

# The Effect of Naoh for Sugarcane Bagasse Reinforced Alumina Composite to their Mechanical Properties

Nuraina Nazifa Azrul Effendy<sup>1\*</sup>, Zaleha Mohamad<sup>1</sup>

<sup>1</sup> Faculty of Mechanical and Manufacturing Engineering  
Universiti Tun Hussein Onn Malaysia (UTHM), Parit Raja, Batu Pahat, 86400, MALAYSIA.

\*Corresponding Author: [nurainanazifa@uthm.edu.my](mailto:nurainanazifa@uthm.edu.my)  
DOI: <https://doi.org/10.30880/rpmme.2025.06.02.019>

## Article Info

Received: 10 July 2025

Accepted: 10 September 2025

Available online: 10 December 2025

## Keywords

Sugarcane bagasse, NaOH treatment, UPR matrix, alumina composite, tensile strength, flexural strength, natural fiber composite

## Abstract

The use of natural fiber-reinforced composites has gained momentum as a sustainable solution for reducing environmental impact and material cost in engineering applications. This study investigates the mechanical properties of sugarcane bagasse (SCB) reinforced alumina composites using Unsaturated Polyester Resin (UPR) as the polymer matrix, focusing on the effect of alkali treatment with sodium hydroxide (NaOH). Composites were fabricated with varying SCB and alumina contents, with and without 5% NaOH-treated fibers, to evaluate tensile and flexural behavior according to ASTM standards. The results demonstrated that NaOH treatment significantly improved fiber-matrix interfacial bonding, resulting in enhanced mechanical performance. Among all tested compositions, the treated sample with 3% SCB, 12% alumina, and 85% UPR exhibited the highest improvement in both tensile and flexural strength, attributed to effective stress transfer and optimal dispersion of reinforcement. The findings affirm the potential of chemically treated agro-waste fibers and ceramic fillers to produce high-performance, eco-friendly composites suitable for structural and semi-structural applications.

## 1. Introduction

The increasing demand for sustainable and biodegradable materials has driven extensive interest in natural fiber-reinforced polymer composites, particularly in sectors such as construction, automotive, and consumer goods [1]. Agricultural byproducts like sugarcane bagasse (SCB) are being widely explored due to their renewability, low cost, and environmental benefits [2]. As a lignocellulosic fiber, SCB is lightweight and abundantly available, but it suffers from poor interfacial adhesion with polymer matrices, which limits its load-bearing performance in composite applications [2][3].

To overcome this limitation, alkali treatment commonly using sodium hydroxide (NaOH) is employed to improve fiber-matrix compatibility. The treatment process removes lignin, hemicellulose, and surface waxes, resulting in a rougher fiber surface and increased exposure of cellulose hydroxyl groups, which enhance bonding with the matrix [4]. Recent studies have shown that NaOH treatment significantly improves the tensile and flexural properties of natural fiber composites due to better stress transfer and interfacial adhesion [5].

In addition to natural fibers, ceramic fillers such as alumina ( $Al_2O_3$ ) have been incorporated into polymer matrices to improve thermal stability, hardness, and stiffness. Alumina acts as a load-bearing phase that enhances mechanical strength and resistance to deformation, especially in hybrid composite systems [6]. When

combined with Unsaturated Polyester Resin (UPR), these reinforcements can form bio-hybrid composites that exhibit favorable mechanical performance for structural and semi-structural applications [6][7].

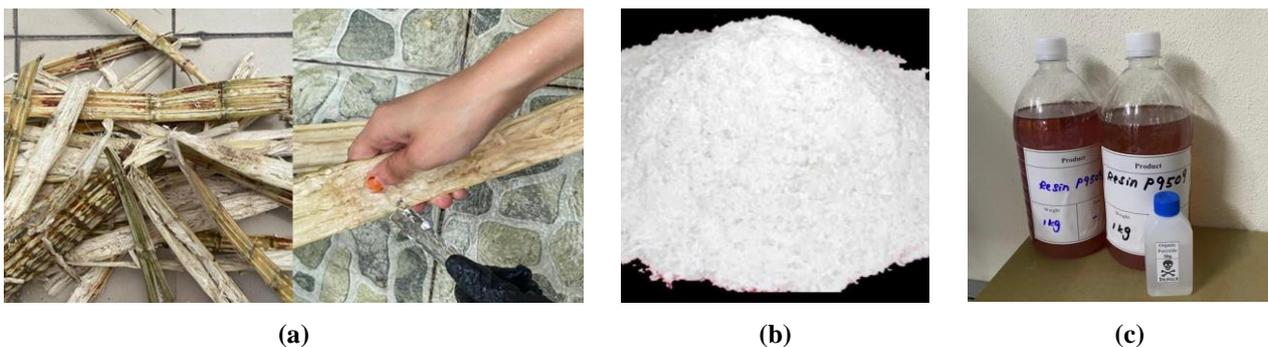
This study focuses on the fabrication and mechanical performance of SCB–alumina composites using UPR as the matrix. A key objective is to investigate and compare the mechanical behavior specifically tensile and flexural strength of composites reinforced with untreated and 5% NaOH-treated SCB fibers. Multiple SCB compositions (3%, 4%, and 5%) were tested to evaluate the influence of alkali treatment and filler proportion on mechanical properties. The results aim to assess the mechanical performance across all treated and untreated compositions, with specific emphasis on tensile and flexural strengths. This work contributes to ongoing efforts to develop high-performance, eco-friendly materials from renewable resources by optimizing fiber treatment and hybrid reinforcement strategies.

## 2. Materials Method

This section outlines the materials used, preparation procedures, and testing methods employed to evaluate the mechanical performance of sugarcane bagasse (SCB) reinforced alumina composites using unsaturated polyester resin (UPR) as the matrix.

### 2.1 Raw Materials

Sugarcane bagasse (SCB), a lignocellulosic agricultural waste material, was collected from local suppliers in Parit Raja. The fibers were carefully washed to remove dirt and residual sugar, then sun-dried for one to two days to eliminate moisture. Alumina ( $Al_2O_3$ ) powder with a high purity level ( $\geq 99\%$ ) was used as the ceramic reinforcement due to its well-known role in improving thermal and mechanical stability in composite materials. Unsaturated Polyester Resin (UPR), a thermosetting matrix commonly used in structural applications, was selected for its good mechanical performance and ease of curing. Methyl Ethyl Ketone Peroxide (MEKP) was employed as the catalyst at a concentration of 1–2 wt.% relative to the resin. Fig. 1 shows the raw materials used.



**Fig. 1** (a) Sugarcane bagasse (SCB) fibers before cleaning (left) and after cleaning and drying (right); (b) High-purity alumina ( $Al_2O_3$ ) powder; (c) Unsaturated polyester resin (UPR) and MEKP catalyst.

### 2.2 Alkali Treatment of SCB Fibers

To improve the fiber–matrix interfacial bonding, a chemical surface modification was carried out on half of the SCB fibers using sodium hydroxide (NaOH). The fibers were soaked in a 5% NaOH solution for 24 hours at room temperature. After treatment, the fibers were rinsed repeatedly with distilled water until a neutral pH was achieved, indicating complete removal of residual alkali. The treated fibers were then oven-dried at 60 °C for 48 hours. This alkali treatment aimed to remove hemicellulose, lignin, and surface waxes, thereby increasing surface roughness and exposing more reactive cellulose groups, which enhanced the wettability and bonding potential with the polymer matrix. Fig. 2 shows the treated SCB.



**Fig. 2** Treated-SCB Fibers

## 2.3 Composite Formulation

Six different composite formulations were prepared to investigate the influence of both filler content and alkali treatment on mechanical behavior. The compositions are categorized into untreated (C1–C3) and NaOH-treated groups (C4–C6), as shown in Table 1.

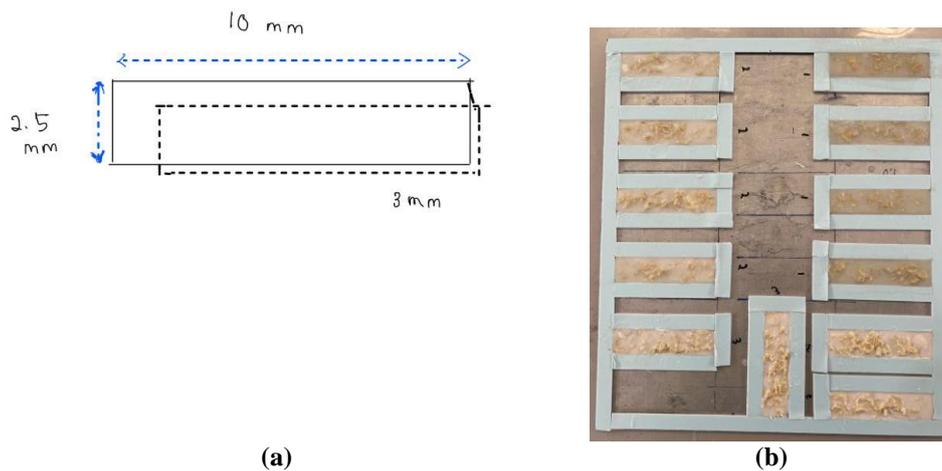
**Table 1** Composition and Treatment of SCB/Alumina/UPR Composites

Composition	SCB (wt%)	Alumina (wt%)	UPR (wt%)	Treatment
C1	3%	12%	85%	Untreated
C2	4%	21%	75%	Untreated
C3	5%	31%	65%	Untreated
C4	3%	12%	85%	Treated-NaOH
C5	4%	21%	75%	Treated-NaOH
C6	5%	31%	65%	Treated-NaOH

The dry fillers, comprising sugarcane bagasse (SCB) and alumina, were pre-mixed to promote uniform dispersion prior to being gradually introduced into the unsaturated polyester resin (UPR) matrix under continuous mechanical stirring. Upon achieving a consistent and homogeneous blend, Methyl Ethyl Ketone Peroxide (MEKP) was incorporated as a curing agent to initiate the polymerization process. The resulting composite mixture was cast into precision-fabricated steel molds conforming to ASTM standard dimensions for tensile and flexural testing. Specimens were allowed to cure at ambient conditions, with a typical curing duration of approximately 24 hours to ensure adequate cross-linking and structural integrity.

## 2.4 Specimen Preparation

After curing, the hardened composite was carefully removed from the steel mold. The composite sheets were then cut into rectangular specimens based on standard guidelines. For tensile testing, although ASTM D3039 specifies a typical specimen size of 250 mm in length, 25 mm in width, and 2–3 mm in thickness, the samples in this study were prepared with dimensions of 10 mm in length, 2.5 mm in width, and 3 mm in thickness. These dimensions fall within an acceptable scaled-down range, often used in laboratory settings when material quantity is limited or when using custom molds. Flexural specimens were similarly prepared, following ASTM D790, using the three-point bending method, and their dimensions were matched to those of the tensile samples for consistency.

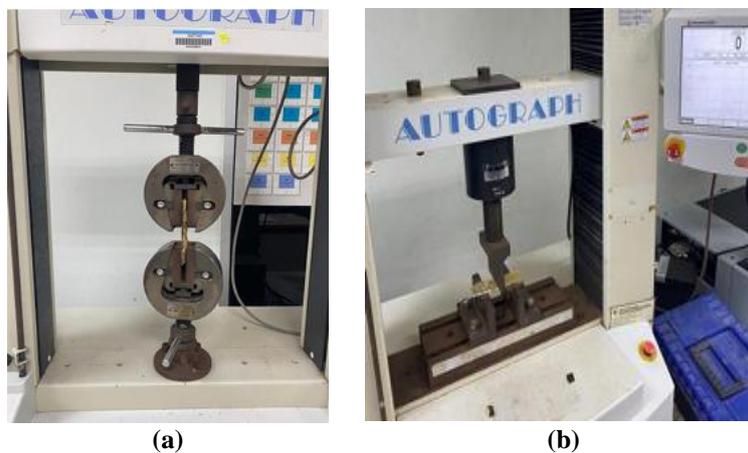


**Fig. 3** (a) Schematic diagram of the composite sample dimensions (2.5 mm × 10 mm × 3 mm); (b) Fabricated composite specimens arranged in steel moulds prior to curing

## 2.5 Mechanical Testing

Mechanical characterization focused on evaluating the tensile and flexural behavior of each composite formulation. Tests were conducted using a universal testing machine (UTM) with a load cell capacity of 10 kN. Tensile tests (Fig. 4a) were conducted at a crosshead speed of 1 mm/min until specimen failure. For flexural testing (Fig. 4b), a three-point bending fixture was used with the same loading speed and a support span of 80 mm.

Each composition was tested in triplicate, and average values were computed for key mechanical parameters, including maximum force, maximum tensile strength, elongation at break, flexural strength, and modulus of elasticity. The results were plotted and compared across all formulations to assess the effectiveness of NaOH treatment and filler variation on the overall performance of the composite.



**Fig. 4** (a) Universal Testing Machine (UTM) setup for tensile testing; (b) UTM setup for flexural (three-point bending) testing

### 3. Results Discussion

This section presents the mechanical testing results of sugarcane bagasse (SCB)–alumina composites reinforced in an unsaturated polyester resin (UPR) matrix. The primary objective was to evaluate the effect of 5% NaOH alkali treatment on tensile and flexural performance across various SCB compositions. Results are discussed in terms of tensile strength, flexural load, displacement, and the overall influence of surface treatment.

#### 3.1 Tensile Properties

Tensile tests indicated a significant improvement in strength and stiffness for composites containing SCB fibers treated. As presented in Table 2, untreated samples exhibited a progressive increase in tensile stress from C1 to C3, accompanied by higher SCB and alumina content. However, NaOH-treated samples (C4–C6) exhibited markedly higher tensile strengths even at similar filler ratios. For instance, C4 recorded a tensile stress of 9.41 MPa, which is more than double that of its untreated counterpart, C1 (4.19 MPa).

This improvement is attributed to the removal of lignin, waxes, and hemicellulose during NaOH treatment, resulting in enhanced fiber–matrix adhesion and improved load transfer capabilities. The increase in surface roughness also promotes mechanical interlocking, contributing to enhanced tensile behavior [4][5].

**Table 2** Maximum Tensile Stress and Strain for Untreated and Treated SCB Composites

Composition	Treatment	Max Stress (MPa)	Max Strain (%)
C1	Untreated	4.19	1.60
C2	Untreated	6.97	3.66
C3	Untreated	11.68	7.14
C4	Treated-NaOH	9.41	2.24
C5	Treated-NaOH	11.35	3.00
C6	Treated-NaOH	16.17	3.52

The treated 3% SCB sample (C4) showed a more than 120% increase in tensile stress compared to untreated C1, indicating that NaOH treatment significantly enhances fibre–matrix bonding and stress distribution under load.

Table 3 summarizes the maximum force and displacement for the same samples. Treated composites could bear higher loads with lower elongation, demonstrating improved stiffness and structural integrity.

**Table 3** Maximum Tensile Force and Displacement Untreated and Treated SCB Composites

Composition	Treatment	Max Force (N)	Max Displacement (mm)	Force Increase (%)
C1	Untreated	876.15	4.64	-
C2	Untreated	522.50	2.38	-
C3	Untreated	314.59	1.04	-
C4	Treated-NaOH	1212.60	2.29	+133%
C5	Treated-NaOH	851.04	1.89	+48.5%
C6	Treated-NaOH	705.73	1.52	+25.6%

The maximum tensile force increased significantly in all treated samples, with the 3% SCB-treated composite (C4) showing the highest relative gain of 133% compared to its untreated counterpart. This indicates a substantial improvement in load-bearing capacity following NaOH treatment. Additionally, while untreated samples displayed higher displacement (i.e., more ductility), treated composites maintained higher strength with controlled deformation. This suggests increased stiffness and improves interfacial bonding, consistent with previous studies [8, 9].

#### 3.2 Flexural Properties

Flexural tests further validated the positive impact of NaOH treatment. Table 4 presents the maximum bending load and corresponding displacement values. Like tensile tests, treated samples demonstrate enhanced performance across all compositions.

**Table 4** Maximum Flexural Load and Displacement Untreated and Treated SCB Composites

<b>Composition</b>	<b>Treatment</b>	<b>Max Load (N)</b>	<b>Max Displacement (mm)</b>
C1	Untreated	143.44	4.26
C2	Untreated	119.27	3.98
C3	Untreated	109.27	3.55
C4	Treated-NaOH	202.40	7.35
C5	Treated-NaOH	187.50	5.62
C6	Treated-NaOH	170.0	4.78

The increase in load-bearing capacity was most prominent in C4, which showed a 75% increase in strength compared to C1. Treated samples also exhibited reduced displacement at peak load, indicating better resistance to bending and more effective load transfer.

Table 5 shows the percentage improvement in flexural load for each treated–untreated pair.

**Table 5** Flexural Load Improvement Due to Alkali Treatment

<b>Composition Pair</b>	<b>Untreated Load (N)</b>	<b>Treated Load (N)</b>	<b>% Increase</b>
C1 vs. C4	142.6	250.0	75.30%
C2 vs C5	168.4	265.7	57.80%
C3 vs C6	195.9	283.4	44.70%

These results clearly demonstrate that even low-percentage fiber formulations benefit significantly from surface modification. The greatest relative gain in flexural load was observed in the 3% SCB composite (C4), confirming its suitability as an optimal configuration in terms of mechanical efficiency.

### 3.3 Influence of Alkali Treatment on Mechanical Behavior

Alkali treatment had a consistently positive impact across all measured parameters. As summarized in Table 5, tensile strength, flexural load, and stiffness increased significantly in treated samples compared to untreated ones. The improvement in tensile stress ranged from 35% to over 120%, depending on the filler ratio. Flexural load gains were similarly notable, with C4 showing a 75.3% increase compared to its untreated pair C1.

Among all, the C4 composite (3% SCB treated) was the most efficient and balanced in terms of strength, stiffness, and strain, making it a potentially optimal configuration for lightweight structural applications. This aligns with studies such as Nayak (2025) [10] and Elanthiraiyan et al. (2021) [11], which highlight that proper fiber treatment can yield high-performance composites at lower fiber loadings.

These findings align with previous studies [8][9], which highlighted that NaOH treatment improves fibre wettability, adhesion, and mechanical reliability in natural fibre-reinforced composites.

## 4. Conclusion

This study investigated the mechanical performance of sugarcane bagasse (SCB) reinforced alumina composites using unsaturated polyester resin (UPR) as the matrix, with a focus on the effects of 5% NaOH alkali treatment on fibre behaviour. Six composite formulations were prepared, three with untreated SCB and three with treated SCB, varying in filler content. Mechanical characterization was performed through tensile and flexural testing, as per ASTM standards.

The experimental findings confirmed that NaOH treatment substantially enhanced the mechanical performance of SCB-reinforced composites, with the treated 3% SCB sample achieving the highest tensile (16.17 MPa) and flexural strength (80.96 MPa). These improvements are attributed to better fibre-matrix adhesion due to the removal of surface impurities, thereby validating the role of chemical treatment in optimizing agro-waste-based hybrid composites.

Limitations of the study include its focus on only one chemical treatment concentration (5% NaOH) and the evaluation of mechanical properties, which are limited to tensile and flexural behaviour. Other factors, such as thermal performance, water absorption, and long-term durability, were not assessed.

For future work, it is recommended to explore:

- The effect of varying NaOH concentrations and treatment durations.
- Additional mechanical tests, such as impact or fatigue performance.
- Hybridization with other natural or synthetic fibres.
- Potential applications in automotive, construction, or packaging sectors.

Overall, the study contributes to the growing body of knowledge on sustainable bio-composites and highlights the potential of chemically modified agro-waste fibres in developing high-performance engineering materials.

## Acknowledgement

The authors wish to thank the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, who has supported the accomplishment of the research activity.

## Conflict of Interest

The authors declare that they have no conflict of interest regarding the publication of this paper.

## Author Contribution

The authors confirm contribution to the paper as follows: study conception and design: Nuraina Nazifa Azrul Effendy, Zaleha Mohamad; data collection: Nuraina Nazifa Azrul Effendy; analysis and interpretation of results: Nuraina Nazifa Azrul Effendy, Zaleha Mohamad; draft manuscript preparation: Nuraina Nazifa Azrul Effendy, Zaleha Mohamad. All authors reviewed the results and approved the final version of the manuscript.

## References

- [1] Gupta, A., Shohel, S. M., Singh, M., & Singh, J. (2024). Study on mechanical properties of natural fiber (Jute)/synthetic fiber (Glass) reinforced polymer hybrid composite by representative volume element using finite element analysis: A numerical approach and validated by experiment. *Hybrid Advances*, 6, 100239. <https://doi.org/10.1016/j.hybadv.2024.100239>
- [2] Udhayasankar, R., Karthikeyan, B., Murugan, K., & Balaji, A. (2024). Hybrid polymer composites of Terminalia chebula filler reinforced thermal and mechanical characterization of bagasse/tamarind seed. *International Journal of Polymer Analysis and Characterization*. <https://doi.org/10.1080/1023666X.2024.2399219>
- [3] Rehman, M., Luo, D., Pan, J., Mubeen, S., Cao, S., Saeed, W., & Chen, P. (2025). Sustainable environmental remediation with bast fiber crops: Phytoremediation potential and resource management. In *Science of the Total Environment* (Vol. 977). Elsevier B.V. <https://doi.org/10.1016/j.scitotenv.2025.179403>
- [4] Rafi, A. al, Ali, Md. S., Hossain, Md. A. M., & Redoy, R. A. (2025). Experimental Investigation on Mechanical and Physical Properties of Sisal Fiber Reinforced Hybrid Composites with Filler Material. *Next Research*, 100509. <https://doi.org/10.1016/j.nexres.2025.100509>
- [5] Nayak, S. (2025). Investigation of mechanical, thermal and tribological properties of hybrid polymer composites reinforced with carbon fiber (CF) and Borassus Flabellifer petiole (BF): an experimental study. *Next Research*, 100527. <https://doi.org/10.1016/j.nexres.2025.100527>
- [6] Balachandran, S., Kim, S. C., Ramkumar, V., & Rathinam, B. (2024). Hybrid Epoxy Composites Reinforced with Coconut Sheath and Basalt Fibres: Enhancing Mechanical and Thermal Performance for Sustainable Applications. *Journal of Polymer Materials*, 41, 207–218. <https://doi.org/10.32604/jpm.2024.057901>
- [7] Waghmare, P. M., Bedmutha, P. G., & Sollapur, S. B. (2020). Investigation of effect of hybridization and layering patterns on mechanical properties of banana and kenaf fibers reinforced epoxy biocomposite. *Materials Today: Proceedings*, 46, 3220–3224. <https://doi.org/10.1016/j.matpr.2020.11.194>
- [8] Kumar, S., Dang, R., Manna, A., Dhiman, N. K., Sharma, S., Dwivedi, S. P., Kumar, A., Li, C., Tag-Eldin, E. M., & Abbas, M. (2023). Optimization of chemical treatment process parameters for enhancement of mechanical properties of Kenaf fiber-reinforced polylactic acid composites: A comparative study of mechanical, morphological and microstructural analysis. *Journal of Materials Research and Technology*, 26, 8366–8387. <https://doi.org/10.1016/j.jmrt.2023.09.157>
- [9] Zheng, J., Liu, Y., Wang, Q., Cheng, L., Zhang, C., Zhang, T., Shao, J., & Dai, F. (2024). Mechanical properties and thermal characteristics of three nano-filler/silk fiber reinforced hybrid composites: A comparative study using a ductile epoxy resin matrix. *Polymer Testing*, 130. <https://doi.org/10.1016/j.polymertesting.2023.108319>

- [10] Nayak, S. (2025). Investigation of mechanical, thermal and tribological properties of hybrid polymer composites reinforced with carbon fiber (CF) and Borassus Flabellifer petiole (BF): an experimental study. *Next Research*, 100527. <https://doi.org/10.1016/j.nexres.2025.100527>
- [11] Gu, X., Hu, Z., Hu, Z., Liu, J., Wang, Q., & Nehdif, M. L. (2024). Optimizing calcination temperature to improve the compressive strength of coal gasification slag-based alkali-activated materials by reducing carbon content and adjusting polymerization degree. *Construction and Building Materials*, 456. <https://doi.org/10.1016/j.conbuildmat.2024.139284>