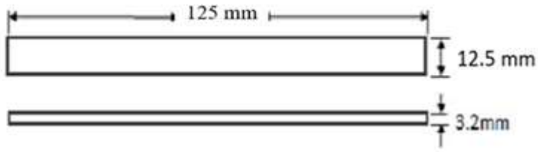

Figure 3. Flexural Samples

The schematic of the flexural testing can be seen in Figure 4 below.

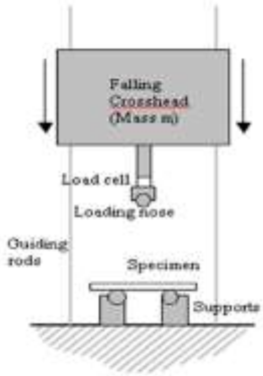

Figure 4. Schematic of flexural testing

III. Result and Discussion

A. The Effect of Aggressive Environment on Tensile Strength

Observations were conducted to examine the impact of aggressive environments on composite materials. Specifically, the study examined the effect of soaking on the mechanical properties of composites. The experiment compared composites that were exposed to open air without soaking (referred to as "normal") with composites that were soaked.

This comparison is referred to as "Layout I test specimens" (a simple comparative experiment). Tensile and flexural strength tests were conducted on six samples according to ASTM standards.

The findings showed that the aggressive environment affected the composites' mechanical properties (performance). In the tensile strength test, the unexposed or not-soaked specimens had a tensile stress value of 39.18 MPa, while the exposed specimens had a value of 34.31 MPa. Figure 5 below compares the average tensile stress values of unexposed (not soaked) and exposed specimens.

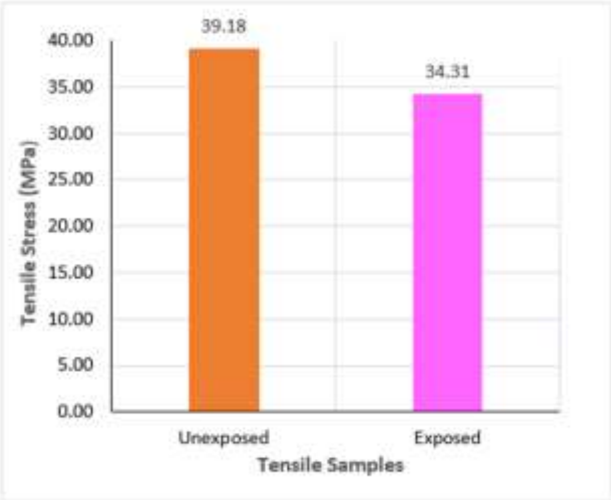

Figure 5. Comparison of the tensile strength of exposed and unexposed composites in aggressive environments

As shown in Figure 5, there is a difference in the average value of tensile strength of 4.87 MPa between the two groups of specimens. This result indicates that the aggressive environment decreased the tensile strength of the composite by 12.43%. The decrease in tensile strength is due to the destruction of the reinforcement-matrix-filler composite interfacial bond due to the penetration of water into the composite. Tododjahi (2014) found that soaking polyester composites in water for 30 days yielded the lowest tensile strength of 84.47 MPa. Conversely, specimens without soaking exhibited the highest tensile strength of 176.90 MPa. The decrease in tensile strength of the composite is due to the diffusion of water into the composite, which weakens the interfacial bond between the matrix and the fiber.

Data regarding the stress and strain experienced by each specimen was gathered while testing abaca fiber and glass fiber hybridized composites to determine their tensile strength. The stress and strain data were then analyzed to produce a composite elastic modulus value. The modulus of elasticity is calculated by dividing the stress by the elongation. Figure 6 displays a comparison between the tensile modulus and elasticity values of hybrid composites made from Normal specimens and K_1 specimens treated with aggressive environments.

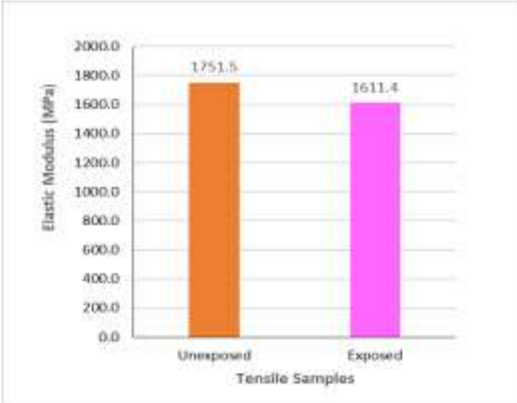

Figure 6. Comparison of tensile elastic modulus of exposed and unexposed composites

Figure 6 shows that the tensile elastic modulus of the unexposed (normal) test specimen is 1751.5 MPa, whereas the exposed specimen is valued at 1611.4 MPa. This is a drop of 140.1 MPa, or 8%. The decrease in elastic modulus value corresponds not only to the infiltration of water into the composite gap but also to the temperature of the soaking water. When warm or hot water molecules enter the polymer chain, the composite has more room for relaxation of the polymer molecules, causing a decrease in tensile strength and tensile elastic modulus. This is due to the breakdown of the reinforcement-matrix-filler composite interface bonding due to water ingress. A high amount of water causes fiber swelling, which can fill the gap between the fiber and the polymer matrix and ultimately improve the composite's mechanical properties.

B. The Effect of Aggressive Environment on Flexural Strength

The objective of testing the flexural (bending) strength of hybridized composites made of abaca fiber and glass fiber is to ascertain the maximum value of bending stress that the composite can withstand. Bending tests are commonly employed to determine the flexural modulus or flexural strength of hybrid composites. Flexural strength testing was performed using the ASTM D-790 standards. Figure 7 displays the results of testing the flexural strength of both normal composites and composites that underwent aggressive environmental treatment.

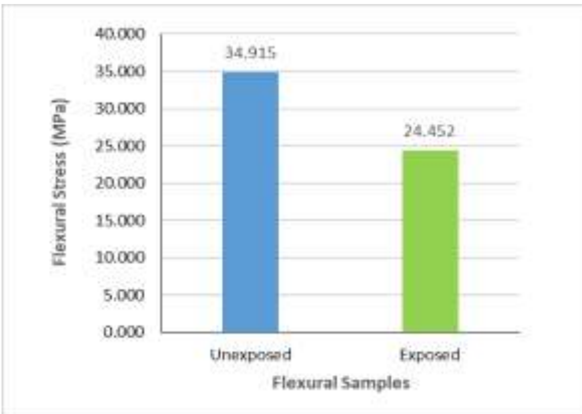

Figure 7 Comparison of flexural strength of exposed and unexposed composites in aggressive environments

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Figure 7 shows a difference of 10.463 MPa in the average flexural strength between the two groups of specimens. These findings indicate that the aggressive environment caused a decrease of 29.97% in the flexural strength of the composite material. The decrease in flexural strength is a result of water infiltration into the composite gap during the soaking process. The process of soaking results in the absorption of water into the composite parts, including small cavities and fibers. This absorption occurs owing to the voids that are captured during the composite production process. As a result, the water absorption leads to an increase in the weight of the tested composite. This aligns with the research conducted by Tododjahi (2014) on the effect of soaking on the mechanical properties of glass fiber-reinforced polyester composites. The test results show a strong correlation between the strength of a composite material and environmental influences, especially in aggressive environments. The present study employed the hand lay-up method. The results revealed that specimens immersed in water for 30 days had the lowest bending strength at 113.77 MPa, while specimens without immersion treatment obtained the highest bending strength at 279.40 MPa.

Figure 8 below presents a comparison of the bending modulus of elasticity values between normal specimens and exposed specimens with the same fiber composition (Abaca-Abaca-Abaca).

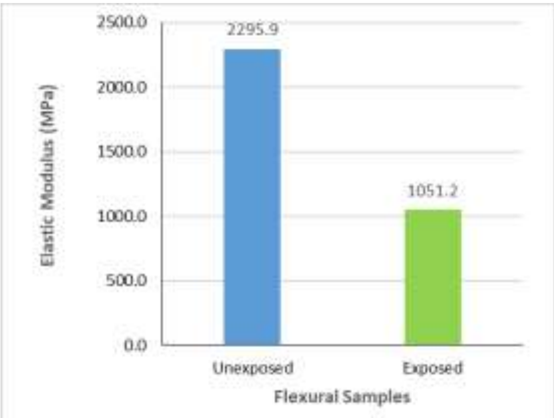

Figure 8. Comparison of flexural elastic modulus of exposed and unexposed composites in aggressive environments

Figure 8 shows that the flexural modulus of elasticity for the normal unexposed specimens is 2295.9 MPa, while for the exposed specimen, it is 1051.2 MPa. This is a decrease of 1038.7 MPa, or 54.2%. Soaking the composite causes damage that weakens the bonding of the fibers with the matrix and even destroys the secondary bonds between polymer chains that play a role in the cohesion or bonding of polymer materials (Boubakri, 2009). Therefore, absorbed water reduces the mechanical cohesion of the composite, resulting in a decrease in the value of the flexural modulus.

C. The Effect of Composite Material Arrangement Configuration on Tensile Strength

The purpose of this study was to conduct tensile strength testing on composites made from a combination of abaca fiber and glass fiber. The objective was to find out how the arrangement of the composite materials affects its performance. The testing was done according to the ASTM D-3039 standard. The tensile characteristic response data of abaca fiber and glass fiber hybridized composites in four configurations are presented in Table 1.

TABLE I. Tensile Strength and Elastic Modulus of Composites

Configuration	Tensile Strength (MPa)	Tensile Elastisc Modulus (MPa)
K_1	34,307	1611,4
K_2	14,935	758,9
K_3	21,564	832.6
K_4	28,447	1023,6

According to the data in Table 1, the K_1 (Abaca-Abaca-Abaca) specimen exhibits the maximum tensile strength and tensile elastic modulus. The K_2 (Glass-Glass-Glass) specimen has the lowest tensile strength and the lowest elastic modulus. Figure 9 below provides additional details on the tensile strength test results for the composite of the four material arrangement configurations.

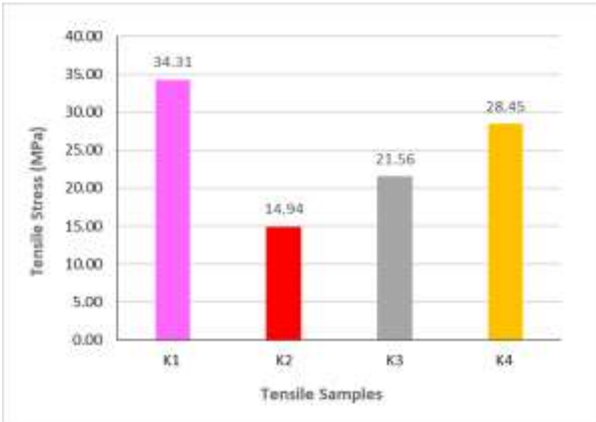

Figure 9. Comparison of tensile stresses of composites with four configurations

Among the test specimens, K_1, which has a 3-layer abaca fiber material arrangement, exhibits the highest tensile strength of 34.41 MPa. On the other hand, K_2, with a 3-layer glass fiber material arrangement, demonstrates the lowest tensile strength of 14.94 MPa. Based on both of these two values, it may be deduced that natural fibers possess a higher tensile strength compared to synthetic fibers. This is also attributed to the higher water absorption ability of natural fibers compared to synthetic fibers. This is further supported by the findings of Kumar's (2019) study, where four different types of samples were created using a combination of glass fiber, banana fiber, and epoxy resin matrix. These samples included composites reinforced solely with epoxy resin, composites reinforced solely with banana fiber, composites reinforced solely with glass fiber, and a mixture of glass fiber, banana fiber, and epoxy resin. According to the present research findings, the hybrid fiber-reinforced composite has a tensile strength of 176.31%, higher than the epoxy-reinforced composite without fiber reinforcement. Similarly, the flexural strength of the hybrid fiber composite is 269.44%, surpassing that of the other three samples.

Figure 10 displays the elastic modulus value obtained from the tensile strength test.

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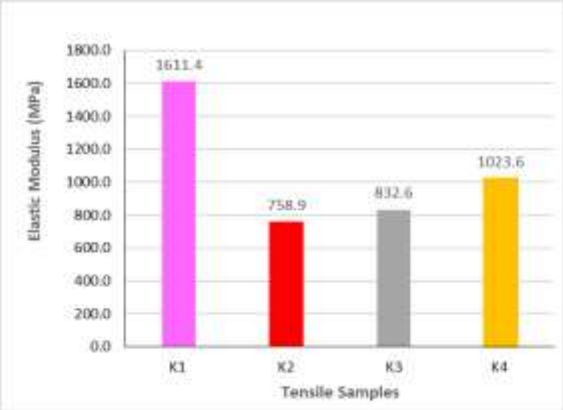

Figure 10. Comparison of tensile elastic modulus with four configurations

Based on Figure 10 above, it can be concluded that the configuration of the composite material arrangement affects the tensile elastic modulus of the composite, where composites with a higher abaca fiber material arrangement will have a higher elastic modulus value. The aforementioned characteristics of natural fibers, including their high tensile strength, folding ability, buoyancy, resilience, bending capability, length, high porosity, and resistance to salt water, contribute to this occurrence. This also aligns with the initial hypothesis that the arrangement of the composite material affects the performance of the composite.

D. The Effect of Composite Material Arrangement Configuration on Flexural Strength

Table 2 presents the test results for composites' flexural strength and flexural modulus of elasticity with four different configurations, which were exposed to aggressive environmental conditions by soaking them in saltwater.

TABLE 2. Flexural Strength and Modulus of Elasticity Values of Composites

Configuration	Flexural Strength (MPa)	Flexural Elastic Modulus (MPa)
K_1	24.452	1051.2
K_2	16.645	659.4
K_3	20.603	1232.1
K_4	19,201	830,9

Table 2 displays differences in the flexural strength and flexural modulus of elasticity values among the four specimen configurations. Specimen K_1 (Abaca-Abaca-Abaca) had the highest flexural strength, measuring 24.452 MPa, while specimen K_2 (Glass-Glass-Glass) displayed the lowest flexural strength, measuring 16.645 MPa. The test specimens K_3 (Glass-Abaca-Glass) and K_4 (Abaca-Glass-Abaca) exhibit flexural strengths of 20.603 MPa and 19.201 MPa, respectively. While the highest flexural modulus of elasticity was found in the K_1 test specimen of 1051.2 MPa and the lowest in the K_2 test specimen of 659.4 MPa.

To obtain more details, refer to Figures 11 and 12 below, which display the data regarding the composite flexural strength test results for four different material arrangement configurations.

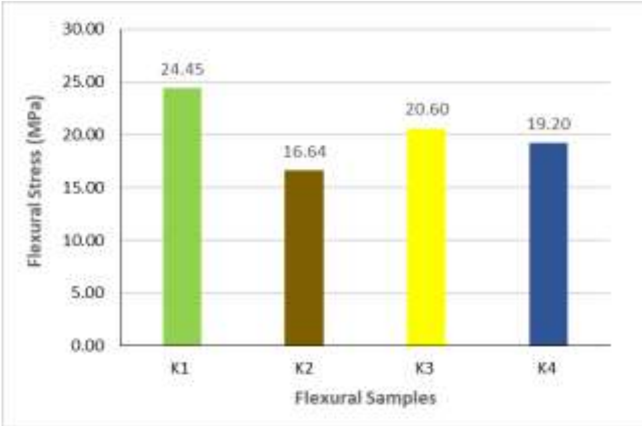

Figure 11. Comparison of flexural stresses of composites with four configurations

Figures 11 and 12 show that composites with an abaca fiber arrangement configuration exhibit higher flexural stress compared to composites with a glass fiber arrangement configuration, as well as hybridization of both types of fibers. The same applies to the flexural modulus of elasticity value obtained from the test results. Thus, it can be inferred that the composite material arrangement's configuration affects the composite's mechanical properties (performance).

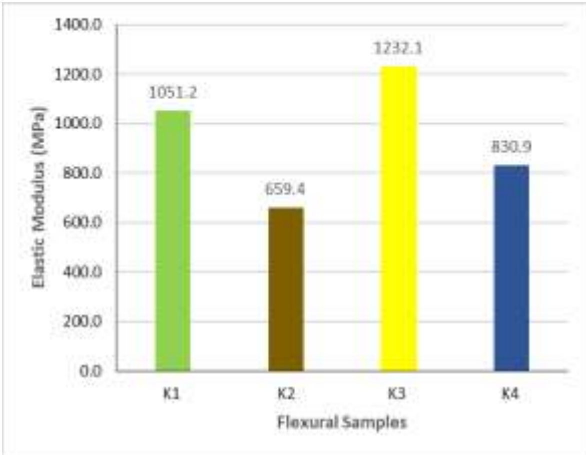

Figure 12. Comparison of flexural elastic modulus of four configurations

E. SEM Test of Fracture Morphology

The SEM (Scanning Electron Microscope) with JEOL JCM 7000-type test equipment, operating at 15 kV, was used to observe the morphology of composite fractures. A Scanning Electron Microscope (SEM) was used to examine three tensile test specimens that experienced failure. These specimens consisted of the NTA test specimen (normal, unsoaked, and exposed as a control, consisting of three layers of abaca fiber), the K_1TA test specimen (exposed, consisting of three layers of abaca fiber), and the K_4TA test specimen (exposed, consisting of abaca-glass-abaca layers).

Figures 13 to 15 below display the comparative SEM test results of the three test specimens.

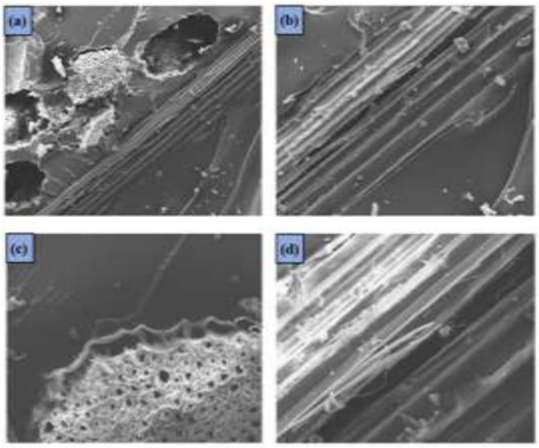

Figure 13. SEM images of NTA composites

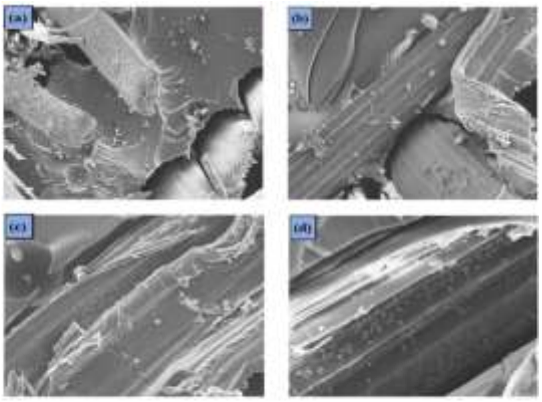

Figure 14. SEM images of K_1TA composites

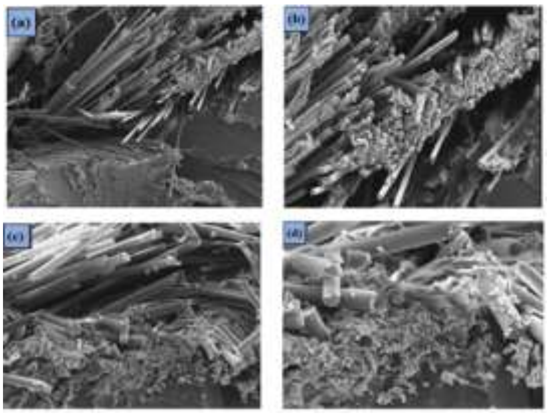

Figure 15. SEM images of K_4TA composite

IV. CONCLUSION

The study aimed to examine the effect of an aggressive environment and the arrangement configuration of composite materials on the performance of the composite. Additionally, the study aimed to analyze the scanning electron microscope (SEM) morphology of composite faults that experienced tensile failure. In general, the mechanical strength of the composites decreased due to aggressive environmental treatments. When not soaked, the composite exhibits a tensile strength of 39.18 MPa and a flexural strength of 34.92 MPa. The composite, which was soaked at a temperature of 50 °C for a duration of 15 days, exhibits a tensile strength of 34.31 MPa and a flexural strength of 24.45 MPa.

The mechanical properties (performance) of a composite material are influenced by its configuration. In particular, a composite with a 3-layer arrangement of abaca fiber exhibits higher tensile strength and flexural strength than three other configurations, consisting of either a 3-layer glass fiber or hybridization of the two types of fiber.

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