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The Effect of Alkali Soaking Time on The Deflection of Coir Fiber Composites

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Alkali Treatment;
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ABSTRACT

Natural fiber composites have the potential to serve as environmentally friendly materials; however, the quality of fiber–matrix interfacial bonding is strongly influenced by the initial treatment of the fibers. This study aimed to analyze the effect of alkali immersion time on the flexural deflection of epoxy-matrix palm fiber composites. Palm fibers were soaked in a 5% NaOH solution for varying durations of 0, 1, 3, 5, and 7 hours. The composites were fabricated with a volume fraction of 70% epoxy and 30% palm fiber and were tested for flexural deflection in accordance with ASTM D790 under a constant load of 6 kg (≈58.86 N). Each variation was tested using three replicate specimens. The results showed that flexural deflection decreased as immersion time increased, reaching a minimum at 5 hours, and then increased again at 7 hours. The highest average deflection was observed in composites without alkali treatment (5.20 mm), while the lowest deflection (4.23 mm) occurred at 5 hours of immersion, indicating improved flexural rigidity. Statistical analysis showed a coefficient of variation below 6%, indicating good data consistency. This behavior is associated with the reduction of lignin and hemicellulose content and improved fiber–matrix interfacial bonding. Overall, an alkali immersion time of 5 hours was identified as the optimal condition for improving the flexural deflection performance of palm fiber–epoxy composites.

INTRODUCTION

The demand for lightweight, strong, environmentally friendly, and renewable materials has driven the development of natural fibers as composite reinforcement materials (Muriman et al., 2022; Salo et al., 2026; Suparno, 2020). One of the promising natural fibers is palm fiber, sourced from Arenga pinnata, which is widely found in Indonesia. These fibers offer advantages in terms of biodegradability, local availability, low density, and low cost, making them consistent with sustainability principles (Teke et al., 2021). However, despite their great potential, the use of palm fiber in structural composite applications still faces challenges, particularly in terms of interfacial bonding between the fibers and the matrix. The fiber surface, which is coated with lignin and wax, results in suboptimal mechanical and chemical bonding with the matrix. This condition can reduce composite mechanical performance, especially under bending and compressive loads that may lead to buckling (Boimau, 2022; Fauzi, 2024).

One widely used approach to improve fiber–matrix bonding in natural fiber composites is alkali treatment (alkalization), which involves soaking the fibers in a sodium hydroxide

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(NaOH) solution (Millenio et al., 2022; Samlawi et al., 2018). This treatment removes lignin and hemicellulose, increases surface roughness, and enhances the contact area for bonding with the matrix. However, the effectiveness of alkalization strongly depends on solution concentration and soaking duration, requiring further investigation to determine optimal conditions (Purboputro & Hariyanto, 2017). Arenga pinnata is a single-trunked, unbranched tree with an average height of 15–20 meters and a trunk diameter of approximately 30–40 cm. The trunk is generally covered by a black fibrous layer known as palm fiber. The tree begins producing fibers approximately five years after planting, before entering the flowering phase. Fiber characteristics are influenced by the age and height of the tree. Palm fiber is black, up to 0.50 mm in diameter, resistant to temperatures up to 150 °C, and has a flash point of around 200 °C. The main advantages of palm fiber are its high durability and resistance to seawater. Its chemical composition consists of approximately 52.3% cellulose, 13.3% hemicellulose, 31.5% lignin, and 4% ash (Mahmuda et al., 2013).

A composite is a combination of two or more materials consisting of reinforcement and matrix, resulting in new mechanical and physical properties that differ from those of the constituent materials (Pratama et al., 2014). Reinforcement is one of the key factors influencing the mechanical properties of composites (Hanada, 2021). Although fiberglass is commonly used as reinforcement, it is relatively expensive. Therefore, research and development of natural fiber composites continue as an alternative to synthetic fiber-reinforced and metal-based materials (Shifa et al., 2024; Wahyudi, 2015). This is due to several advantages of natural fibers, such as environmental friendliness, low density, recyclability, biodegradability, non-toxicity, and low processing cost (Bekele et al., 2023; Raharjo et al., 2023; Serra-Parareda et al., 2020).

The problems that can be formulated in this research include: How does the long variation of palm fiber soaking in NaOH solution affect the deflection of palm fiber composites? What is the optimal immersion time that produces the best deflection?

Currently, research on the use of natural fibers as composite reinforcers has developed rapidly. Different types of fiber such as bamboo fiber, hemp, coconut fiber, and pineapple leaves have been researched. However, research on palm fiber is still relatively limited, especially in the context of testing structural strength such as deflection. In addition, studies that examine the effect of soaking time on alkaline treatment to determine deflection in palm fiber composites have not been widely conducted.

In the previous study, the preparation of palm oil fiber through the alkalization process used a 5% NaOH solution with varying soaking periods (1 hour, 3 hours, and 5 hours). Therefore The main objective of this study is to analyze the mechanical strength of palm fiber-based composites that have been given soaking treatment using a 5% NaOH solution at a variation of immersion time: 1 hour, 3 hours, 5 hours and 7 hours. Mechanical testing is carried out through deflection tests to determine deflection. The expected benefits of this research are to make a theoretical contribution to the development of composite materials science, especially in understanding the influence of alkaline treatment on the mechanical properties of palm oil-based natural fiber composites, becoming a practical reference for researchers and industry practitioners in determining the optimal conditions of alkaline treatment to improve the bending performance of palm oil fiber composites, providing direct experience for researchers in the manufacturing and testing process Natural fiber composites and mechanical data analysis are considered for the development of environmentally friendly and sustainable alternative materials for lightweight structural applications, and contribute to the utilization of the local potential of palm oil as a composite raw material that adds value and supports the circular economy.

METHOD

The research method carried out this time is an experimental method where it begins with a literature study followed by the preparation of composite materials and then the preparation of test tools.

In this research, the variables include:

a. Independent variable: Fiber immersion time in 5% NaOH solution (1 hour, 3 hours, 5 hours, 7 hours)
b. Bonded variables: Composite mechanical strength
c. Control variables: Solution concentration (fixed 5%), resin type, drying time, specimen dimensions, composite manufacturing method.

The manufacture of composite specimens, through *the hand lay-up method*, utilizes an epoxy resin matrix.

Mechanical testing is carried out through:

Bending *test* to determine deflection. The load that is used is 6 kg.

The procedure for this research consists of the following stages

1. Material Collection and Preparation.
2. The palm fibers are cleaned of coarse dirt and dust. Epoxy resin and hardener are prepared as matrix materials.
3. A 5% NaOH solution is prepared in sufficient quantities for five groups of immersion times.
4. Alkalization Treatment (Alkali Treatment) by soaking palm fiber in a 5% NaOH solution with a duration of 1 hour, 3 hours, 5 hours and 7 hours.
5. After soaking, wash the fibers with aquades, then dry them naturally for 24 hours.
6. Composite Manufacturing
7. The dried palm fibers are mixed with epoxy resin using the *hand lay-up method* with a ratio of 70:30 (resin:fiber by weight).
   The printing process is carried out on a flat mold, lightly pressurized and allowed to harden at room temperature for 48 hours.
8. The test is performed when the specimen has dried completely. The deflection test with specimens is based on ASTM D790: it is performed to determine the strength of the deflection value. Each variation of the immersion time was tested 3 repetitions. The deflection test procedure is as follows:
   a. Measure the length, width and thickness of the rod from the rigid clamp to the other end.
   b. Attach the clamp to the end of the specimen to be tested.
   c. Installing the clamping plate at a point with a certain distance from the stack.
   d. Install the dial gauge on each clamping plate that has been installed on the rod.
   e. Calibrate the scale from a dial gauge.
   f. Hang the load and then record how much deflection appears.

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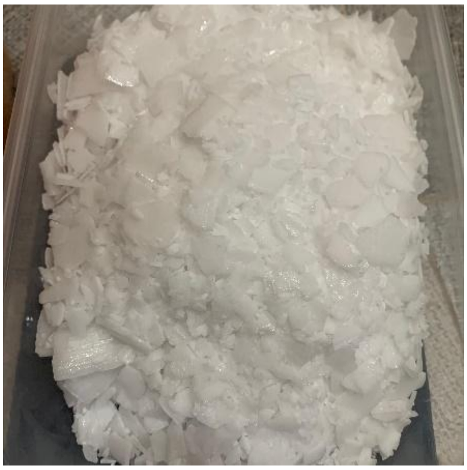
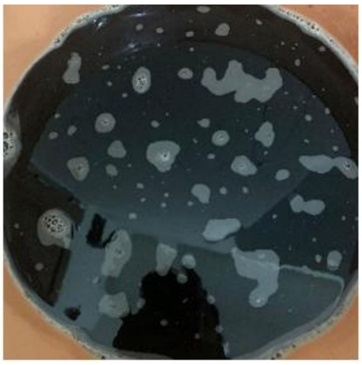
9. Data Analysis. The results are displayed in the form of tables, comparison graphs, and interpretations.
10. The test result data will be analyzed to determine the significance of the effect of immersion time on the mechanical properties of composites. The results are displayed in the form of tables, comparison graphs, and interpretations.

Picture 1. Epoxy resins and hardeners



Picture 2. NaOH

Picture 3. Olive Fiber



Picture 4. Fiber soaking process with 5% NAOH solution

Picture 5. Composite Printing

Picture 6. Specimens

The expected results of this study are:

a. Quantitative information on the effect of 5% NaOH immersion duration on the mechanical strength of palm kernel fiber composites.
b. It is known that the optimal immersion time provides the best mechanical performance.
c. Technical recommendations for the use of palm fiber as an alternative reinforcing material in lightweight structural applications.

RESULT AND DISCUSSION

The results of the flexural deflection test of the palm–epoxy fiber composite with a volume fraction Vm:Vf = 70:30 at a constant load of 6 kg (≈58.86 N) are shown in table 1. The test was performed using three repeat specimens (X1, X2, and X3) for each variation in alkaline immersion time, namely 0, 1, 3, 5, and 7 hours. The main parameters analyzed are maximum deflection as an indicator of deflection behavior and bending stiffness of composites.

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Table 1. Average value of deflection, Standard deviation and coefficient of variation

Soaking Time (hours)	Deflection			Average (mm)	Standard Deviation	CV (%)
	X1 (mm)	X2 (mm)	X3 (mm)			
0	5,3	5,1	5,2	5,20	0,10	1,92
1	4,7	4,7	4,8	4,73	0,06	1,22
3	4,2	4,6	4,7	4,50	0,26	5,88
5	4,0	4,3	4,4	4,23	0,21	4,92
7	4,8	4,9	5,3	5,00	0,26	5,29

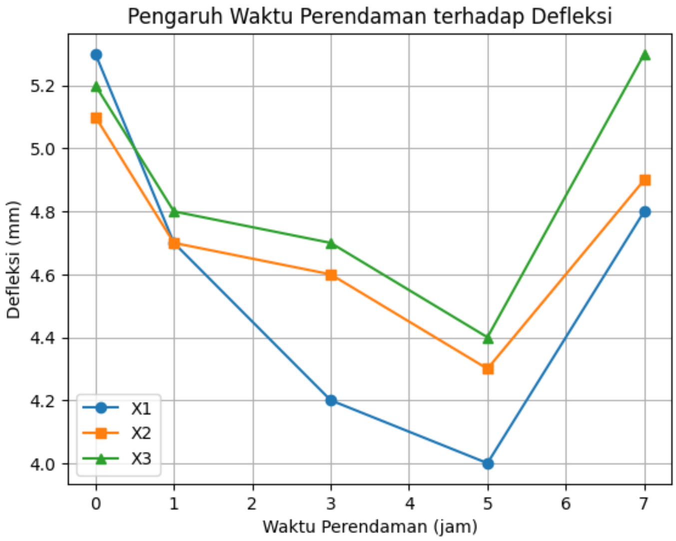

Figure 7. Graph of the Effect of Immersion Time on Deflection

From table 1 and graph 7, it can be seen that composites without alkaline treatment (0 hours) showed an average deflection value of 5.20 mm, which is the second highest value after 7 hours of immersion. This relatively large deflection value indicates that the interface bond between the palm fiber and the epoxy matrix is still less than optimal, so the composite is more flexible due to the low load transfer efficiency.

The administration of alkaline treatment for 1 hour reduced the average deflection to 4.73 mm. This decrease shows an increase in flexural stiffness caused by the improvement of fiber surface quality, especially due to reduced lignin and hemicellulose content that inhibit fiber-matrix adhesion.

At the 3-hour immersion time, the average deflection value was recorded at 4.50 mm. Although the deflection is lower than the 0 and 1-hour variations, this value is not yet the lowest. In addition, the standard values of deviation and coefficient of variation in these variations are relatively larger, which indicates the beginning of an increase in variation between specimens.

The lowest average deflection was obtained at the 5-hour immersion time, which was 4.23 mm. These results show that an alkaline immersion time of 5 hours is the optimal condition in this study, as it is able to produce the highest bending stiffness at the same load. Under this condition, alkaline treatment is estimated to be quite effective in removing lignin and hemicellulose without causing significant degradation of the cellulose structure, so that the fiber-matrix interface bond is at the most optimal condition.

However, at a longer immersion time, i.e. 7 hours, the deflection value again increases to 5.00 mm. This increase indicates that excessive alkaline treatment begins to cause degradation of fiber structures, particularly in cellulose components, thereby decreasing the intrinsic rigidity of the fiber and impacting the increased flexural deflection of composites.

The decrease in deflection value up to the alkaline soaking time of 5 hours is closely related to changes in the chemical composition of palm oil fibers, especially in lignin and hemicellulose content. Alkaline treatment using NaOH is able to dissolve some of lignin and hemicellulose which are amorphous and hydrophilic, thereby increasing the cellulose fraction which plays a role as the main component determining the stiffness of the fiber. The reduction of lignin and hemicellulose causes the fiber surface to become rougher and more reactive, which improves the mechanical adhesion between the fiber and the epoxy matrix and improves the efficiency of load transfer during bending loading. However, at longer soaking times, alkaline degradation can begin to attack the cellulose structure itself, thereby degrading the intrinsic strength and stiffness of the fibers. This condition explains the increased deflection again at the 7-hour immersion, although the fiber–matrix surface bond is still formed.

Judging from statistical analysis, the standard deviation values (0.06–0.26 mm) and coefficient of variation (1.22–5.88%) across all immersion time variations were still within acceptable limits (CV < 10%). This shows that the test results are consistent and the fabrication and composite testing processes are carried out stably.

Overall, the test results showed that alkaline treatment with a soaking time of 5 hours provided the best flexural deflection performance in the palm–epoxy fiber composite, while too short or too long immersion resulted in greater deflection due to suboptimal interface bonding or degradation of the fiber structure. This pattern is in line with the general characteristics of alkali-treated natural fiber composites, where there is an optimum immersion time resulting in increased maximum flexural rigidity. Thus, it can be concluded that the alkaline NaOH treatment with a soaking time of 5 hours provides the best flexural deflection performance in the ipalm–epoxy fiber composite in this study.

CONCLUSION

Based on the results of the research that has been conducted, it can be concluded that the alkaline immersion time has an effect on the flexural deflection of the palm fiber-epoxy composite with a volume fraction Vm:Vf = 70:30 at a constant load of 6 kg (≈58.86 N). Composites without alkaline treatment exhibit relatively high deflection values, which indicates that the interface bond between the fiber and the matrix is still less than optimal. The administration of alkaline treatment caused a decrease in flexural deflection to reach the optimum condition at the 5-hour immersion time, with the lowest average deflection value of 4.23 mm. This condition shows that the 5-hour alkaline treatment is able to maximally increase the bending stiffness of the composite, which is associated with reduced lignin and hemicellulose content and increased effectiveness of fiber-matrix interface bonds without causing significant degradation of the cellulose structure.

However, at a longer immersion time, i.e. 7 hours, the deflection value again increases. This indicates that excessive alkali treatment has the potential to cause degradation of the fiber

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structure, thereby lowering the intrinsic rigidity of the composite. Statistical analysis showed a relatively small standard deviation and coefficient of variation (CV < 6%), which indicates that the test results were consistent and had a low data dissemination rate.Overall, this study shows that an alkaline immersion time of 5 hours is the optimal condition to improve the flexural deflection performance of palm – epoxy fiber composites. These results are expected to serve as a reference in the development of palm fiber-based natural fiber composites for lightweight structural applications that require a balance between rigidity and deformation ability.

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