

Tensile Properties of Alkali-Treated Coco Coir Fibers

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RESEARCH ARTICLE

Abstract

The research investigated the impact of alkali treatment on the tensile properties of coco coir fibers, with a focus on the practical implications of the findings. Specifically, it examined the effects of treatment duration and sodium bicarbonate (NaHCO_3) concentration on tensile strength and elongation. The study compared untreated fibers to those treated with 12% or 15% NaHCO_3 solutions for 3, 5, or 7 days. Tensile testing, conducted according to ASTM D3822 by DOST-PTRI, revealed that the highest tensile strength of 143.61 MPa was achieved with a 12% NaHCO_3 solution for three days. This finding has significant implications for industries that rely on coco coir fibers for their products. Conversely, untreated fibers exhibited the highest elongation of 31.02%, which may be beneficial in certain applications. Statistical analysis using one-way ANOVA indicated a significant difference in tensile properties between untreated and treated groups. Additionally, a two-way ANOVA demonstrated that treatment duration significantly impacted both tensile strength and elongation. The interaction of concentration and duration also showed a substantial effect on both properties. These findings suggest that a carefully controlled combination of treatment duration and NaHCO_3 concentration can optimize the tensile strength of coco coir fibers for specific applications, albeit at the expense of elongation. This knowledge can be applied to various industries, including manufacturing, construction, and agriculture, thereby contributing significantly to the socio-economic advancement of coco coir-producing associations, and by extension, the communities and economies they support.

Keywords: alkali treatment, coco coir fibers, elongation at break, tensile properties, tensile strength

DOI: <http://doi.org/10.52631/jeet.v3i1.306>

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Submitted 30 May 2024

Revised 4 August 2024

Accepted 30 October 2024

Citation

Pardo, K. J. (2024). Tensile Properties of Alkali-Treated Coco Coir Fibers. *Journal of Engineering and Emerging Technologies*, 3(1), 27-36. doi: 10.52631/jeet.v3i1.306

1 INTRODUCTION

Coco coir fiber, a product of coconut husks, is a highly versatile and in-demand material with unique properties. These properties include water retention, biodegradability, strength, and durability. Its high toughness and emerging applications, such as its use in concrete production and stormwater management, have been the focus of numerous studies. The global demand for coco coir fiber is on the rise, and ongoing research aims to enhance its tensile properties and mechanical strength. These efforts are opening new possibilities for its use in manufacturing, construction, and agriculture, thereby contributing significantly to the socio-economic advancement of coconut coir-producing associations.

The study aimed to investigate how alkali treatment affected the tensile properties of coco coir fibers. The central problem was understanding the differences in tensile strength and elongation

between untreated fibers and those treated with alkali solutions at varying concentrations (12% and 15%) and treatment durations (3, 5, and 7 days). By comparing these properties, the study sought to determine if and how alkali treatment could be optimized to enhance the mechanical performance of coco coir fibers, potentially leading to their expanded use in engineering applications. The study objectives are: to determine the tensile properties of untreated and alkali-treated coco coir fibers in terms of tensile strength and elongation; to compare the tensile strength and elongation of the untreated and treated fibers; and to investigate the effect of varying concentrations of sodium bicarbonate solution in different treatment durations of 3, 5, and 7 days.

The potential of coco coir fibers as a sustainable construction material is highlighted, with studies demonstrating their ability to enhance mechanical properties and offer a more environmentally friendly alternative in various construction applications. The focus on sustainability underpins the investigation of alkali-treated coco coir fibers, as it has been proven to significantly improve fiber strength and presents promising prospects for construction materials. Chemical treatments play a crucial role in improving the mechanical properties of natural fibers for composite materials.

Various chemical treatments, such as alkali, silane, acetylation, and malleated coupling agents, emphasize their impact on promoting better fiber-matrix adhesion and enhancing compatibility with different matrices. Furthermore, the effectiveness of sodium bicarbonate treatment is examined, with conflicting results from different studies regarding its impact on material strength. This sets the stage for the investigation of alkali treatment and its potential to enhance the tensile strength of coco coir fibers.

Alkali treatment, specifically mercerization, is highlighted as a significant chemical modification process for natural fibers. The process involves immersing fibers in a concentrated alkali solution, which removes impurities, increases surface roughness, and improves mechanical and morphological properties. The effectiveness of alkali treatment holds relevance to the current study's exploration of sodium bicarbonate solution, suggesting the potential to increase the tensile strength of coco coir fibers.

The research aims to benefit associations utilizing coco coir fibers by helping them improve the quality of their products and save time and money on fiber processing. It also holds significant potential for the Local Government Units of Camarines Norte, offering economic and environmental benefits. Furthermore, the study provides valuable insights for engineers, scientists, researchers, and students in materials science and related fields, offering practical examples and methodological frameworks for further research and development in sustainable materials.

The coco coir fibers are sourced from Basud, Camarines Norte, Philippines. The alkali treatment involved using different concentrations of sodium bicarbonate solution and varying treatment durations, providing a diverse set of data for analysis. Tensile testing was carried out following the ASTM standard at DOST-PTRI to ensure accuracy and reliability. However, the study had limitations, including focusing solely on sodium bicarbonate as the alkali treatment agent, not exploring the effects of other alkali solutions, and not conducting a comparative analysis with other natural fibers or examining microstructural changes in the fibers due to alkali treatment. Furthermore, the statistical analysis overlooked alternatives like data transformation and non-parametric methods, and some assumptions were violated, although the large sample size allowed for the violation of normality to be ignored.

2 METHODOLOGY

The research utilized experimental methods to examine the cause-and-effect relationship between variables, specifically the concentration of the solution and the duration of treatment, and their impact on the tensile strength and elongation of coco coir fibers. The experimental design involved two independent variables and a controlled group, with each treatment group consisting of 30 fiber strands. The study's critical elements were outlined in Table 1, providing sample IDs for each

combination of concentration and duration, totaling 210 fiber strands. These IDs were used in the subsequent analysis of results and discussions.

Table 1. Experimental Design

Treatment		Sample Size (No. of strands)	Sample ID
Concentration (%)	Duration (days)		
0	0	30	Untreated
12	3	30	12C3D
	5	30	12C5D
	7	30	12C7D
15	3	30	15C3D
	5	30	15C5D
	7	30	15C7D
Total		210	

The research conducted the following procedures; selection and preparation of coco coir fibers, preparation of alkali solution for treatment, the alkali treatment of coco coir fibers, and the preparation of test samples for tensile testing. The coco coir fibers were obtained from a reliable source and underwent thorough visual inspection and washing before being air-dried for 48 hours. The alkali solution was prepared based on the desired concentration and treatment groups, and the fibers were then soaked in the solution for 3, 5, or 7 days, depending on the treatment group. After the soaking period, the treated fibers were washed, air-dried, and prepared for tensile testing using a C-template provided by DOST-PTRI.

A series of tests were conducted to assess the impact of different alkali treatment conditions on the tensile strength and elongation properties of fiber samples. Statistical analysis using SPSS version 27 was employed to obtain descriptive statistics for seven treatment groups, including a control group. The mean of each group was calculated, and the optimal treatment combinations for enhancing tensile strength and elongation were identified. ANOVA was used to compare the tensile properties of untreated and alkali-treated coco coir fibers, with careful consideration given to the assumptions of normality and homogeneity. A Two-way ANOVA was also performed to determine the combined effects of concentration and duration. Post-hoc tests were conducted to identify statistically significant pairs.

Overall, the research design and procedure aimed to assess the tensile properties of untreated and alkali-treated coco coir fibers and determine the impact of solution concentration and treatment duration on their tensile strength. The experimental design and detailed procedures provided a systematic and controlled approach to conducting the research, ensuring reliable and meaningful results.

3 RESULTS AND DISCUSSIONS

3.1 Tensile Properties of Untreated and Alkali-treated Coco Coir Fibers

To determine the average tensile strength and elongation of untreated and alkali-treated coco coir fibers, descriptive statistics using SPSS version 27 were performed. The experiment compared the tensile strength of coco coir fibers under different treatment combinations. As shown in Table 2, the fibers treated in a 12% solution for 3 days showed the highest average tensile strength at 143.61 MPa, 15.53% higher than the untreated fibers. In contrast, fibers treated in a 15% solution for five days exhibited the lowest tensile strength at 84.74 MPa, 31.83% lower than the untreated fibers. These results indicate that varying the concentration and duration of treatment has a significant impact on the tensile strength of coco coir fibers. The findings align with prior knowledge of chemical treatments' ability to modify and standardize natural fiber properties [1].

Table 2. Summary of Statistics for Average Tensile Strength per Treatment Group

Treatment	Sample Size (No. of strand)	Ave. Tensile Strength (MPa)
Untreated	30	124.31
12C3D	30	143.61
12C5D	30	87.93
12C7D	30	102.78
15C3D	30	119.84
15C5D	30	84.74
15C7D	30	117.28
Total	210	

The results suggest that a 12% sodium bicarbonate solution is more effective than a 15% solution for treating coconut fibers, and longer treatment durations may negatively affect tensile strength, as shown in Figure 1. Contrary to a previous study, treating the fibers with a 12% solution for five days significantly increased tensile strength. Another study found that treating coir fibers with sodium bicarbonate for five days led to a 25.4% increase in tensile strength.

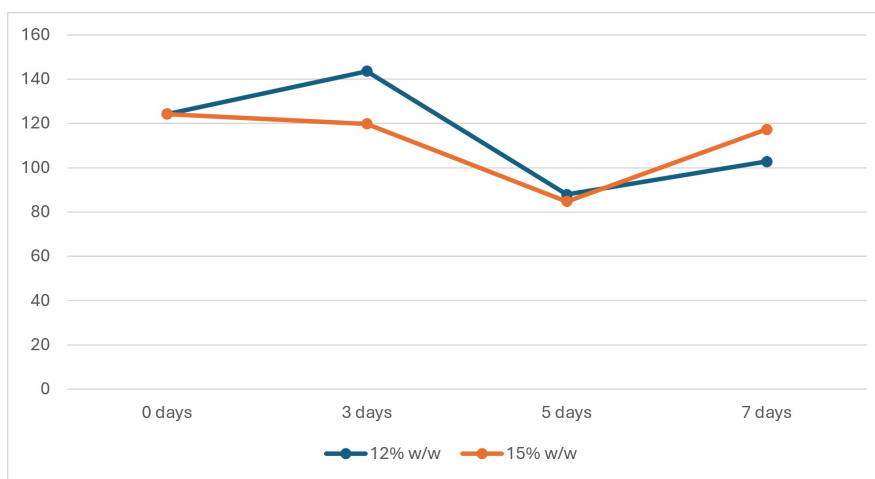


Figure 1. Tensile Strength of Untreated and Alkali-Treated Coco Coir Fibers

Table 3 shows that untreated fibers had the highest elongation of 31.02%, while coco coir fibers treated with a 12% concentration over three days had the lowest elongation with a value of 18.48%. This suggests that alkali treatment reduces elongation regardless of the treatment's concentration or duration. The findings also indicate a potential tradeoff between increased tensile strength and decreased elongation. These results align with the understanding that chemical treatments can modify the structural properties of natural fibers [2].

Table 3. Summary of Statistics for the Average Elongation per Treatment Group

Treatment	Sample Size (No. of strand)	Average Elongation (%)
Untreated	30	31.02
12C3D	30	18.48
12C5D	30	23.24
12C7D	30	23.01
15C3D	30	20.08
15C5D	30	20.75
15C7D	30	27.60
Total	210	

The line chart show in Figure 2 reveals the same trend for 12% and 15% concentrations. The two concentrations have approximately no significant differences. Different studies showed varying effects on the elongation of natural fibers. The study of Fiore and Calabrese [3] shows that the sodium bicarbonate treatment for natural fibers like coco coir led to similar mechanical behavior. However, the treatment had different effects on the two fiber types - it increased the adhesive properties of the flexible flax fibers, leading to a higher elongation. At the same time, it caused a softening effect on the jute fibers.

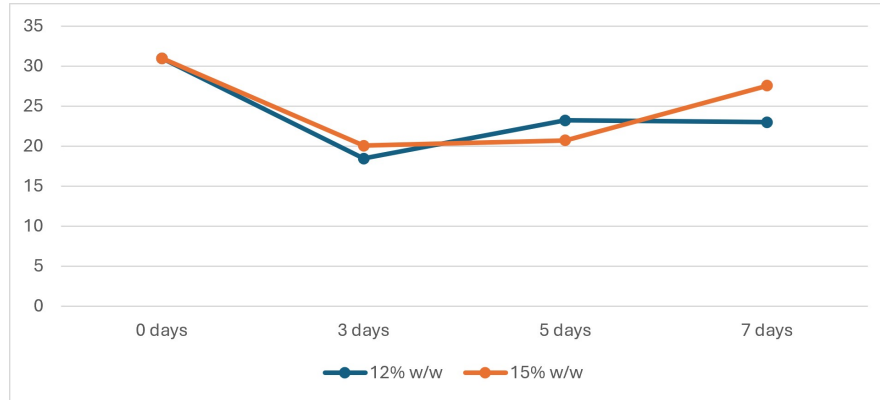


Figure 2. Elongation of Untreated and Alkali-Treated Coco Coir Fibers

3.2 Significant Difference in Tensile Properties between Untreated and Alkali-Treated Coco Coir Fibers

To compare the average tensile strength and elongation of untreated fiber to alkali-treated fibers, one-way ANOVA using SPSS version 27 was conducted. Table 4 shows that the p-value is less than 0.001. This value suggests a statistically significant difference among the treatment groups. This suggests that the alkali treatment has a strong effect on the tensile strength of the fibers, and these effects are not due to random variation but rather because of the treatment. This interpretation aligns with the previous study, which found that the alkali-treated coir fibers exhibited higher tensile strength than untreated fibers [4]. To identify which specific alkali treatments produce significantly different tensile strengths compared to untreated fibers, a Games-Howell post-hoc test was performed. Using the Games-Howell, equal variance is not assumed.

Table 4. Result of Welch ANOVA for Tensile Strength

F	df1	df2	p-value	Decision
9.375	6	89.228	< .001	Reject

Table 5 shows showed significant differences between the following pairs: Untreated vs. 12C3D, Untreated vs. 12C5D, Untreated vs. 12C7D, and Untreated vs. 15C5D. These findings indicate that these specific groups have a significant impact on the tensile strength of the coco coir fibers. The results also suggest that these treatments have caused changes in the structure or composition of the fibers, resulting in either increased or decreased tensile strength. In one study, the tensile properties of coconut coir single fiber with alkali treatment were examined, and it was discovered that the average tensile strength of the fibers increased significantly from 130.9 MPa to 182.8 MPa after the alkali treatment [5].

Table 5. Result of Games-Howell Post-hoc Test for Tensile Strength

	Pairs	Mean Difference	Std. Error	p-value	Decision
Untreated	12C3D	-19.30333	5.00830	.006	Reject
	12C5D	36.38233	4.64875	< .001	Reject
	12C7D	21.52333	4.54226	< .001	Reject
	15C3D	4.46833	5.31774	.979	Fail to reject
	15C5D	39.56767	4.71183	< .001	Reject
	15C7D	7.03233	4.88007	.777	Fail to reject

Table 6 suggests that alkali treatments have a significant effect on the elongation of coco coir fibers compared to untreated fibers. The findings indicate that alkali treatment modifies the structural properties of coco coir fibers, resulting in changes to their elongation properties. This research contributes to understanding how chemical modifications can tailor the mechanical properties of natural fibers, expanding their potential applications [6].

Table 6. Result of One-Way ANOVA for Elongation

F	df1	df2	p-value	Decision
14.517	6	203	< .001	Reject

Furthermore, a post-hoc analysis using Tukey's HSD shown in Table 7 revealed highly significant differences ($p = 0.001$) between the untreated group and most alkali-treated groups, supporting the conclusion that alkali treatment significantly decreases the potential elongation of the coco coir fibers compared to the untreated state.

Table 7. Result of Tukey Post-hoc Test for Elongation

	Pairs	Mean Difference	Std. Error	p-value	Decision
Untreated	12C3D	12.53900	1.64645	< .001	Reject
	12C5D	7.78000	1.64645	< .001	Reject
	12C7D	8.00033	4.64875	< .001	Reject
	15C3D	10.93367	1.64645	< .001	Reject
	15C5D	10.26367	4.64875	< .001	Reject
	15C7D	3.41533	1.64645	.372	Fail to reject

The study found no significant difference between untreated fibers and those treated with a 15% concentration for seven days. Both groups produced fibers with similar elongation properties. The combination of concentration and duration of treatment may change the fiber structure while preserving some original flexibility. Understanding this is important for applications of coco coir fibers. Alkali treatment can make fibers less flexible, which may be desirable or undesirable depending on the intended use. This research contributes to the broader knowledge of how chemical treatments can alter the properties of natural fibers [7].

3.3 Effect of Alkali Treatment on Tensile Properties of Coco Coir Fibers

The effects of alkali treatment were investigated, considering the level of concentration, and treatment duration was tested using two-way ANOVA in SPSS version 27. Based on the findings shown in Table 8, it is inconclusive whether the concentration of the alkali solution significantly affects the tensile strength of coco coir fibers within the tested parameters. It is suggested that treatment duration or the interaction between concentration and duration may have a more significant impact on tensile strength. This contrasts with the study by Hasan et al. [4], which found that the concentration of the alkali solution used in treating coir fibers influences the removal of impurities, disrupts hydrogen bonds, and enhances surface roughness, all contributing to significant changes in tensile strength.

Table 8. Statistical Result on Two-Way ANOVA for Concentration vs. Tensile Strength

	F	p-value	Partial Eta Squared	Decision
Concentration	3.795	.053	.018	Fail to reject

The ANOVA results in Table 9 revealed a p-value of 0.195 for the effect of concentration on elongation. This value exceeds the usual significance level of 0.05, which means that an alkali concentration of 12% or 15% does not significantly influence the elongation of coco-coir fibers. Elongation may not be strongly affected by alkali concentration within the tested range. Thus, the null hypothesis will not be rejected.

Table 9. Statistical Result on Two-Way ANOVA for Concentration vs. Elongation

	F	p-value	Partial Eta Squared	Decision
Concentration	1.689	.195	.008	Reject

The results in Table 10 demonstrate a highly significant p-value (0.001) for the impact of treatment duration (3, 5, and 7 days) on tensile strength, with a large effect size indicated by the partial eta squared value of 0.598. This suggests that approximately 59.8% of the variance in tensile strength can be attributed to treatment duration alone. These findings support the idea that alkali treatment duration significantly affects the tensile strength of coco coir fibers. The study by Ru et al. [8] also found a substantial increase in tensile strength for alkali-treated coir fibers compared to untreated fibers.

Table 10. Statistical Result on Two-Way ANOVA for Duration vs. Tensile Strength

	F	p-value	Partial Eta Squared	Decision
Duration	151.052	< .001	.598	Reject

Additionally, a Scheffe post-hoc test, as shown in Table 11, revealed significant differences in tensile strength outcomes for nearly all treatment durations, emphasizing the substantial impact of treatment duration on coco coir fiber tensile strength. The only non-significant difference was found between untreated fibers and those treated for 3 days ($p = 0.150$), indicating negligible tensile strength differences. This aligns with the broader understanding that treatment time is a critical factor in the chemical modification of natural fibers [9].

Table 11. Post Hoc Tests of Treatment Duration for Tensile Strength

Duration	Mean Difference	Std. Error	Sig.	Remarks	
0	3	-7.4175	3.19958	.150	Fail to reject
	5	37.9750	3.19958	< .001	Reject
	7	14.2778	3.19958	< .001	Reject
3	0	7.4175	3.19958	.150	Fail to reject
	5	45.3925	2.61245	< .001	Reject
	7	21.6953	2.61245	< .001	Reject
5	0	-37.9750	3.19958	< .001	Reject
	3	-45.3925	2.61245	< .001	Reject
	7	-23.6972	2.61245	< .001	Reject
7	0	-14.2778	3.19958	< .001	Reject
	3	-21.6953	2.61245	< .001	Reject
	5	23.6972	2.61245	< .001	Reject

In Table 12, the ANOVA results showed a highly significant p-value (0.001) for the impact of

treatment duration (3, 5, and 7 days) on elongation. The partial eta squared value of 0.117 indicates a small-to-medium effect size. This suggests that the duration of alkali treatment significantly affects the elongation of coco coir fibers. Furthermore, the partial eta squared value (0.117) indicates that about 11.7% of the variation in elongation is due to differences in treatment duration. This finding implies that longer treatment durations may bring about more substantial changes to fiber structure, such as the removal of lignin or reorganization of cellulose, which in turn affects elongation properties. It's also possible that there's a treatment duration beyond which further improvements in elongation become minimal or even harmful. This discovery underscores the importance of treatment duration as a critical factor when chemically modifying natural fibers [6]. Following the main analysis, a Scheffe post-hoc test was conducted to pinpoint specific differences between the treatment durations.

Table 12. Statistical Result on Two-Way ANOVA for Treatment Duration vs. Elongation

	F	p-value	Partial Eta Squared	Decision
Duration	13.451	< .001	.117	Reject

The Scheffe post hoc test shown in Table 13 reveals that most comparisons of treatment durations resulted in significantly different elongation outcomes for coco coir fiber. This indicates that treatment duration has a considerable impact on fiber elongation. The only exception was a non-significant difference between the 3-day and 5-day treatment durations. These findings align with the general principles of chemical modification of natural fibers, highlighting the importance of fine-tuning process parameters to achieve desired outcomes [10].

Table 13. Post Hoc Tests of Treatment Duration for Tensile Strength

Duration	Mean Difference	Std. Error	Sig.	Remarks
0 3	11.7363	1.42586	< .001	Reject
0 5	9.0218	1.42586	< .001	Reject
0 7	5.7078	1.42586	.001	Reject
3 0	-11.7363	1.42586	< .001	Reject
3 5	-2.7145	1.16421	.146	Fail to reject
3 7	-6.0285	1.16421	< .001	Reject
5 0	-9.0218	1.42586	< .001	Reject
5 3	2.7145	1.16421	.146	Fail to reject
5 7	-3.3140	1.16421	.047	Reject
7 0	-5.7078	1.42586	.001	Reject
7 3	6.0285	1.16421	< .001	Reject
7 5	3.3140	1.16421	.047	Reject

The results from Table 14 revealed a statistically significant interaction effect between concentration and duration on tensile strength ($p = 0.001$). The partial eta squared value of 0.209 indicates a moderate effect size. This finding means that the effect of alkali concentration on the tensile strength of coco coir fibers depends on the treatment duration (3, 5, or 7 days) and alkali concentration (12 w/w% or 15 w/w%).

Table 14. Statistical Result on Two-Way ANOVA for Combined Effect vs. Tensile Strength

Source	F	Sig.	Partial Eta Squared	Decision
Concentration*Duration	26.866	< .001	.209	Reject

The partial eta squared value of 0.209 suggests that around 20.9% of the variability in tensile strength is influenced by the combined impact of concentration (12% and 15%) and duration (3, 5, and 7 days). Certain concentration and duration combinations can either enhance or impede

fiber modification. Understanding how these factors interact is crucial for achieving the desired outcome. This finding highlights the complex nature of chemical treatments on natural fibers, where multiple factors interact nonlinearly, leading to intricate and sometimes unexpected results [11].

Table 15 shows that the effect of alkali concentration on elongation is influenced by the treatment duration, and vice versa. Although the effect size is small, it is statistically significant and cannot be ignored. Certain combinations of concentration and duration may enhance elongation, while others may hinder it. This demonstrates the complexity of chemical treatments for natural fibers, often involving non-linear interactions between multiple factors.

Table 15. Statistical Result on Two-Way ANOVA for Combined Effect vs. Elongation

Source	F	Sig.	Partial Eta Squared	Decision
Concentration*Duration	4.646	< .001	.044	Reject

4 CONCLUSIONS AND RECOMMENDATIONS

Based on the findings, it was concluded that treating coconut coir fibers with a 12% concentration of alkali solution for three days is the most effective method for enhancing their tensile strength. However, this treatment may reduce the fibers' elongation due to structural and compositional changes. Alkali treatment using sodium bicarbonate has a significant impact on the tensile strength and elongation of the fibers, likely resulting from the removal of non-cellulosic materials and modifications to cellulose structure and surface characteristics. Additionally, it was found that a minimal change in alkali concentration had little effect on the tensile properties of the fibers. The duration of treatment was also found to influence the strength properties of the fibers, potentially due to gradual alkali impact or damage from over-treatment.

The study recommended using a 12% alkali solution and a 3-day treatment period for applications requiring high tensile strength in coco coir fibers, while untreated fibers are preferred for applications requiring flexibility. Further research was suggested to investigate the specific mechanisms by which alkali treatment alters tensile properties, as well as to explore lower alkali concentrations to reduce costs and environmental impact. Additionally, the study recommended conducting further experiments to determine the optimal treatment duration and to understand the interaction between alkali concentration, treatment duration, and their impact on elongation for fine-tuning fiber properties.

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