

Impact of chemical treatment on compression properties of *Pentaclethra macrophylla* /*Arachis hypogaea* hybrid composite for structural applications

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Abstract

Lately, there's been a growing interest in replacing synthetic fibers with natural ones for composite materials, mainly because of environmental concerns. However, natural fiber composites face a significant challenge: they struggle with poor bonding to hydrophobic matrices due to their hydrophilic nature, which leads to subpar mechanical properties. Fortunately, this issue can be addressed through chemical treatment. In this study, fibres were extracted from the fruits of *Arachis hypogaea* and *Pentaclethra macrophylla*, then treated with NaOH solutions at concentrations of 2%, 4%, 6%, 8%, and 10%. These were then made into composites, subjected to compression testing, and analyzed using ANOVA and regression analysis. The results showed that the compression strength and yield strength peaked with the 6% NaOH treatment, increasing by 61.6% and 75.4%, respectively. The ANOVA results indicated a P-value below the significance level of 0.05 for both compression strength and yield strength, suggesting that the treatment significantly affects these properties. However, the P-value for Young's modulus was above the significance level, indicating that the treatment did not significantly impact it. Overall, the research suggests that a moderate alkaline treatment of these fibers can enhance the compression properties of hybrid natural fiber composites, making them suitable for load-bearing structural applications.

Keywords: Natural fibre, compression properties; chemical treatment, hybrid composite, sustainable materials.

INTRODUCTION

Right now, there's a growing global awareness about the issues surrounding synthetic fiber-reinforced composites and plastic pollution, mainly because they just don't break down in the environment. This has sparked a surge of interest among manufacturers to create sustainable and biodegradable composite materials that use natural fibers from plants as reinforcement. Natural fibers come with a bunch of advantages, like being lightweight, non-toxic, readily available, cost-effective to process, and having good mechanical properties—all while being friendly to the environment due to their biodegradable nature. However, there are some downsides to using natural fibers. Their tendency to absorb water and their weak bonding with hydrophobic polymers can lead to poor mechanical properties in the resulting bio-composites.

To tackle this issue, we need to modify the surface of natural fibers through a chemical treatment process before we start fabricating the composite. One of the most popular methods for this is alkaline treatment. This process effectively strips away the non-cellulose components from the fiber's surface, which helps reduce its hydrophilic properties and enhances the bonding between the fiber and the matrix. As a result, the mechanical properties in the composite is improved [5,6,7,8]. Numerous studies have highlighted the positive impact of alkaline treatment on the mechanical characteristics of bio-composites made from natural fibers. For instance, research on kenaf, bamboo, and poly-lactic acid bio-composites found that this treatment significantly boosted compatibility and mechanical strength, making them ideal for construction applications[9]. Similarly, studies on bio-composites reinforced with *Prosopis juliflora* bark, banana, and coconut fibers showed an increase in both compression and tensile strength after alkaline treatment[10]. Additionally, research involving *Pentaclethra macrophylla* fiber reinforced composites indicated that tensile strength improved as the concentration of NaOH increased[11]. It's also been noted that alkaline treatment enhances the mechanical properties of abaca fiber reinforced polyethylene composites[12]. The studies on roselle and sugar palm fibre reinforced composites have shown that treating them with NaOH leads to better mechanical properties[13]. Similarly, research on jute fabric reinforced bio-epoxy composites has indicated that the alkaline treatment of the fibers enhances their mechanical properties[14]. It turns out that the highest mechanical properties for a hybrid epoxy composite made from areca, kenaf, and snake grass were achieved using alkaline-treated fibers[15].

However, even with the wealth of research on how alkaline treatment affects the mechanical properties of natural fiber composites, there's still a noticeable gap in studies

focusing on the compression properties of these composites. This is particularly important for many applications, yet it hasn't been thoroughly explored in the literature regarding the impact of alkaline treatment.

While the fibres from the fruits of *Pentaclethra macrophylla* and *Arachis hypogaea* haven't been thoroughly explored for their potential use in hybrid structural composites, there's a lot to uncover. *Pentaclethra macrophylla*, often referred to as the 'Oil bean,' is native to Nigeria's North Central and Southern regions, as well as the coastal areas of West and Central Africa[16]. On the other hand, *Arachis hypogaea*, better known as the 'peanut,' is a staple crop in Nigeria, especially in the northern parts[17]. In this study, the compression properties of hybrid fiber composites made from *Arachis H.* and *Pentaclethra M.* was examined. The goal was to understand how alkaline treatment affects these fibres and to evaluate their potential as reinforcement materials for hybrid composites, particularly in structural applications.

MATERIALS AND METHODS

2. 1 Processing of materials

The fibres (see Figure 1) were obtained from the fruit husk of the *Pentaclethra M.* and *Arachis H.* plants, which are found in Anambra state. We gathered sodium hydroxide (NaOH) pellets, distilled water, methyl ethyl ketone peroxide (MEKP) catalyst, cobalt naphthenate accelerator, a release agent, and polyester resin with a density of 1.114 g/cm³ from Enugu State. After harvesting the fruit, the seeds were removed and the empty husks were washed in water. It was then dried in an oven at 40°C for 72 hours. Once dried, the husk was milled, sieved through a 250µm particle size sieve, and mixed in equal volumes. Next, the mixture was treated with NaOH solutions at concentrations of 2%, 4%, 6%, 8%, and 10% w/v for one hour. After treatment, the samples were neutralized with distilled water and dried again at 40°C for another 72 hours.

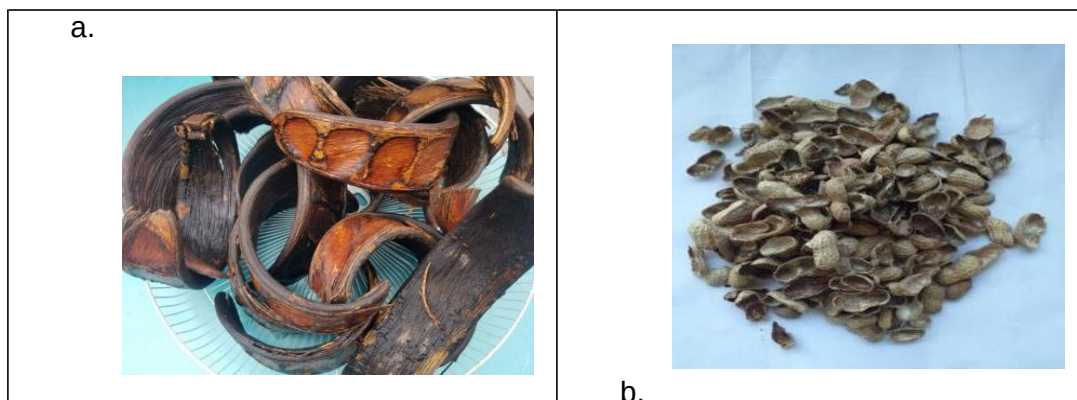


Figure 1: (a) Fruit husk of *Pentaclethra M.* (b) fruit husk of *Arachis H.*

2. 2 Composite fabrication

The hand-lay up method was used for this process. In this step, the right amount (30% weight fraction) of each treated sample was blended with the corresponding polyester, accelerator, and catalyst. After mixing everything together, it was poured into a standard mold and allowed to cure for 72 hours at room temperature. Once cured, the composite (see Figure 2) was cut into samples measuring 13 x 13 x 25 mm. The same procedure was followed for the untreated (0%) fiber-reinforced composite.

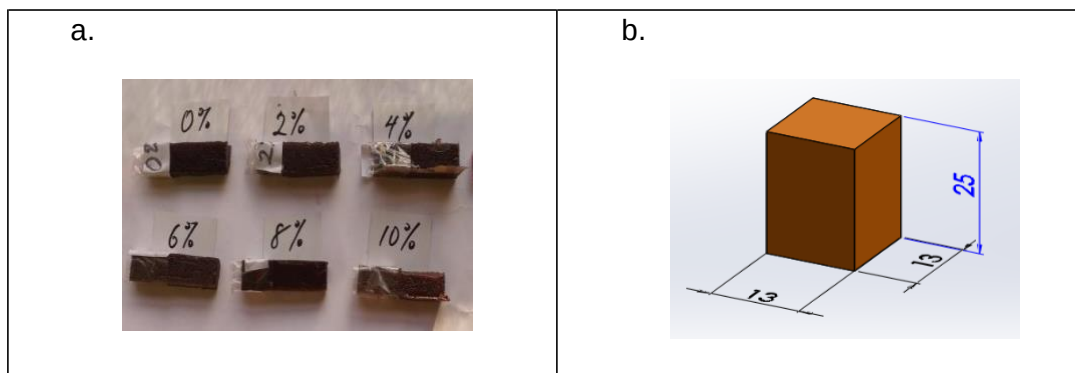


Figure 2: (a) Cured composite samples (b) Cut Sample model

2. 3 Compression test

This test was carried out following the ASTM D695 method with a universal testing machine. Each of the treated samples was put under compression force, and the load and deformation values were recorded until the sample failed. The compression strength (CS), yield strength (Cy), and Young's modulus (E) were determined using Eqs. (1), (2), and (3), respectively.

$$C_S = \frac{P_p}{L_C \times W_C} \quad (1) \quad c_y = \frac{P_y}{L_C \times W_C} \quad (2)$$

$$E = \frac{\Delta C}{\Delta \varepsilon} \quad (3)$$

where PP is the maximum load (N), Py is the yield load, LC is the length, Wc is the width, ΔC is the gradient stress in the elastic region (MPa), Δε is the gradient strain in the elastic region [18, 19].

2. 4 Statistical Analysis

The data from the compression test was carefully analyzed for accuracy using one-way analysis of variance (ANOVA) and further validated through regression analysis in Minitab 16 software.

RESULT AND DISCUSSION

3. 1 Compression test

The compression test conducted on the fibre composite treated with 0%, 2%, 4%, 6%, 8%, and 10% NaOH showed an average compression strength of 72.657, 91.432, 92.030, 117.388, 95.503, and 81.357 N/mm², respectively. The ANOVA results (see Figure 3a) indicated a P-value of 0.005, which is below the significance threshold of 0.05. This suggests that there are statistically significant differences between some of the means, leading to rejection of the null hypothesis. This finding was validated through regression analysis (Figure 3b), where a P-value of 0.004 along with the quadratic regression model outlined in Eq. (4) were obtained.

$$C_s = 71.11 + 12.26 * K - 1.123 * K^2 \quad (4)$$

Where, CS is the compression strength and K is the concentration.

The P-value, which is below the significance threshold of 0.05, suggests that the treatment significantly affects the compression strength of the composite. Additionally, the R-squared value shows that 72.03% of the variation in the composite's compression strength can be linked to the concentration of NaOH used in the fiber treatment. Moreover, the Turkey grouping data (Figure 3c) indicates that the fiber composite treated with 6% NaOH has a notably higher mean compared to the untreated (0%) fiber composite, with a 99.43% confidence level that each interval accurately reflects the true difference between specific pairs of group means.

A.

One-way ANOVA: Compression strength(N/mm²) versus Concentration(%)

Source	DF	SS	MS	F	P
Concentration(%)	5	3387	677	6.19	0.005
Error					

B.**Polynomial Regression Analysis: Compression strength(N/mm²) versus Concentration(%)**

The regression equation is
 Compression strength(N/mm²) = 71.11 + 12.26 Concentration(%) - 1.123
 Concentration(%)**2

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	2482.24	1241.12	8.40	0.004
Error	15	2216.98	147.80		
Total	17	4699.22			

C.**Grouping Information Using Tukey Method**

Concentration(%)	N	Mean	Grouping
6	3	117.39	A
8	3	92.50	A B
4	3	92.03	A B
2	3	91.43	A B
10	3	81.36	B
0	3	72.66	B

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

All Pairwise Comparisons among Levels of Concentration(%)

Individual confidence level = 99.43%

Figure 3:(a) ANOVA for compression strength (b) Regression for compression strength
(c) Turkey group information

The individual value plot (Figure 4a) showed that the highest average was found in the 6% treated fiber composite, while the untreated (0%) fiber reinforced composite had the lowest average. Looking at the residual plots, it can be seen that the residuals lined up nicely along a straight line in the normal probability plot (Figure 4b). The constant variance was evident, as the data points in the versus fits plot (Figure 4c) were scattered randomly. Additionally, the independence of the residuals was confirmed since there was no noticeable trend over time in the versus order plot (Figure 4d). Overall, the results from the residual plots indicate that the model satisfies the necessary assumptions.

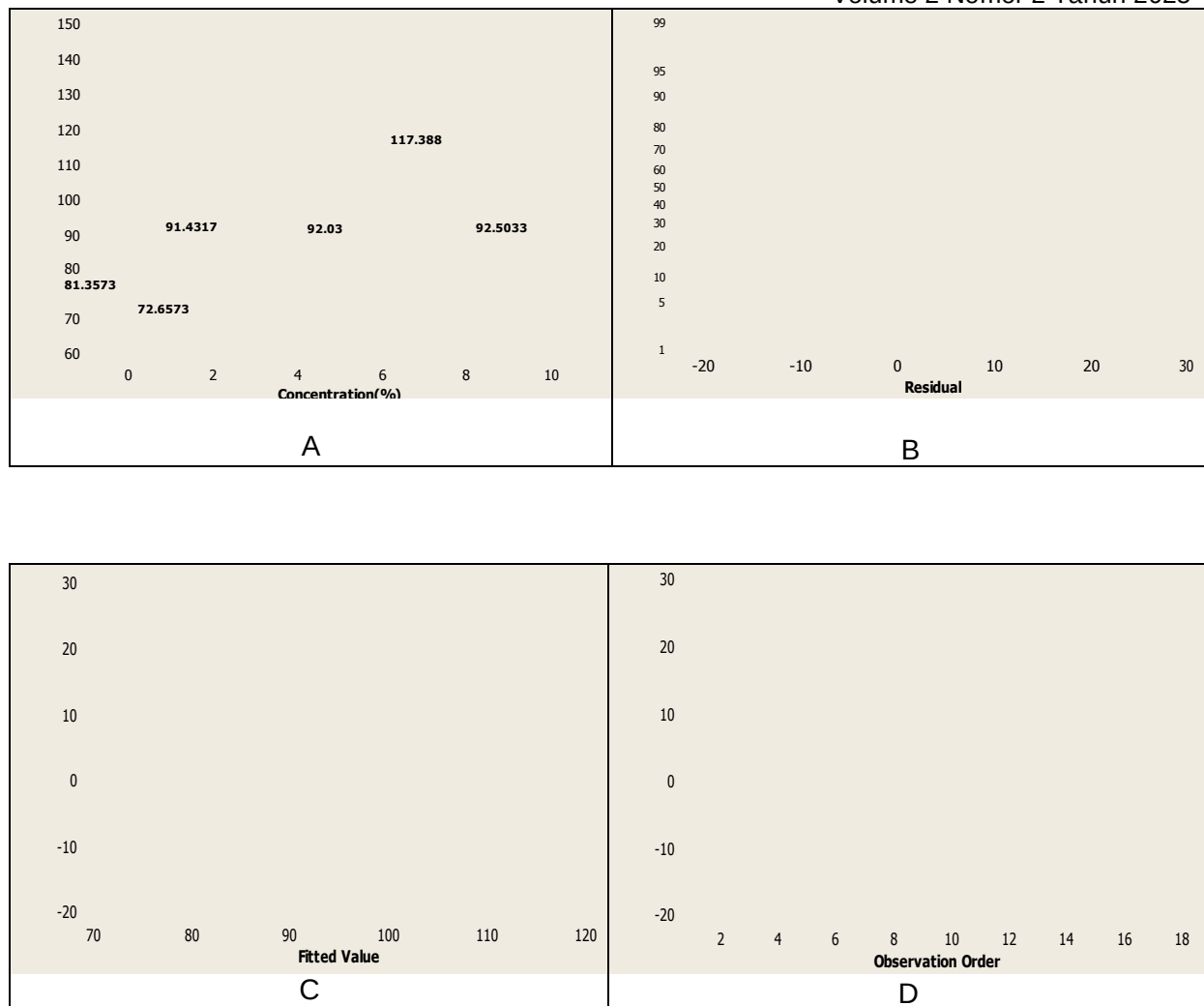


Figure 4: (a) Individual value plot (b)normal probability plot (c) Versus fits plot (d) Versus order plot.

When looking at the yield strength, the ANOVA results shown in Figure 5a revealed a P-value of 0.005, which is well below the significant threshold of 0.05. This suggests that there are indeed statistically significant differences between some of the means, leading to the rejection of the null hypothesis. To further validate this finding, regression analysis was conducted, as illustrated in Figure 5b. The regression yielded a P-value of 0.002, along with the quadratic regression model detailed in Eq. (5):

$$C_y = 66.10 + 13.90 * K - 1.245 * K^2 \quad (5)$$

The P-value, which falls below the significance level of 0.05, suggests that the treatment significantly affects the yield strength of the fiber composite. Additionally, the R-squared value indicates that 72.16% of the variation in the yield strength can be linked to the concentration of NaOH treatment applied to the fiber. Moreover, the Turkey grouping information (Figure 5c) shows that the fiber composite treated with 6% NaOH has a notably higher mean compared to the untreated (0%) fiber composite, with a 99.43% confidence level that each individual interval captures the true difference between specific pairs of group means.

A.**One-way ANOVA: Yield strength(N/mm²) versus Concentration(%)**

Source	DF	SS	MS	F	P
Concentration(%)	5	4036	807	6.22	0.005
Error	12	1557	130		
Total	17	5593			

S = 11.39 R-Sq = 72.16% R-Sq(adj) = 60.56%

B.**Polynomial Regression Analysis: Yield strength(N/mm²) versus Concentration(%)**

The regression equation is

Yield strength(N/mm²) = 66.10 + 13.90 Concentration(%) - 1.245 Concentration(%)**2

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	3220.38	1610.19	10.18	0.002
Error	15	2372.78	158.19		
Total	17	5593.16			

C.**Grouping Information Using Tukey Method**

Concentration(%)	N	Mean	Grouping
6	3	116.50	A
8	3	92.33	A B
4	3	91.90	A B
2	3	91.37	A B
10	3	81.25	B
0	3	66.42	B

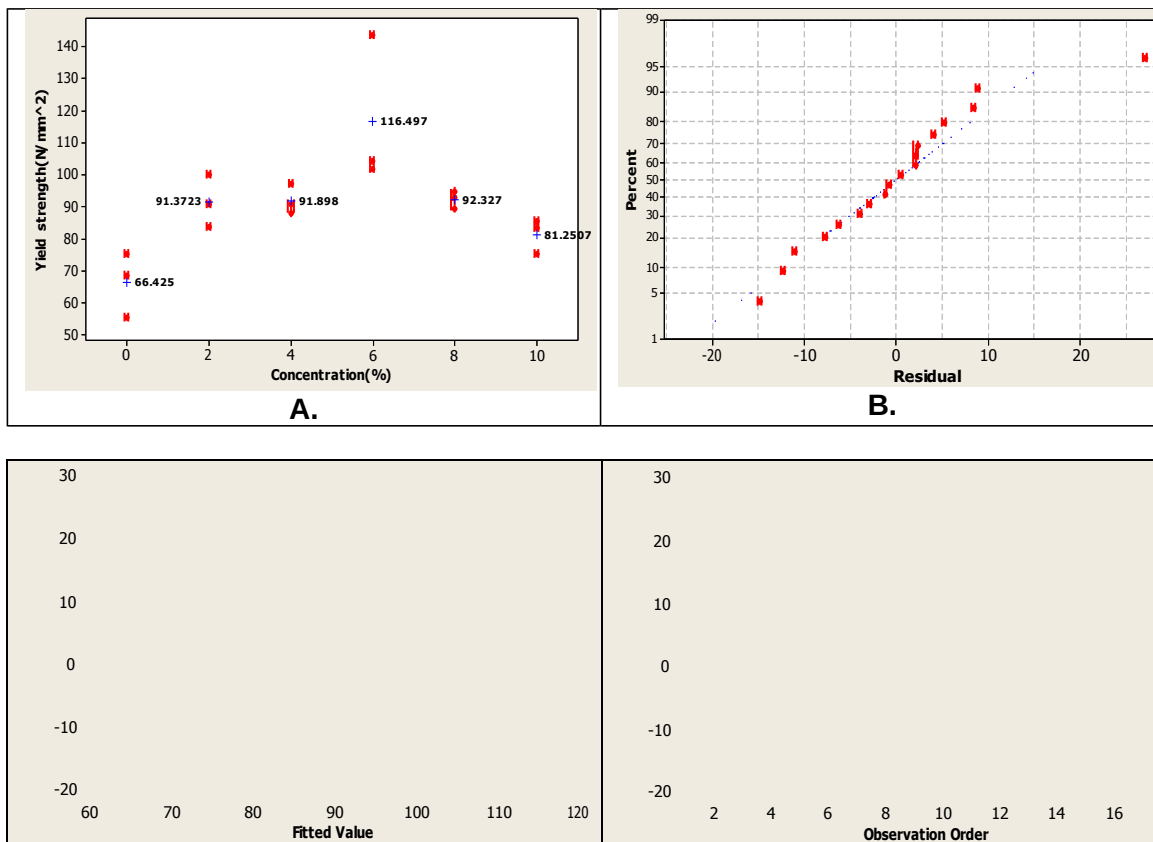
Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Concentration(%)

Individual confidence level = 99.43%

Figure 5:(a) ANOVA for yield strength (b) Regression for yield strength
(c) Turkey group information for yield strength

In addition, the individual value plot (Figure 6a) showed that the highest average value of 116.50 N/mm² was achieved with the 6% treated fiber composite, while the untreated (0%) fiber reinforced composite had the lowest average value of 66.42 N/mm². The analysis of the residual plots indicates that the model adheres to the necessary assumptions. The normal probability plot (Figure 6b) demonstrated that the residuals aligned along a straight line, and the versus fits plot (Figure 6c) confirmed a constant variance, as the data points were randomly scattered. Furthermore, the versus order plot (Figure 6d) illustrated the independence of the residuals, showing no discernible pattern over time.



C.	D.
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Figure 6: (a) Individual value plot (b) Normal probability plot (c) Versus fits plot (d) Versus order plot.

When it comes to the Young modulus, the ANOVA results (Figure 7a) showed a P-value of 0.790, which is above the significance threshold of 0.05. This suggests that the differences between the means aren't statistically significant. Therefore, the decision was to fail to reject the null hypothesis, since it can't be concluded that the data deviates from a normal distribution. Additionally, the P-value of 0.421 from the regression analysis (Figure 7b) also exceeds the significance level of 0.05, indicating that the concentration of NaOH treatment doesn't have a statistically significant impact on the Young modulus of this fiber composite at that level of significance [20]. Furthermore, the Tukey grouping information (Figure 7c) showed that the groups share the same letter, which means their means are not significantly different.

A **One-way ANOVA: Young modulus(N/mm²) versus Concentration(%)**

Source	DF	SS	MS	F	P
Concentration(%)	5	952825	190565	0.47	0.790
Error	12	4847243	403937		
Total	17	5800068			

S = 635.6 R-Sq = 16.43% R-Sq(adj) = 0.00%

B. **Polynomial Regression Analysis: Young modulus(N/mm²) versus Concentration(%)**

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	632576	316288	0.92	0.421
Error	15	5167492	344499		
Total	17	5800068			

C. **Grouping Information Using Tukey Method**

Concentration(%)	N	Mean	Grouping
6	3	1788.2	A
2	3	1624.4	A
4	3	1573.2	A

10	3	1279.4	A
8	3	1259.5	A
0	3	1146.1	A

Means that do not share a letter are significantly different.

Figure 7:(a) ANOVA for Young modulus (b) Regression for Young modulus
(c) Turkey group information for Young modulus

In a nutshell, the results indicated that the compression strength of the untreated (0%) fiber composite increased from 72.673 N/mm² to a peak value of 117.388 N/mm² after being treated with 6% NaOH for 1 hour, marking a significant rise of 61.6%. Additionally, the yield strength increased from 66.425 N/mm² to 116.497 N/mm² due to the same 6% NaOH treatment, which translates to a remarkable 75.4% increase. This aligns with previous research on cotton/bamboo fiber epoxy composites, where a 2 wt% NaOH treatment was found to enhance the compression properties of the composite [21]. Similarly, it supports findings that alkaline treatment boosts the compressive strength of sisal fiber reinforced slag composites [22]. Moreover, the mechanical properties of banana fiber epoxy composites also showed improvement when treated with a 5% NaOH solution [23].

A remarkable increase of 86.21% in compression strength was observed with the alkaline treatment of kenaf/bamboo polylactic acid biocomposite [9]. This boost is attributed to the way alkaline treatment alters the fiber's surface, enhancing the interfacial bonding with the matrix and significantly improving the mechanical properties [24,25,26]. Additionally, the results indicate that alkaline treatment has a minimal effect on the Young modulus of the hybrid composite. Moreover, the data shows that when the concentration of NaOH treatment for the *Pentaclethra macrophylla*/*Arachis hypogaea* hybrid composite exceeds 6%, the compressive properties start to decline. This aligns with findings that excessive treatment can damage the fibers, weakening their adhesion to the matrix and ultimately leading to reduced mechanical properties of the composite [27].

CONCLUSION

This study dives into how alkaline treatment affects the compression properties of a hybrid composite made from *Arachis H.* and *Pentaclethra M.* fruit husk fibers. The composite was created, put through a compression test, and analyzed using one-way Analysis of Variance (ANOVA) and regression analysis. The findings showed that treating with NaOH significantly boosted both the compression strength and yield strength, while having a negligible effect on the Young modulus of the composite. Specifically, a 6% NaOH treatment led to impressive increases of 61.6% in compression strength and 75.4% in yield strength, marking the highest values for the composites. This enhancement in compression properties can be attributed to the surface modification of the fibers caused by the moderate NaOH

treatment, which increases surface roughness and improves the bonding between the fibers and the matrix. Overall, these results indicate that a moderate treatment of these fibers can significantly enhance the compression strength of the hybrid composite made from Arachis H. and Pentaclethra M., making it a promising reinforcement material for structural applications.

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