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ANALYSIS OF THE EFFECT OF NaOH PERCENTAGE ON THE TENSILE STRENGTH OF SISAL FIBER (*AGAVE SISALANA*) AND POLYURETHANE COMPOSITES USING THE COMPRESSION MOLDING METHOD

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Abstract

The percentage of NaOH is one of the parameters that greatly affects the sisal fiber composite (*Agave Sisalana*). The purpose of this study was to observe and analyze the effect of the percentage of NaOH on the tensile strength of sisal fiber composites (*Agave Sisalana*). The materials used are sisal fiber (*Agave Sisalana*) and polyurethane resin at various percentages of NaOH, namely without treatment (0%), 4%, 7%, and 10% with soaking time for 2 hours and drying in the sun for a maximum of three days or until the fiber is completely dry. Composite manufacturing was carried out using the compression molding method for 24 hours at a pressure of 50 bar. The tests carried out in this study were tensile tests referring to the ASTM D 638 standard. The percentage of NaOH without treatment (0%) has the lowest maximum tensile value of 6.688 MPa, while the percentage of 7% NaOH has the highest maximum tensile strength value of 11.821 MPa. Then, the percentage of NaOH without treatment (0%) has the lowest maximum elastic modulus value of 0.072 GPa, and the highest maximum elastic modulus value of 0.152 GPa is also found at 7% NaOH percentage.

Keywords: Composite, Percentage of NaOH, Tensile Strength, Modulus of Elasticity, Compression Molding, Sisal Fiber

INTRODUCTION

Indonesia is one of the countries where technology is developing rapidly. Current technological advances have increased the need for raw materials, especially in the field of materials. Material needs require several properties such as stiffness, strength, and lightness. Such needs are applied to everyday life such as automotive, construction, and technology. With this increasing demand, knowledge about materials is also growing in an effort to find alternatives to fulfill it, one of which is composite materials (Suryawan et al., 2019).

Composites are materials produced by combining two or more materials that have different properties from their constituent materials. Today, natural or synthetic materials are used to make composites, each with its own advantages and disadvantages. Composite materials are widely used in the manufacturing sector. These materials have advantages over metal-type materials, such as corrosion resistance, ease in molding, light weight, and in some cases, increased strength and stiffness (Suryawan et al., 2019). The two main parts of a composite material are the matrix and the filler. Filler is the main component that determines the properties of the composite material and acts as reinforcement. Natural and synthetic fibers make up this reinforcement, and each type of fiber has a different role in determining the final quality of the composite material as well as strengthening it (Haryadi et al., 2015). Many natural fibers with potential for use in composite production have been identified by several studies. Fibers from banana trees, sisal, pineapple, pandanus, bamboo, jute, sugarcane stalks, water hyacinth, and other plant fibers (Habibie et al., 2021). The best way to increase the economic value of natural fibers is to use them as an alternative to synthetic fibers. The effect of volume fraction, type of fiber used, addition of two different reinforcing fibers (hybrid), and the impact of NaOH treatment have been the subject of several studies on natural fiber composites (Respati et al., 2021).

Research was conducted by Paundra F, et al., (2022) to investigate the effect of varying percentage of volume fraction on the tensile strength of hybrid composites reinforced with banana and pineapple leaf fibers in polyester matrix. Percentage differences of 10:20, 15:15, 12.5:17.5, 17.5:12.5, and 20:10 are listed. Fibers from pandan leaves and banana stems were cooked for 45 minutes at 110°C to make hybrid composites using compression molding technique. The 20:10 volume fraction composition produced the highest tensile strength value, which was 26.55 MPa (F Paundra et al., 2022).

NaOH treatment of oil palm fruit fibers was studied by Ella Sundari et al. (2023). Effects were observed on the concentration at different soaking times. The percentage of NaOH was varied from 0, 5, and 7%, soaking time was 2 hours. The tensile strength of palm fruit fibers decreased as the concentration of NaOH solution and soaking time increased. The mechanical characteristics of composites made from palm fruit fibers improved after the alkalization process. With 7% NaOH alkali variation, the maximum tensile strength was 22.46 N/mm^2, impact strength was 0.15 J/mm^2, and maximum bending strength was 87.50 N/mm^2 (Sundari et al., 2023).

Research conducted by Nur Farhani Ismail et al. (2021) on kenaf fiber showed similar results to those of Ella Sundari et al. (2023). It is known that the higher the alkali concentration in fiber processing, the lower the fiber strength. Conversely, the surface characteristics of the fiber improve when the waxy layer on the fiber surface is lost, resulting in an increase in the adhesion of the fiber matrix. This study showed that 6% NaOH was the concentration at which fiber strength and surface properties reached the optimum level (Ismail et al., 2021).

Polymer composites have important functions in daily activities. The reinforcing component in the polymer matrix can be either natural or synthetic fibers. However, in this case, the matrix used is a commercial polymer such as polyurethane resin (Komariyah, 2016). Polyurethane has advantages such as water and chemical resistance, friction resistance and weather resistance. Polyurethane resin is a suitable polymer produced for household and industrial needs. In addition to chemical and friction resistance, this type of polyurethane resin also has fine coating elasticity, high adhesion, excellent impact resistance, recyclability, and is applied in various forms. Polyurethane resins are very effective when used to make composite materials, but have not been widely applied or optimally utilized (Silvia et al., 2022). Polyurethane resins have many characteristics that make them a popular choice for manufacturing composites for various applications, such as construction, automobiles, sports equipment, and the aviation industry. These characteristics make polyurethane resins a popular choice as they are able to provide an optimal combination of strength, durability, and flexibility for a wide range of usage conditions (Komariyah, 2016).

Natural fiber plants such as sisal (*Agave Sisalana*) have an average yield of about 3-5% (Yogi, 2021). Waste generated from the process of making sisal plant fiber usually reaches 95-97% and can cause problems for the environment. Indonesia produces 92 tons of sisal plant fronds (*agave sisalana*) annually, which are then processed into fiber with a yield of 5% or around 4.6 tons. Sisal fibers are used in the domestic industry for cable wrapping, sacks, and fishing nets. However, this type of natural fiber has great potential to be used as a raw material that can be used in industries such as the vehicle/automotive industry. However, until now sisal fiber is still not well utilized (Basuki & Lia, 2017).

Referring to previous cases and research, therefore the authors are interested in conducting this research using natural fibers and polyurethane resins by paying attention to the effect of the percentage of NaOH on the tensile strength produced in the manufacture of sisal fiber composites (*agave sisalana*) because research on the manufacture of composites using polyurethane-matrixed sisal fibers with the compression molding method has never been done before. Polyurethane resins are very useful in composite manufacturing. The first is its outstanding mechanical properties, including high strength and ductility. These properties make polyurethane resin a basic material in composite manufacturing, as it can increase the strength and durability of composites. Polyurethane resins are suitable for applications that require resistance to impact or dynamic loads because they are able to absorb energy before failure occurs (Komariyah, 2016). Before starting the composite manufacturing process using natural fibers such as sisal fibers, it is important to soak the natural fibers and consider variations in the percentage of NaOH. This is because natural fibers still have content such as lignin and hemicellulose which must be cleaned before the composite manufacturing process. According to previous studies, the ideal alkalization percentage is between 4% to 10%. However, it must be adjusted to the type of natural fiber used due to differences in characteristics such as thickness in the natural fiber. By varying NaOH in the sisal fiber soaking process, it is expected that there will be an increase in the bond between the filler (reinforcement) and the matrix, so as to produce composites with optimal tensile strength.

METHODS

The materials used in this study are sisal fiber (*agave sisalana*) as reinforced and polyurethane resin as a matrix. The composition ratio used is 80% polyurethane resin and 20% sisal fiber. the process of making composites by soaking the sisal fiber with NaOH solution without treatment (0%), 4%, 7%, and 10% for 2 hours in order to clean the dirt contained in the fiber (F Paundra et al., 2022). Then, wash the sisal fibers using clean water after the soaking process with 4%, 7%, and 10% NaOH. After the washing process, it will continue with the drying process for ± 3 days in the sun until the fiber is completely dry. Next, the composite manufacturing process is carried out by compression molding method with a pressure of 50 bar using sisal fiber and polyurethane resin which has a thickness of 0.3 cm (Fajar Paundra, 2024).

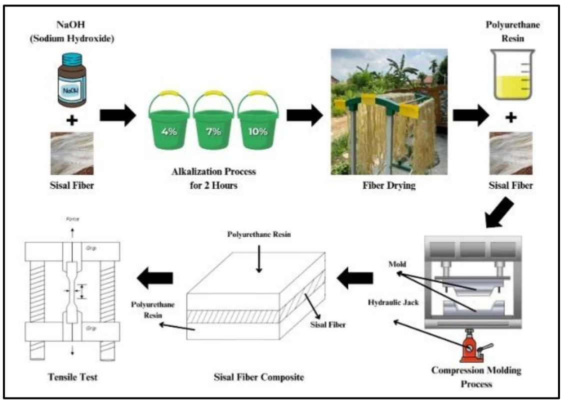


Figure 1. Composite Manufacturing

Figure 1 is the process of making composites using the compression molding method starting from fiber soaking to the tensile testing process. The compression molding compression molding method is a material manufacturing technique that involves placing composite materials in an open mold, which is then closed and applied high pressure to form the final product. This method is suitable for sisal fiber and polyurethane resin-based composites (Silvia et al., 2022). The mold used was 18 x 18 x 0.3 cm in size. The pressure used is 50 bar. After the composite manufacturing process, fiber surface testing and tensile testing were carried out.

Tensile testing aims to obtain the maximum tensile strength and elongation values of the composite. To find the tensile strength and elongation can use equations (1) and (2). Tensile testing refers to the ASTM D 638 standard. ASTM D 638 is shown in Figure 2 (Susilowati, 2017).

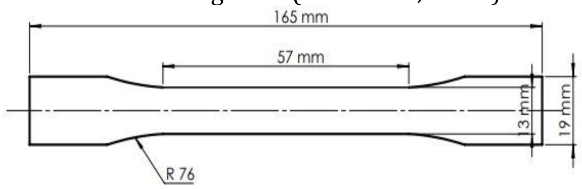


Figure 2. ASTM D 638 Tensile Test Standard

Two types of machines are commonly used in tensile testing: load control machines and movement control machines. In the tensile testing process, mechanical properties such as maximal tensile strength (also known as ultimate tensile strength) (W. T. Putra, 2019). Equation 1 is a formula that can be used to calculate the tensile strength of a specimen.

$$\sigma = \frac{F}{A} \qquad (1)$$

Description:
σ = Maximum Tensile Strength (MPa)
F = Force (N)
A = Cross-Sectional Area (mm^2)

The constant is the ratio between strain and stress. This constant will be referred to as the modulus of elasticity or young's modulus (Sulaeman, 2018). The equation to calculate the modulus of elasticity is as follows.

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \qquad (2)$$

Description:
E = Modulus of Elasticity (GPa)
$\Delta\sigma$ = Stress (MPa)
$\Delta\varepsilon$ = Strain

RESULTS AND DISCUSSION

This study aims to determine the results of testing the tensile strength of sisal fiber composites (*agave sisalana*) using the compression molding method with varying percentages of NaOH. The following specimens of composite manufacturing results can be seen in Figure 3.

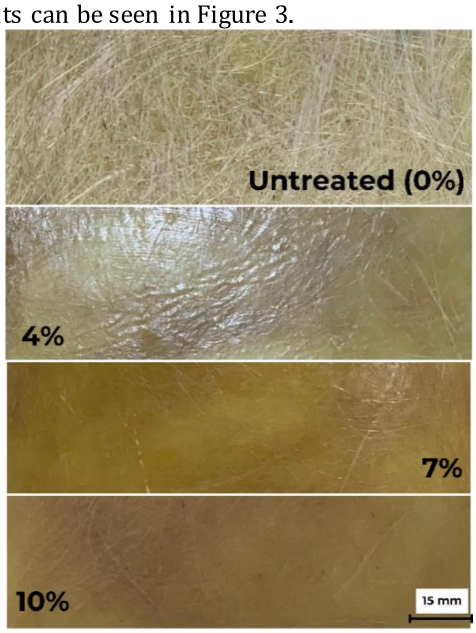


Figure 3. Specimens of Composite Manufacturing Results

Figure 3 shows the results of making composites using sisal fibers (*Agave Sisalana*) with polyurethane matrix at a percentage of NaOH without treatment (0%), 4%, 7%, and 10%. Figure 4 has a difference in physical form visually using the human eye without any help. The use of variations in the percentage of NaOH gives the results of observation and analysis of the four different composite specimens. The difference can be seen from the diameter and condition of the fiber to the dirt, the higher the percentage of NaOH used, the smaller the diameter and the condition of the fiber to the dirt, the cleaner it will look.

Likewise, on the contrary, at a low NaOH percentage, the diameter and dirt on the sisal fiber are clearly visible because the alkalization process has not been carried out using NaOH.

Fiber Surface Testing

Fiber surface testing has the purpose of understanding the effect of NaOH (Sodium Hydroxide) soaking on the surface of natural fibers which will affect the tensile strength of the composite. Fiber surface testing is carried out using a stereo microscope after the NaOH soaking process, which is an important step in cleaning impurities and increasing the attachment between the filler (fiber) and the matrix (resin). Variations in the percentage of NaOH used in this study include no treatment (0%), 4%, 7%, and 10%, to find the optimal percentage that can provide maximum tensile strength in natural fibers. Figure 4 shows the results of sisal fiber samples without treatment (0%).

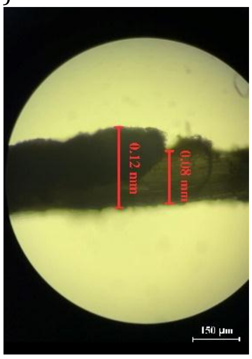


Figure 4. Micro Photograph of Untreated Sisal Fiber (0%)

Figure 4 is a sample of sisal fiber (*Agave Sisalana*) without treatment (0%), it is found that the fiber still has impurities attached, causing the fiber diameter to be 0.12 mm with impurities and 0.08 mm without impurities. The fiber surface in this condition remains smooth. The alkalization process using NaOH is essential in removing these impurities, which not only cleans the fibers but also increases the tensile strength by promoting better interaction between the fibers and the resin. With impurities still present, the fibers cannot deliver maximum performance due to the obstructions on the surface that hinder a strong attachment between the fibers and the resin (Ren et al., 2019). Therefore, the alkalization process is crucial in preparing the fibers to function optimally as reinforcement in the composite. Figure 5 shows the results of sisal fiber samples that have been immersed in 4% NaOH.

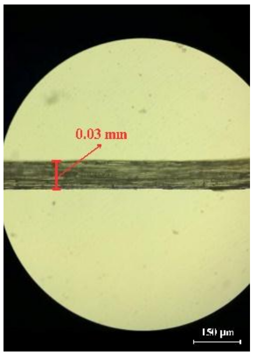


Figure 5. Micro Photograph of 4% Sisal Fiber

Figure 5 is a sisal fiber that has been soaked in 4% NaOH solution, the fiber starts to look cleaner compared to the untreated condition. The fiber diameter shrinks significantly from 0.12 mm to 0.03 mm after soaking. At this concentration, microfibrillar structures began to form, although they were not yet clearly visible. Microfibrillar structure refers to the microscopic arrangement of small fibers within the main fiber that provides strength. This initial formation of microfibrillar structures indicates that the alkalization process is beginning to have a positive effect on the fibers (Nurazzi et al., 2021). With fewer impurities, sisal fibers show the potential for improved attachment to polyurethane resins, although they have not yet reached optimal conditions. The importance of this microfibrillar structure lies in the ability of the fibers to distribute the load evenly, ultimately increasing the mechanical strength of the composite. Figure 6 shows the results of sisal fiber samples that have been subjected to 7% NaOH immersion.

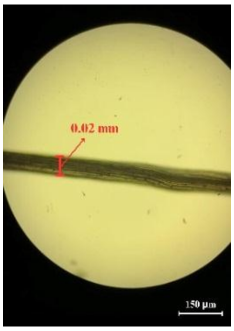


Figure 6. Micro Photograph of 7% Sisal Fiber

Figure 6 is a sisal fiber that has been soaked in 7% NaOH solution, the sisal fiber looks very clean and the microfibrillar structure is clearly visible. The fiber diameter is even smaller, becoming 0.02 mm from the initial size of 0.12 mm in the untreated condition and 0.03 mm in 4% soaking. The 7% NaOH concentration proved effective in cleaning the fibers from impurities and maximizing the formation of microfibrillar structures. This structure is important as it provides a significant increase in the tensile strength of the fiber, making it more suitable as a component in composites. The clear formation of microfibrillar structures indicates that the alkalization process at this concentration allows the fibers to achieve optimal mechanical performance, which is crucial for composite applications that require high strength (Nurazzi et al., 2021). In addition, the optimally formed microfibrillar structure enhances the fiber's ability to withstand loads and prevent deformation, making the composite more durable and efficient in various applications. Figure 7 shows the results of sisal fiber samples that have been immersed in 10% NaOH.

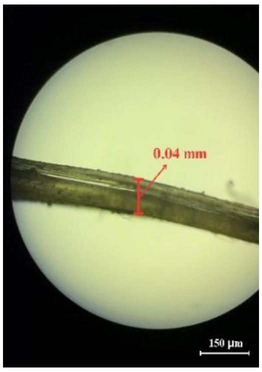


Figure 7. Micro Photograph of 10% Sisal Fiber

Figure 7 shows sisal fibers that have been soaked in 10% NaOH solution, although the fibers are very clean, there are signs of brittleness. The surface of the fibers looks porous and some fibers are even detached after soaking. The fiber diameter at this concentration was 0.04 mm. This shows that too high a NaOH immersion can damage the integrity of the fiber, causing brittleness even though the microfibrillar structure is still formed (Ren et al., 2019). Therefore, although 10% NaOH is effective in cleaning the fibers, the negative effects on tensile strength and brittleness indicate the need for balance in the alkalization process. Too much NaOH can cause degradation of cellulose in the fiber, which eventually weakens the overall structure of the fiber and reduces its strength (Nurazzi et al., 2021). This confirms that the alkalization process must be carefully regulated to ensure that the benefits of cleaning and strength improvement are not offset by adverse structural damage.

Overall, this study confirms the importance of the alkalization process using NaOH to clean sisal fibers from impurities and improve their tensile strength. It was found that 7% NaOH concentration was the best in forming microfibrillar structures without damaging the fibers. The alkalization process successfully transformed sisal fibers from initially having a smooth surface to having a clearly visible microfibrillar structure after immersion in 7% NaOH. This shows that cleaning and rearranging the microfibrils in the fiber can improve the ability of the fiber to bond with the resin. This is very important to obtain composites with good mechanical properties.

Figure 8 shows the schematic mechanism of untreated and treated sisal fibers using NaOH treatment using a stereo microscope for sisal fibers (*Agave Sisalana*) with an immersion time of 2 hours. The microfibril structure of sisal fibers plays an important role in forming bonds between fibers and resins and affects the tensile strength of natural fiber composites. When sisal fibers have a good microfibril structure, it allows a stronger bond between the fibers and resin in the composite. This happens because the microfibril structure provides more contact points between the fiber and the resin matrix, which is important for increasing the interaction strength between them (Ren et al., 2019). In addition, the regular microfibril structure also helps in distributing the mechanical load evenly across the fiber. This means that the fibers can withstand the pull better, reducing the risk of breakage or failure at certain points. Thus, the overall tensile strength of the natural fiber composite will also increase. This is because the strong microfibril structure will increase the individual tensile strength of each fiber, enhancing the composite's capacity to bear higher loads without failure. Furthermore, the NaOH treatment not only cleans the surface of the sisal fibers by removing impurities but also exposes more microfibrils, increasing the surface area for bonding with the resin. This enhanced fiber-matrix adhesion leads to a more uniform and robust composite structure, significantly improving the mechanical properties of the composite. Consequently, the treated fibers contribute to a composite material with superior tensile strength, making it more suitable for applications requiring high strength and durability (Nurazzi et al., 2021).

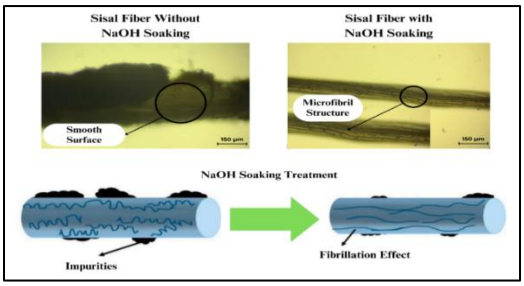


Figure 8. Schematic Mechanism of Sisal Fiber Without Soaking and with NaOH Soaking

Tensile Testing

The data generated from tensile testing can be calculated by dividing the force by the cross-sectional area (Margono et al., 2020). The results obtained from this tensile test can be seen in Figure 9.

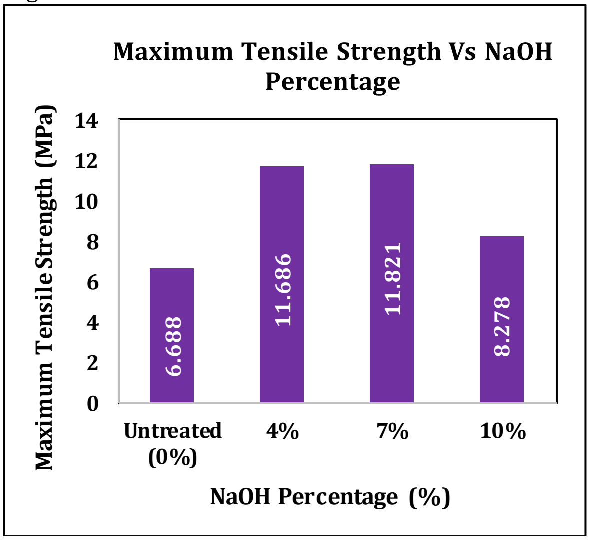


Figure 9. Graph of NaOH Percentage Against Maximum Tensile Strength

Figure 9 shows that the lowest value of maximum tensile strength against the percentage of NaOH is found in the percentage of NaOH without treatment (0%) with a tensile strength value of 6.688 MPa because no alkalization process is carried out on sisal fibers which results in impurities. With impurities still present, the fiber cannot provide maximum performance due to barriers on the surface that hinder a strong attachment between the fiber and resin (Nurazzi et al., 2021).

Then, the tensile strength value tends to increase with increasing percentage of NaOH, it can be seen at 4% NaOH percentage with a tensile strength value of 11.686 MPa. The highest value of maximum tensile strength against the percentage of NaOH is at 7% NaOH percentage with a tensile strength value of 11.821 MPa. However, at a percentage of 10% NaOH the tensile strength value decreased by 8.278 MPa due to the recommended percentage of NaOH which is at 4%-10%, so that the higher the percentage of NaOH used it will make the fiber brittle and the resulting tensile strength will decrease (Lastri, 2023)

When the sisal fiber used is not subjected to the NaOH soaking process, the fiber when used as a reinforcement (filler) does not have a strong bond between the fiber and the matrix. This is because there are still impurities attached to the fiber and the fiber cannot provide maximum performance due to a barrier on the surface that inhibits a strong attachment between the fiber and the resin. At 4% and 7% NaOH percentage, there is an increase in the tensile strength value which occurs due to the fact that the fiber has started to clean and is able to provide maximum performance due to the absence of obstructions on the surface that make a strong attachment between the fiber and resin. However, the 10% NaOH percentage experienced a decrease in tensile strength value because even though the fibers were clean from the dirt attached, the fibers began to become brittle which resulted in a strong attachment between the fibers and the resin starting to decrease (Purkuncoro, 2017). In addition to the maximum tensile strength value against the percentage of NaOH above, this study also has an elastic modulus value against the percentage of NaOH. The graph of the percentage of NaOH against the elastic modulus can be seen in Figure 10.

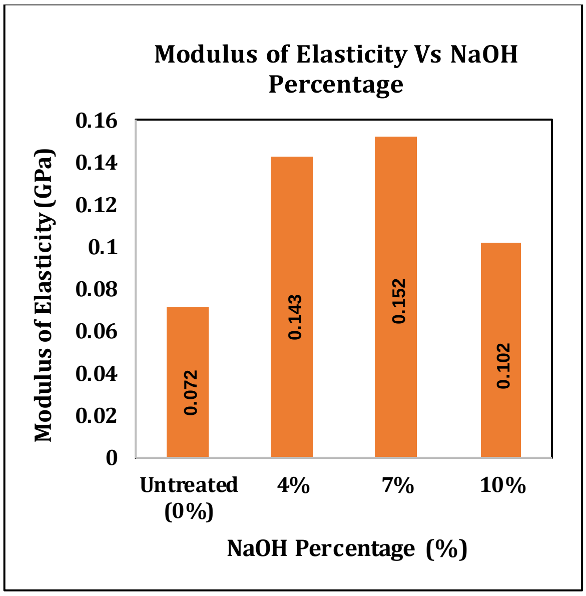
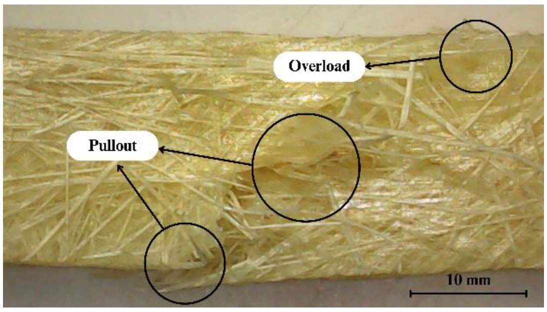


Figure 10. Graph of NaOH Percentage Against Modulus of Elasticity

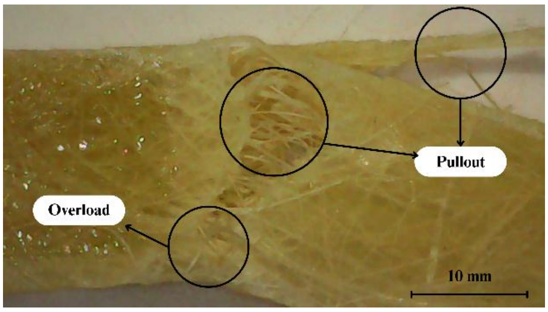
Figure 10 shows the value of elastic modulus against the percentage of NaOH in sisal fiber composites obtained by the formula $E = \frac{\Delta\sigma}{\Delta\varepsilon}$. At 7% NaOH percentage shows the highest elastic modulus value of 0.152 GPa, then there is a percentage of NaOH without 4% and 10% which have values of 0.143 GPa and 0.102 GPa, respectively. The lowest elastic modulus value is found in the percentage without treatment (0%) of 0.072 GPa.

At a percentage of NaOH without treatment (0%), 4%, and 7% experienced an increase in the value of the elastic modulus but at a percentage of NaOH 10% the value of the elastic modulus decreased due to sisal fibers that have begun to become brittle after the NaOH immersion process so that the bond between the fiber and polyurethane resin is less than optimal and also the tensile strength value obtained at a percentage of NaOH 10% is lower than the percentage of NaOH 7%, because the value of tensile strength affects the value of the elastic modulus. The value of tensile strength is directly proportional to the value of the modulus of elasticity (G. P. Putra, 2022).

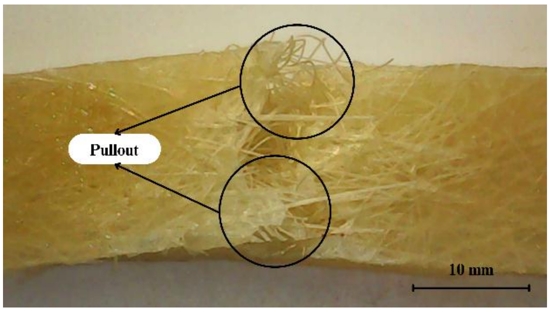
Factors caused by an increase in the percentage variation of NaOH affect the bonding of the matrix and fibers of each composite specimen. This is because the chemical treatment with NaOH alters the surface properties of the fibers, impacting their ability to bond with the matrix. The sisal fiber, in particular, contains impurities on its surface, such as waxes and oils, which result in a less than optimal bond with the polyurethane resin. These impurities hinder adhesion, leading to weak interfacial bonding and consequently reducing the tensile strength of the composite. With inadequate bonding, the load transfer between the matrix and the fibers becomes inefficient, resulting in lower tensile strength values. Additionally, the variation in NaOH concentration can further influence this process. An optimal concentration is necessary to remove surface impurities and enhance fiber roughness, promoting better adhesion to the matrix. Therefore, achieving the right balance in NaOH concentration is crucial for improving fiber-matrix bonding and enhancing the composite's tensile properties.



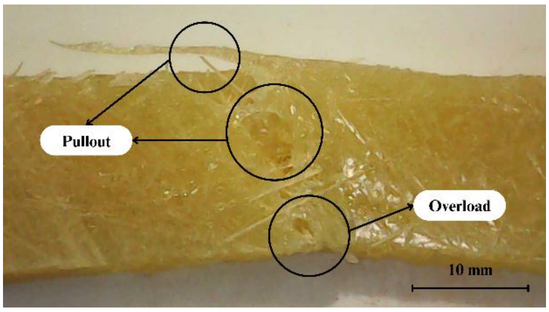
a. Untreated (0%)



b. NaOH 4%



c. NaOH 7%



d. NaOH 10%

Figure 11. Tensile Test Fracture

Figure 11 shows the results of macro photographs of tensile testing specimens on sisal fiber composites (*Agave Sisalana*). The macro photo of the fracture in the specimen is a ductile fracture characterized by considerable plastic deformation, so that the fracture surface is rough and stringy (Fajar Paundra, 2024)

The type of fracture in each sample has several forms of fracture. Fractures with pullout and overload types are the most common, overload is a fracture that occurs due to fiber breakage caused by fiber breakage due to the strong bond between the matrix and the fiber boundary. In these fractures, the fracture is slightly flatter on the surface and has visible broken fibers. Pullout is a non-strong bond between the matrix and the fiber, allowing the fiber to detach from the matrix (Fajar Paundra, 2024). The faults that occur in the specimens are pullout and overload types caused by the increase in the percentage of NaOH which increases significantly resulting in the specimen experiencing an increase in strength and a decrease in strength which causes pullout and overload faults (Rochman, 2020).

CONCLUSIONS

Based on the results of the discussion, the following conclusions are drawn:

1. The highest tensile strength is found at 7% NaOH percentage with a tensile strength value of 11.821 MPa and the lowest tensile strength is found at the percentage of NaOH without

treatment (0%) with a tensile strength value of 6.688 MPa.

2. The highest elastic modulus value in tensile testing is found in the percentage of 7% NaOH with a value of 0.152 GPa and the lowest elastic modulus value in tensile testing is found in the percentage without treatment (0%) with a value of 0.072 GPa.

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