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Mechanical Performance of Untreated and Treated Sugarcane Bagasse Reinforced Epoxy Composite

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Abstract

This research explores the mechanical performance of sugarcane bagasse (SCB) fiber-reinforced epoxy composite, examining the effect of alkali treatment. A sustainable way to reinforce polymer matrices is by using agricultural waste, such as SCB. The study classifies both the condition of untreated and NaOH-treated SCB fibers in three different compositions, such as 5%, 4%, and 3%. Composite samples were produced and tested for tensile and flexural properties. This testing refers to ASTM D3039 for tensile, while ASTM D790 for flexural. The results indicate that SCB treated with alkali enhanced fiber-matrix adhesion, thereby improving mechanical performance. The composite with 5% treated SCB had the best tensile and flexural strengths, thanks to better fiber dispersion and stronger interface bonding. This study shows that using agricultural waste, such as SCB, can improve composite performance and promote sustainability.

1. Introduction

The growing interest in using natural fibers and agricultural waste as reinforcements in polymer composites stems from the shift toward sustainable engineered materials. Sugarcane bagasse (SCB), a byproduct of the sugar industry, contains cellulose, hemicellulose, and lignin, making it suitable as reinforcement. However, untreated fibers often have poor interfacial contact with the matrix. Alkaline treatment, typically with sodium hydroxide (NaOH), improves the bonding ability and surface roughness of the fibers.

Natural fiber-reinforced composites offer economic and environmental advantages because they are cheaper, biodegradable, and renewable compared to synthetic fiber composites. However, challenges such as moisture absorption, fiber-matrix compatibility, and property variability remain. Therefore, alkali modification and other surface treatments are crucial for enhancing the interfacial adhesion and performance of the composites.

This study aims to create and analyze epoxy composites reinforced with SCB, both treated and untreated. A researcher reported that alkali-treated SCB composites had greater tensile strength compared to untreated ones. This is because they exhibit better interfacial adhesion, which reduces problems such as fiber pullout and matrix debonding [1]. We will evaluate mechanical properties, focusing on tensile and flexural strength, to assess performance. Our main goal is to find the best fiber mix for mechanical strength while maintaining sustainability and staying within budget. A researcher states that other important reasons include environmental balancing, improved crash performance with high stability, health issues, and low prices [2].

2. Methodology

2.1 Preparation of Sugarcane Bagasse Fibers

Mechanical testing, composite fabrication, and material preparation are the steps in the experimental procedure. To achieve a uniform particle size, SCB was collected, sun-dried, and ground to a fine powder before sieving. Research on particle size variations reveals distinct mechanical behaviors [3]. This highlights the need for uniformity in composite materials. The fibers to be chemically treated were soaked in a 5% NaOH solution at room temperature. NaOH is important in this study because of the benefits that it will get from it, and several researchers also agree with this statement, such as one of the researchers, who stated that mechanical properties were significantly enhanced by varying the concentration of NaOH, suggesting that this is a crucial factor in producing fibers for composite applications [4]. After treatment, the fibers were sun-dried again to ensure complete dryness. For example, Figure 1 shows the SCB that has been collected, while Figure 2 shows the cleaning process for the SCB.

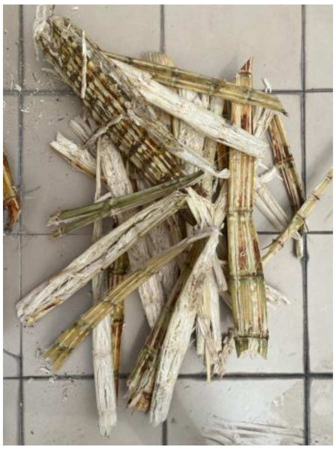


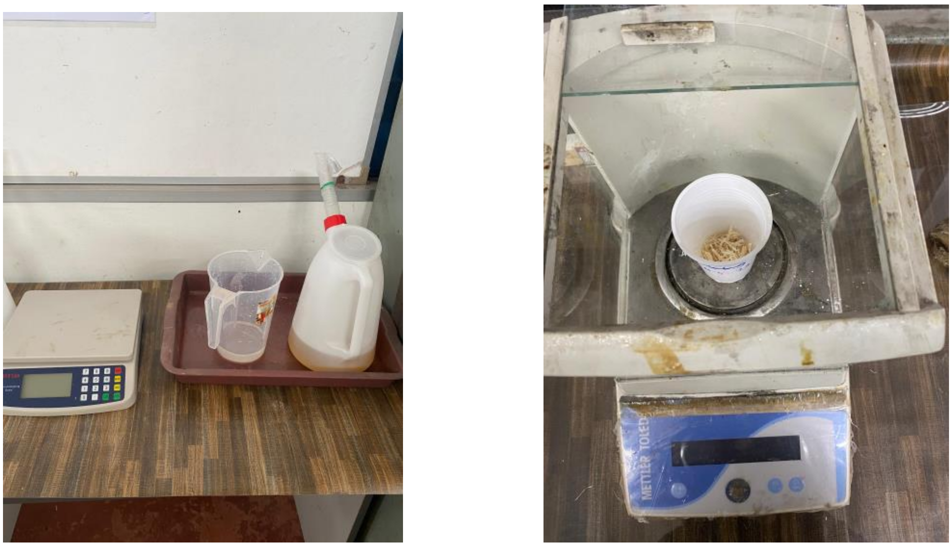
Fig. 1 *Collected SCB*

Fig.2 *Cleaning process of SCB*

2.2 Composition Preparation

The matrix, epoxy resin, and hardener were mixed in a 2:1 ratio. Figures 3 show the process of fiber composition and matrix preparation. The preparation of SCB fibers was manually mixed with resin to create three compositions:

- Composition A: 5% SCB + 95% epoxy
- Composition B: 4% SCB + 96% epoxy
- Composition C: 3% SCB + 97% epoxy

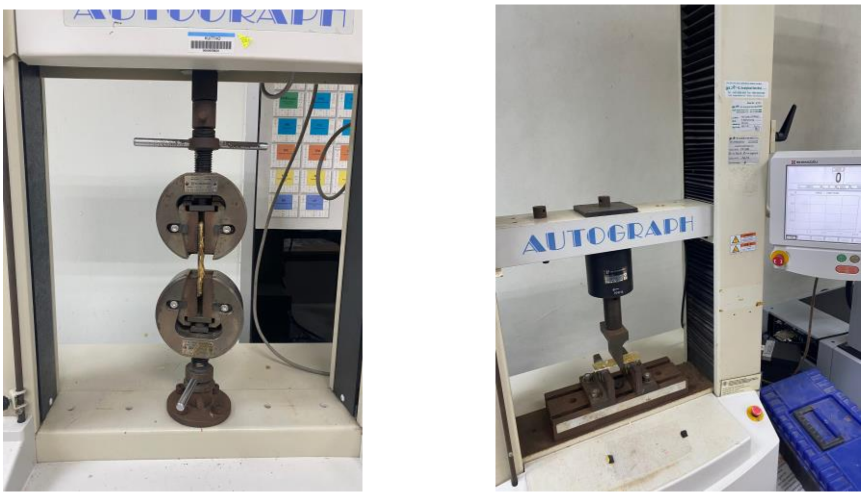


(a) (b)

Fig. 3 *Composition for (a) matrix and (b) fibers preparation*

2.3 Composite Fabrication and Testing Procedure

The mixture was then poured onto a steel plate that had already been used to measure the specimens' sizes in accordance with ASTM D3039 and D790. A Universal Testing Machine (UTM) was used for mechanical testing, with a crosshead speed of 10 mm/min. Tensile testing measured the modulus of elasticity, strain, and ultimate tensile strength. Flexural tests determined the maximum flexural stress and strain at break. To ensure statistical accuracy, three samples of each composition were tested. Figures 5 and 6 show the UTM machine for tensile and flexural tests.



(a) (b)

Fig. 4 *UTM machine for (a) tensile and (b) flexural tests*

3. Results and Discussion

3.1 Tensile Strength

The percentage of SCB in the treated composites influenced their tensile strength. Composition A, which contained 5% treated SCB, showed the highest average tensile strength of 25.43 MPa. This improved performance stems from sufficient reinforcement from the higher fiber content and the strong interfacial bonding created by the NaOH treatment. Researchers discovered that chemical treatments promote interfacial adhesion between polymer matrices and natural fibers, thereby enhancing microstructural strengthening mechanisms [5]. Compositions B and C demonstrated lower tensile strengths, indicating that lower fiber content reduces load-bearing capacity. Table 1 shows the data for maximum tensile strength.

Table 1 *Maximum tensile strength*

Composition	Sample	Untreated	Treated
5% SCB	1	680.63 N	1527.81 N
	2	855.63 N	1828.44 N
	3	299.06 N	183.38 N
(Average)		611.77 N	1213.21 N
4% SCB	1	582.19 N	1475.94 N
	2	467.18 N	1391.88 N
	3	279.38 N	859.06 N
(Average)		442.91 N	1242.29 N
3% SCB	1	390.31 N	1130.94 N
	2	283.75 N	1560.63 N
	3	220.31 N	425.63 N
(Average)		298.12 N	1039.01 N

3.2 Tensile Strain and Modulus

The modulus of elasticity and tensile strain followed a similar pattern. Composition A exhibited the highest modulus and strain, indicating both stiffness and ductility. This suggests a balanced mechanical profile, meaning the material can stretch under stress while maintaining its structure. Weak surface contaminants were removed during treatment, thereby improving matrix infiltration and stress transfer at the fiber-matrix interface. A researcher discovered that untreated fibers in composites tend to cluster, creating voids that increase the likelihood of crack formation [6]. Table 2 shows the data for maximum tensile strain, while Table 3 shows the data for tensile modulus.

Table 2 *Maximum tensile strain*

Composition	Sample	Untreated (%)	Treated (%)
5% SCB	1	3.83	8.09
	2	12.54	6.46
	3	3.84	11.96
(Average)		6.74	8.84
4% SCB	1	8.14	11.32
	2	18.03	5.70
	3	6.19	6.45
(Average)		10.79	7.82
3% SCB	1	47.09	6.33
	2	28.44	4.55
	3	7.50	2.96
(Average)		27.68	4.61

Table 3 *Tensile modulus*

Composition	Sample	Untreated (GPa)	Treated (GPa)
5% SCB	1	2.37	2.52
	2	0.91	3.78
	3	0.78	0.21
(Average)		1.35	2.17
4% SCB	1	0.95	1.74
	2	0.35	3.25
	3	0.60	1.78
(Average)		0.63	2.26
3% SCB	1	0.11	2.38
	2	0.13	4.57
	3	0.39	1.92
(Average)		0.21	2.96

3.3 Flexural Strength

The tensile results showed in the flexural characteristics. Treated Composition (A) had the highest flexural strength at 44.58 MPa. This indicates that the composite effectively resists bending forces, making it suitable for structural applications. This outcome was influenced by improved fiber-matrix contact, which helped distribute the load throughout the composite. Previous researchers stated that 25% of weight sugarcane bagasse/polypropylene composites showed better flexural properties [7]. Table 4 presents the data on the maximum force from flexural testing.

Table 4 *Maximum force of flexural testing*

Composition	*Sample*	*Untreated*	*Treated*
5% SCB	*1*	*197.813 N*	*128.438 N*
	2	*134.375 N*	*166.250 N*
	3	*82.188 N*	*212.188 N*
(Average)		*138.79 N*	*168.96N*
4% SCB	*1*	*75.623 N*	*123.438 N*
	2	*78.438 N*	*125.938 N*
	3	*88.750 N*	*75.313 N*
(Average)		*80.94N*	*108.23 N*
3% SCB	*1*	*61.563 N*	*99.688 N*
	2	*56.563 N*	*75.625 N*
	3	*44.375 N*	*20.313 N*
(Average)		*54.17 N*	*65.21 N*

3.4 Effect of SCB Composition Ratio

Untreated samples showed brittle failure with weak matrix-fiber bonding. In contrast, treated samples exhibited more uniform, ductile fractures. The NaOH treatment removed contaminants and improved fiber surface roughness, resulting in a more cohesive, mechanically stronger structure. A researcher revealed that chemical treatment of sugarcane bagasse fibers could enhance the mechanical and morphological properties of unsaturated polyester composites [8]. This finding underscores the need to optimize fiber loading to enhance composite performance, particularly in natural fiber-reinforced polymer systems. A previous researcher found that a higher SCB content in epoxy resin increased the glass transition temperature, further indicating improved fiber-matrix interaction and superior mechanical performance [9].

4. Conclusion

This study has shown that sugarcane bagasse can improve the mechanical performance of epoxy composites when processed and used in the right amounts. Composition A (5% treated SCB) achieved the highest tensile and flexural strength among all the tested formulations. This result highlights the positive effects of alkali treatment and appropriate filler loading. In line with global efforts to support sustainability, these results support the use of agricultural waste as reinforcement in polymer composites. The findings suggest potential applications in consumer goods, automotive, packaging, and construction. Future research may evaluate the long-term durability, thermal characteristics, and water absorption of these composites in various environmental conditions.

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Conflict of Interest

Authors declare that there is no conflict of interest regarding the publication of the paper.

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