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Stabilizing Alkaline Treatment Parameters for Enhancing Tensile Strength of Bamboo Fiber Composites

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Abstract

Bamboo fibers are increasingly recognized for their sustainability and versatility in composite manufacturing, yet their inherent mechanical properties are insufficient for many industrial applications. This study aims to enhance the tensile strength of bamboo fiber composites through alkaline treatment, specifically focusing on the effects of sodium hydroxide (NaOH) treatment at concentrations of 2% and 10% for durations of 1 and 10 hours. The research employs tensile testing using a Universal Testing Machine (UTM) in accordance with ASTM D3039 standards to evaluate the treated and untreated composites. Results indicate significant improvements in tensile strength of the treated bamboo fiber composites. These findings confirm that stable alkaline treatment parameters enhances the mechanical properties which is tensile strength, making bamboo fiber composites more viable for high-performance industrial applications.

1. Introduction

In contemporary society, there is a pronounced shift towards sustainable development across industries, driven by a heightened awareness of environmental preservation [1]. The dependency on synthetic materials derived from non-renewable resources like petroleum has significantly contributed to pollution and greenhouse gas emissions during production [2]. This has prompted both manufacturers and consumers to gravitate towards eco-friendly alternatives, aligning with stringent global environmental regulations [3]. Natural fibers, with their renewable and biodegradable properties, are increasingly valued for their potential in enhancing composite materials sustainably [4]. Among these, bamboo stands out for its composition primarily comprising cellulose, hemicellulose, and lignin [5].

However, raw natural fibers often lack the necessary properties for direct industrial use, necessitating various treatments to optimize their characteristics [6]. In this context, alkaline treatment, notably using sodium hydroxide (NaOH), emerges as a transformative method to enhance bamboo fibers [7]. This process involves purifying bamboo fibers by eliminating impurities, hemicellulose, and lignin, resulting in a cleaner substrate with improved bonding potential with polymer matrices. This research focuses on stabilizing alkaline treatment parameters to enhance the tensile strength of bamboo fiber composites, thereby advancing their sustainability and performance.

Bamboo fiber is valued for its sustainability, but its mechanical properties are often insufficient for industrial use due to components like lignin and pectin hindering effective adhesion in composites [8], [9]. To unlock its full potential, treatments are necessary [9]. Alkaline treatment with sodium hydroxide (NaOH) has proven effective in enhancing bamboo fiber composites' mechanical properties [9], [10]. This research aims to reinforce bamboo fiber composites using alkaline treatment, stabilizing and improving its tensile strength for various industrial applications.

2. Methodology

The experiment setup involved the utilization of bamboo fibers as the reinforcing material and epoxy resin as the matrix. The materials required for the experiment included bamboo fiber, sodium hydroxide (NaOH) solutions at 2% and 10% concentrations, distilled water for rinsing, epoxy resin, and simple molds or trays for composite fabrication. The preparation of bamboo fibers commenced with the careful extraction from their bundles, followed by immersion in NaOH solutions for varying durations of 1 and 10 hours to undergo alkaline treatment. Subsequently, the treated fibers were rinsed with water and air-dried for 24 hours at room temperature. Composite fabrication involved the preparation of epoxy resin as the matrix, followed by the mixing of treated bamboo fibers with the resin in a 50:50 ratio. The mixture was then poured into simple mold, allowing the composite samples to cure at room temperature for 48 hours. Tensile testing was conducted on the cured composite specimens using a Universal Testing Machine using ASTM D3039 standard, with rectangular-shaped samples prepared and a crosshead speed set at 2.2m/min. Load-displacement data were recorded, and tensile strength was calculated for each sample, with each test repeated five times to ensure accuracy and reliability.

2.1 Alkaline Treatment

In this experiment, bamboo fibers were subjected to an alkaline treatment process by immersing them in sodium hydroxide (NaOH) solutions with varying concentrations and durations. Specifically, the raw bamboo fibers were immersed in 2% NaOH and 10% NaOH solutions for durations of 1 hour and 10 hours. Sodium hydroxide pellets were utilized to prepare these solutions. This step was essential to ensure the effectiveness of alkaline treatment, which aims to modify the fibers' mechanical properties. Figure 1 shows the raw bamboo fibers used before the treatment, while Figure 2 shows the sodium hydroxide pellets employed to create the NaOH solutions. This experimental setup allowed for a comprehensive analysis of how different NaOH concentration and immersion times impact the bamboo fibers, providing valuable insights into the stable conditions for fiber treatment.

Fig. 1 *Raw bamboo fibers*

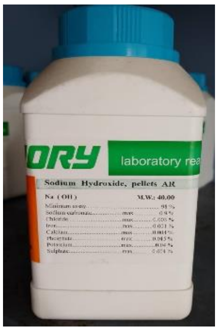

Fig. 2 *Sodium hydroxide (NaOH) pellets*

2.2 Composite Fabrication Process

The composite fabrication process involved using epoxy resin, a hardener for epoxy (modified cycloaliphatic amines), and both treated and untreated bamboo fibers, to use epoxy resin to make the composite, it was necessary to mix it with hardener in a ratio of 2:1 (epoxy resin to hardener). This step ensures that the composite can solidify properly. In this experiment, we used a 50:50 ratio of bamboo fibers to epoxy resin. After mixing the components, the mixture was placed in a tray with a thickness of 3mm. The composite then allowed to cure at room temperature for 48 hours. Figure 3 shows (a) epoxy resin, (b) hardener for epoxy resin and (c) composite in tray before it fully cured from the experiment.

(a)

(b)

(c)

Fig.3 *Composite Fabrication Process (a) epoxy resin; (b) hardener for epoxy; (c) composite in tray before fully cured*

2.3 Tensile Testing

For tensile testing, in this experiment a Universal Testing Machine. Rectangular-shaped specimens were prepared form cured composites materials. Following the ASTM D3039 standard for short random composite, the specimen dimensions were 250mm in length, 25mm in width and 3mm in thickness. During the tensile testing, a crosshead speed of 2.2 mm/min was used. The maximum force and maximum strain were recorded from this testing. Figure 4 shows Tensile testing process (a) The Universal Testing Machine, (b) the tensile testing process and (c) the specimen after testing.

(a) **(b)** **(c)**

Fig. 4 *Tensile testing (a) Universal Testing Machine; (b) Tensile testing process; (c) Specimen after testing*

3. Results and Discussion

From the tensile testing experiment, we determined the maximum force and maximum strain for each specimen. To ensure the accuracy and reliability of the results, each of the conditions was repeated five times. This repetition helps account for any variability in the specimens and provides a more robust data set for analysis. Table 3.1 presents the detailed results of the tensile testing experiment. The table includes the maximum force and maximum strain values for each of five repetitions under each condition.

Table 3.1 *Table of tensile testing result*

Temperature (°C)		**Specimen**	**Maximum Force (N)**	**Maximum strain (%)**
Room Temperature				
NaOH concentration (%)	Duration (hour)			
0	-	1	1497.19	3.16350
		2	1590.94	2.43000
		3	1532.19	2.48600
		4	1531.88	3.41300
		5	1304.38	3.30500
2	1	1	1579.06	3.11200
		2	1522.81	3.27300
		3	1576.25	2.77100
		4	1660.00	4.01400

		5	1786.25	3.07000
	10	1	2792.19	3.64500
		2	2748.13	4.08300
		3	2616.56	3.65850
		4	2620.00	4.19800
		5	2832.50	3.56900
10	1	1	1230.31	3.55750
		2	1309.38	3.45500
		3	1326.25	3.33750
		4	1400.94	5.25500
		5	1420.94	3.59300
	10	1	1342.81	3.16750
		2	1412.19	3.34100
		3	1434.38	3.60500
		4	1296.25	2.91100
		5	1319.69	3.20750

The untreated specimens exhibited variable tensile strengths, with maximum forces ranging from approximately 1304N to 1591N. The corresponding maximum strain values ranged from 2.43% to 3.41%. these values set a baseline for comparison with the treated specimens. Bamboo fibers treated with 2% NaOH for 1 hour showed an increase in tensile strength, with maximum forces ranging from approximately 1523N to 1786N. the corresponding maximum strain values also varied, indicating improved but somewhat, inconsistent results compared to untreated fibers. This might happen due to the defect that appeared during curing the specimen which air traps.

The most significant improvement was observed in specimens treated with 2% NaOH for 10 hours, these specimens exhibited the maximum forces ranging from approximately 2617N to 2833N, significantly higher than both untreated and other treated fibers. The maximum strain values were also relatively higher, indicating enhanced flexibility and strength. This suggests that 2% NaOH treatment for 10 hours is a stable parameter that enhances the mechanical properties of bamboo fiber composites.

Specimens treated with 10% NaOH showed mixed results. For a 1-hour duration, the maximum forces were lower, ranging from approximately 1230N to 1421N. the 10 hours treatment with 10% NaOH showed some improvement but did not surpass the 2% NaOH for 10 hours treatments, indicating possible fiber degradation at higher concentration or prolonged exposure. Figure 5 represents the graphs of maximum strain versus maximum force for (a) untreated, (b) 2% for 1hour, (c) 2% for 10 hours, (d) 10% for 1 hour, and (e) 10 % for 10 hours of bamboo fiber composites specimens.

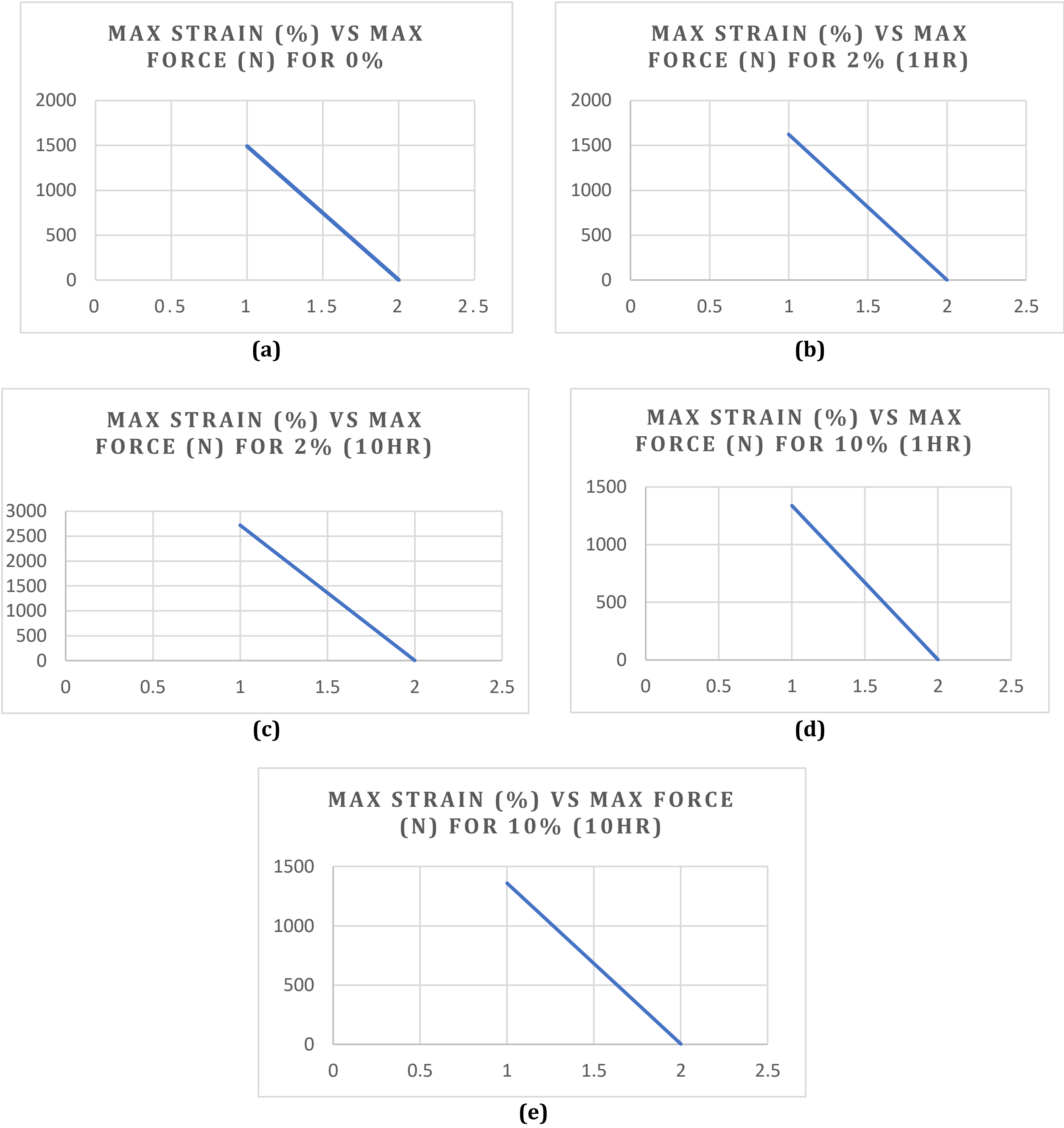

Fig. 5 *Graph of maximum strain vs maximum force of bamboo fiber composite specimens (a) Untreated bamboo fiber graph; (b) 2% NaOH (1hour) graph; (c) 2% NaOH (10hours); (d) 10% NaOH (1hour); (e) 10% NaOH (10 hours)*

4. Conclusion

In conclusion, the tensile strength of both untreated and treated bamboo fiber composites are significantly influenced by the alkaline treatment process. The theoretical framework suggests that alkaline treatment process enhances the mechanical properties of bamboo fiber composites. This was confirmed by this experiment findings, which identified that the most effective treatment parameters for improving the mechanical properties of bamboo fiber composites are immersion in 2% NaOH for 10 hours. The impact of the alkaline treatment on bamboo fiber was evaluated through tensile tests conducted in accordance with the ASTM D3039 standard. The results showed that bamboo fiber composites treated with 2% NaOH for 10 hours exhibited the highest maximum force during tensile testing, indicating superior strength compared to other specimens. This finding highlights the most stable parameters for alkaline treatment to enhance the performance of bamboo fiber composites, providing valuable insights for future research and applications in composite material development.

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References

[1] I. Elfaleh *et al.*, "A comprehensive review of natural fibers and their composites: An eco-friendly alternative to conventional materials," *Results in Engineering*, vol. 19. Elsevier B.V., Sep. 01, 2023. doi: 10.1016/j.rineng.2023.101271.

[2] J. L. Arthur *et al.*, "Environmental Impacts of Petroleum Emissions: an Exploration of TOR's Exposures and Experiences," 2023, doi: 10.21203/rs.3.rs-2806055/v1.

[3] L. Laasri, "Natural fiber composite features, applications, and markets," in *Multiscale Textile Preforms and Structures for Natural Fiber Composites*, Elsevier, 2023, pp. 31–61. doi: 10.1016/B978-0-323-95329-0.00005-3.

[4] Y. Feng, H. Hao, H. Lu, C. L. Chow, and D. Lau, "Exploring the development and applications of sustainable natural fiber composites: A review from a nanoscale perspective," *Compos B Eng*, vol. 276, May 2024, doi: 10.1016/j.compositesb.2024.111369.

[5] S. Palanisamy, K. Vijayananth, T. M. Murugesan, M. Palaniappan, and C. Santulli, "The Prospects of Natural Fiber Composites: A Brief Review," *International Journal of Lightweight Materials and Manufacture*, Jul. 2024, doi: 10.1016/j.ijlmm.2024.01.003.

[6] X. Li, L. G. Tabil, and S. Panigrahi, "Chemical treatments of natural fiber for use in natural fiber-reinforced composites: A review," *Journal of Polymers and the Environment*, vol. 15, no. 1. pp. 25–33, Jan. 2007. doi: 10.1007/s10924-006-0042-3.

[7] W. Ouarhim, N. Zari, R. Bouhfid, and A. E. K. Qaiss, "Mechanical performance of natural fibers-based thermosetting composites," in *Mechanical and Physical Testing of Biocomposites, Fibre-Reinforced Composites and Hybrid Composites*, Elsevier, 2018, pp. 43–60. doi: 10.1016/B978-0-08-102292-4.00003-5.

[8] M. R. Sanjay, G. R. Arpitha, L. L. Naik, K. Gopalakrishna, and B. Yogesha, "Applications of Natural Fibers and Its Composites: An Overview," *Natural Resources*, vol. 07, no. 03, pp. 108–114, 2016, doi: 10.4236/nr.2016.73011.

[9] W. Nhuapeng, T. Chintonguyad, and W. Thamjaree, "The Influence of Alkaline Treatment on Tensile Properties of Short Bamboo Fiber Reinforced Epoxy Resin Biocomposites," in *Journal of Physics: Conference Series*, IOP Publishing Ltd, Feb. 2022. doi: 10.1088/1742-6596/2175/1/012004.

[10] M. S. Islam, K. L. Pickering, and N. J. Foreman, "Influence of alkali treatment on the interfacial and physico-mechanical properties of industrial hemp fibre reinforced polylactic acid composites," *Compos Part A Appl Sci Manuf*, vol. 41, no. 5, pp. 596–603, May 2010, doi: 10.1016/j.compositesa.2010.01.006.