Jurnal Polimesin
Department of Mechanical Engineering
State Polytechnic of Lhokseumawe
http://e-jurnal.pnl.ac.id/polimesin
e-ISSN : 2549-1999 No. : 1 Month : February
p-ISSN : 1693-5462 Volume : 24 Year : 2026

Processing dates: received on 2026-01-05, reviewed on 2026-01-24, accepted on 2026-02-07 and online availability on 2026-02-28

Effect of electrolyte medium on the tensile strength of coconut coir–epoxy composites via liquid plasma treatment

Sudirman[1*], Muh Firdan Nurdin[1], Marhadi Budi Waluyo[1], Eva Tri Wulandari[1], Denal Lebang[1]
[1] Department of Mechanical Engineering, University of Borneo Tarakan, Tarakan 77115, Indonesia
*Corresponding author: sudirman_dhuha@borneo.ac.id

Abstract

The application of coconut coir in polymer composites is often restricted by poor interfacial adhesion due to the fiber's hydrophilic nature. This study investigates the enhancement of tensile strength in coconut coir–epoxy composites via microwave-induced liquid plasma treatment with an electrolyte medium. The experiment employed a randomized design with four fiber treatment groups: untreated (control), plasma-treated in distilled water, plasma-treated in 10% NaCl, and plasma-treated in 10% NaOH. The plasma process was conducted at 400 W for 5 minutes under vacuum conditions (60–70 cmHg). Tensile test results indicate that the electrolyte medium significantly influences the treatment effectiveness. Plasma treatment in a 10% NaOH medium achieved the highest average tensile strength (5.70 MPa), corresponding to a 9.2% improvement over untreated fibers. In contrast, plasma treatment in distilled water resulted in a 21.6% reduction in tensile strength (4.08 MPa). The observed enhancement in the alkaline medium is likely related to combined chemical and physical effects induced by the plasma environment, which may contribute to improved fiber–matrix mechanical interlocking. These findings demonstrate that selecting a conductive, alkaline electrolyte medium is critical for optimizing liquid plasma treatment of natural fibers for composite applications.

Keywords:
Coconut coir composite, tensile strength, liquid plasma, alkali treatment, interfacial adhesion

1 Introduction

In recent decades, the development of natural fiber–based composite materials has increased significantly in response to the growing demand for environmentally friendly and sustainable materials. Natural fibers offer several advantages, including abundant availability, biodegradability, low density, and lower energy consumption during production compared to synthetic fibers [1]. Among various natural fibers, coconut coir fiber has attracted considerable attention due to its good mechanical properties, resistance to moisture and biological degradation, and wide availability in tropical regions, making it suitable for construction and engineering applications [2,3].

Despite these advantages, the use of coconut coir fiber as a reinforcement in polymer composites is often limited by weak interfacial bonding between the fiber and the polymer matrix, particularly with epoxy resin [2,4,5]. This limitation arises from the fiber surface's hydrophilic nature, which leads to poor compatibility with relatively hydrophobic polymer matrices and restricts efficient stress transfer from the matrix to the fibers, thereby reducing the composite's mechanical performance [4,5].

Chemical surface modification using alkaline solutions (NaOH) has been widely applied to improve fiber–matrix adhesion by removing lignin, hemicellulose, and surface impurities, thereby increasing surface roughness and enhancing mechanical interlocking [2,6,7]. Several studies have reported improvements in tensile, flexural, and impact properties of coconut fiber–reinforced composites after alkali treatment [2,4,6]. However, excessive alkali concentration or prolonged treatment time may degrade the cellulose structure, damage fiber cell walls, and reduce the fibers' intrinsic tensile strength [7,8].

In addition to chemical degradation, liquid-based treatments involving prolonged immersion have been reported to induce early mechanical deterioration due to moisture penetration and weakening of interfiber interactions, which adversely affect the mechanical performance and durability of natural fiber composites [9]. These limitations highlight the need for alternative surface modification techniques that are both effective and environmentally sustainable.

Physical surface modification using plasma technology has emerged as a promising approach to overcome the drawbacks of conventional chemical treatments. Low-temperature plasma can modify fiber surfaces by activating polar functional groups, increasing surface free energy, and generating micro-scale roughness without significantly altering the fibers' internal structure [10,11]. Plasma-treated natural fibers have demonstrated improved wettability and interfacial adhesion with polymer matrices, thereby enhancing the mechanical properties of composite materials [8,12].

Most previous plasma-based studies, however, have focused on dry gas plasma systems, which primarily induce surface activation with limited delignification effects. Liquid plasma treatment has been introduced as an alternative approach that combines physical plasma activation with mild chemical reactions occurring in liquid media. Studies have shown that liquid plasma can enhance interfacial shear strength and surface roughness of coconut coir fibers. However, hydrolytic degradation and reduction in fiber tensile strength may occur when water-based media are used [13].

The novelty of the present study lies in the application of microwave-induced liquid plasma using NaOH and NaCl electrolyte solutions, designed to generate a synergistic effect between chemical surface modification and plasma-induced physical activation in a single treatment process. The electrolyte solutions promote fiber swelling and partial delignification, while plasma-generated reactive species enhance surface functionalization and micro-roughness. This integrated approach is expected to improve interfacial adhesion and tensile strength of coconut coir fiber–epoxy composites more effectively and sustainably than conventional alkali or plasma treatments alone.

This study aims to investigate the effects of plasma treatment in NaOH and NaCl solutions on the tensile properties and interfacial bonding behavior of coconut coir fiber–epoxy composites, providing insights into the development of high-performance and environmentally friendly natural fiber–reinforced polymer composites.

2 Research methodology

2.1 Research design

This study used a quantitative experimental approach to evaluate the effects of liquid plasma media on the mechanical properties of coconut coir composites. The experimental design followed a Completely Randomized Design (CRD) with one main factor: the type of treatment medium, consisting of four levels: untreated (S0), plasma in distilled water (S1), plasma in 10% NaCl solution (S2), and plasma in 10% NaOH solution (S3). The dependent variables measured were tensile strength, strain, and modulus of elasticity. Each treatment group was replicated five times (n = 5) to ensure the statistical validity of the data.

2.2 Materials

The reinforcement material used was coconut coir fiber (Cocos nucifera) obtained from young coconuts, selected for their superior

fibril flexibility compared to mature coconuts. The polymer matrix used was epoxy resin (Bisphenol A-epichlorohydrin) with a polyamide hardener. Supporting materials for the plasma process included distilled water (H_2O) as a solvent and control medium, as well as technical-grade Sodium Chloride (NaCl) and Sodium Hydroxide (NaOH) as electrolyte media for plasma discharge.

2.3 Equipment

The main equipment used in this study included: Liquid plasma vacuum reactor, microwave generator, vacuum pump (to lower reactor pressure below 1 atm), ASTM D638-03 standard specimen mold, Universal Testing Machine (UTM) with a 600 kN capacity for tensile testing, and auxiliary equipment includes digital scales, measuring cylinders, stainless steel containers, and resin-mixing tools.

2.4 Experimental procedure

The experimental stages were carried out systematically as shown in Fig. 1. Coconut coir fibers were prepared and treated using microwave-induced liquid plasma in different media (distilled water, 10% NaCl, and 10% NaOH).

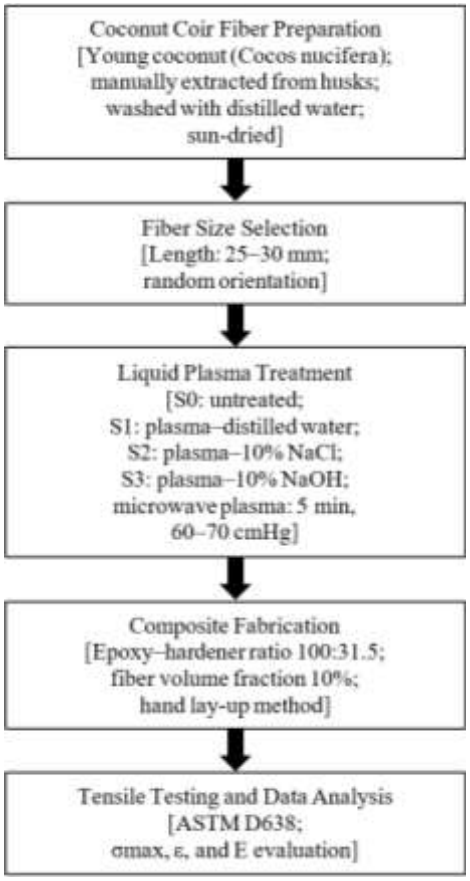

Fig. 1. Experimental procedure

Subsequently, they fabricated epoxy composites by hand lay-up. Tensile properties were evaluated according to ASTM D638. Detailed processing parameters are described in the Materials and Methods section.

a. Fiber preparation

Young coconut fibers were used as reinforcement in the epoxy composite.

b. Liquid plasma treatment

Selection of Liquid Media Concentration: A fixed concentration of 10% (w/v) was maintained for both electrolyte solutions (NaCl and NaOH) to ensure experimental consistency. This specific concentration was selected based on the critical threshold identified by Zulkifli et al. [4] for alkali treatment of natural fibers. Their study demonstrated that concentrations exceeding 10% result in severe cellulose degradation and fiber fibrillation, which negatively impacts tensile performance. Therefore, 10% was chosen as the optimal upper limit to achieve effective surface modification without compromising the structural integrity of the coconut coir fibers.

Fibers were divided into four groups, namely S0 (control), which received no plasma or solution treatment; S1 (distilled water), which underwent plasma treatment using 100% distilled water; S2 (NaCl), which was subjected to liquid plasma treatment in a 10% NaCl solution; and S3 (NaOH), which was treated with liquid plasma in a 10% NaOH solution.

Plasma treatment was performed using a microwave generator and a liquid plasma reactor for 5 minutes (see Fig. 2 and Fig. 3). The plasma treatment was conducted in an ionized gas state containing reactive particles such as electrons and positively charged ions. The NaOH and NaCl solutions served as conductive media, enabling plasma formation when the fibers were exposed to microwaves, and also removed lignin, hemicellulose, and other extractive substances from the fibers. This process results in a cleaner fiber structure, stronger inter-fibril cellulose bonds, and increased surface roughness, which supports fiber-matrix adhesion. The plasma generation process in this solution produces reactive particles that clean the fiber surface from contaminants.

Fig. 2. Microwave plasma discharge

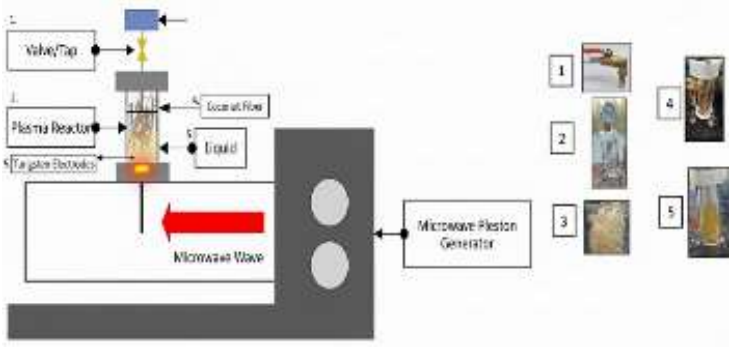

Fig. 3. Schematic diagram of the microwave plasma generation apparatus

Fig. 3 shows a schematic of the microwave plasma generation apparatus, in which dried coconut coir fibers were suspended in the liquid plasma reactor tube. Electrolyte media, consisting of 10% NaCl or 10% NaOH solutions, were introduced through the filling valve until the working volume was reached. Once the reactor system was tightly sealed, the vacuum pump was activated until the chamber pressure ranged from 60 to 70 cmHg, ensuring that non-thermal plasma conditions could be established. If the pressure was unstable, connections were re-inspected to prevent air leakage. Once the appropriate pressure was achieved, the microwave plasma

system and vacuum pump were operated simultaneously for 5 minutes. During the process, pressure conditions and the oil volume in the vacuum system were monitored periodically. After the treatment was completed, the reactor was turned off and allowed to cool before the fibers were removed. The treated fibers were then washed with distilled water until the pH reached neutrality and dried in sunlight until the moisture content stabilized, after which they were used as composite reinforcement.

Composite Fabrication: Composites were fabricated by hand lay-up. Treated fibers were mixed with epoxy resin and hardener at a ratio of 100:31.5. The fiber volume fraction was set at 10% of the total composite volume. The mixture was poured into ASTM D638-03 molds and allowed to cure for 24 hours at room temperature to achieve optimum stiffness. d. Tensile Testing. Tensile tests were conducted using a 600 kN UTM with a constant pulling speed according to ASTM D638-03 standards (see Fig. 4). The measured parameters included maximum tensile stress (σ_{max}), strain (ε), and modulus of elasticity (E).

Fig. 4. UTM with 600 kN capacity

3 Results and discussion

Mechanical testing was performed using tensile testing to evaluate the composite material's strength under axial load. This method was chosen to depict the material's resistance to the gradual application of tensile forces until failure. The testing was conducted using a UTM with a 600 kN capacity, with specimens prepared in accordance with ASTM D638-03. The test results are presented in Table 1.

Table 1. Tensile test results with NaOH and NaCl solutions

No.	Solution composition	Specimen	Maximum force (kN)	Remarks
1	Untreated (Control)	1	0.40	Valid
		2	0.40	Valid
		3	0.62	Valid
		4	0.48	Valid
		5	0.77	Invalid
2	Distilled water	1	0.38	Valid
		2	0.36	Valid
		3	0.14	Invalid
		4	0.42	Valid
		5	0.33	Valid
3	10 % NaOH	1	0.64	Valid
		2	0.54	Valid
		3	0.41	Valid
		4	0.32	Invalid
		5	0.46	Valid
4	10 % NaCl	1	0.53	Valid
		2	0.32	Invalid
		3	0.42	Valid
		4	0.46	Valid
		5	0.44	Valid

Data Validation and Invalid Specimens Specimens were deemed invalid if failure occurred at the grip zone (jaw break) or if slippage was detected during testing, in accordance with ASTM D638. Table 1 identifies the specific specimens excluded from the analysis based on these criteria. Consequently, the average tensile strength and standard deviation for each group were calculated solely from the valid specimens (n=4). Based on the test results in Table 1, the maximum tensile stress for each specimen was calculated as shown in Table 2.

Table 2. Maximum tensile stress of specimens

No.	Solution composition	Specimen	Maximum tensile stress (MPa)
1	Untreated (Control)	1	4.39
		2	4.39
		3	6.81
		4	5.27
	Average values		5.21
2	Distilled water	1	4.17
		2	3.95
		4	4.61
		5	3.62
	Average values		4.09
3	10 % NaOH	1	7.26
		2	5.72
		3	4.55
		5	5.29
	Average values		5.7
4	10 % NaCl	1	5.82
		3	4.61
		4	5.05
		5	4.83
	Average values		5.08

Based on Table 2, the tensile test results indicate that chemical treatment significantly influences the mechanical strength of coconut fibers. Samples immersed in the 10% NaOH solution yielded the highest average tensile stress of 5.70 MPa, followed by untreated samples at 5.21 MPa, 10% NaCl-treated samples at 5.08 MPa, and the lowest value was obtained from the distilled water treatment at 4.08 MPa. This pattern suggests that treatment effectiveness is highly influenced by the solution's ability to modify the fiber surface structure without causing excessive damage.

The tensile strength of the coconut coir–epoxy composites under various liquid plasma treatments is presented in Fig. 5. The graph illustrates the mean values, with error bars representing the standard deviation (SD), which indicates the variability in fiber properties and the homogeneity of the treatment effect.

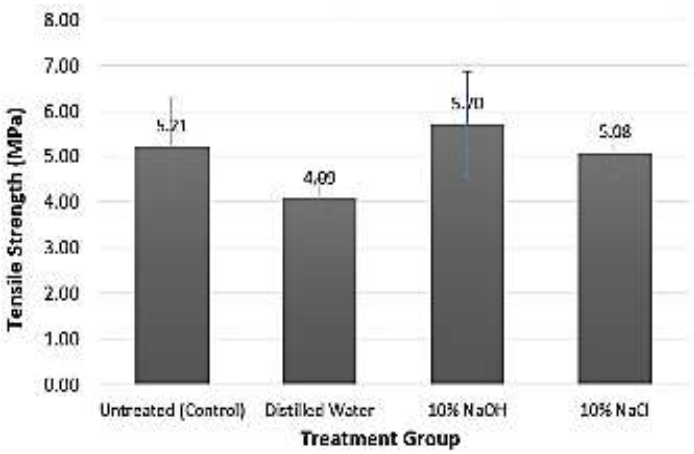

Fig. 5. Tensile strength of coconut coir–epoxy composites with different liquid plasma media. Error bars indicate standard deviation (n=4)

The results demonstrate that the plasma medium plays a critical role in determining the composite's performance. The highest tensile strength was observed in the NaOH-treated group (S3) at 5.70 ± 1.15 MPa, approximately 9.4% higher than in the control group (S0, 5.21 ± 1.07 MPa). This improvement is attributed to the synergistic effect of the alkaline medium and plasma species. The 10% NaOH solution facilitates partial delignification, removing the outer waxy layer and hemicellulose, while the plasma discharge creates micro-etching on the fiber surface. This combination enhances mechanical interlocking between the fiber and the epoxy matrix, enabling more effective stress transfer [1,3].

In contrast, the Distilled Water treatment (S1) resulted in the lowest performance, with a tensile strength of 4.09 ± 0.42 MPa, a 21.5% decrease compared to the control. This reduction is likely caused by the "swelling effect" and hydrolytic degradation. Without electrolyte ions to facilitate conductivity and surface reaction, the water plasma treatment primarily induced moisture absorption into the fiber cell walls, leading to the weakening of the cellulose structure and poor interface adhesion, as observed in similar studies by Putra et al. [13].

Interestingly, the NaCl treatment (S2) showed a tensile strength of 5.08 ± 0.53 MPa, which was statistically comparable to that of the control group. Although NaCl is an electrolyte, its etching capability is less aggressive than that of NaOH. The lower standard deviation in the S1 (0.42) and S2 (0.53) groups compared to S0 and S3 indicates that liquid plasma treatment tends to produce more uniform fiber properties, in contrast to the higher variability observed in untreated natural fibers.

However, it is worth noting that the standard deviation for the NaOH group (1.15) remains relatively high. This suggests that while alkali-plasma treatment effectively increases average strength, the aggressive reaction might cause non-uniform etching on some fibers, leading to variations in failure modes. Future studies could optimize the plasma exposure time to minimize this variability.

The tensile strength results for the different treatment groups are presented in Fig. 5. As illustrated, the 10% NaOH treatment (S3) yielded the highest tensile strength of 5.70 MPa, followed by the Control (S0, 5.21 MPa) and the 10% NaCl treatment (S2, 5.08 MPa), while the Distilled Water treatment (S1) showed the lowest tensile strength at 4.09 MPa. The significant increase in tensile stress for NaOH-treated fibers is primarily caused by the removal of lignin, hemicellulose, and surface impurities (delignification). This process produces cleaner fibers with a rough morphology that enhances interlocking mechanisms and increases adhesion energy. Additionally, alkali treatment increases cellulose crystallinity, which positively correlates with fiber tensile strength. These observations align with principles reported by Sood and Dwivedi [1], Junus et al. [3], and Farrel et al. [5].

Besides chemical modification factors, changes in mechanical properties are also strongly influenced by physical mechanisms arising from liquid plasma interactions. In the microwave-induced liquid plasma process, active species such as high-energy electrons, ions, and free radicals (like OH and H) are formed and bombard the fiber surface (electron bombardment). This process produces a surface etching or micro-ablation effect, physically eroding the fiber's outer layer.

However, the effect of plasma depends heavily on the medium. In the Plasma–Distilled Water variation (S1), the drastic decrease in tensile strength (4.08 MPa) indicates excessive degradation of the cellulose structure. This phenomenon is driven by swelling due to water absorption, which disrupts the regularity of the cellulose structure and triggers the formation of inter-fibril microcracks. Without a protective agent or chemical buffer, free radicals from the water plasma aggressively attack the cellulose walls alongside the hydrolysis process. This causes uncontrolled surface erosion, creating defects rather than useful roughness. This mechanism of hydrolytic degradation aligns with findings by Bisoyi et al. [11] and Putra et al. [13], who observed that uncontrolled water exposure weakens inter-fiber interactions.

Conversely, a different phenomenon occurs in the plasma–10% NaOH variation (S3), which recorded the highest strength. The presence of Na+ and OH- ions in the electrolyte solution not only increases conductivity, facilitating more stable plasma formation, but also creates a synergistic effect. The alkali solution dissolves the lignin and hemicellulose layers (weak barriers), while plasma bombardment etches the exposed cellulose surface. This etching process in an alkaline environment produces a controlled rough surface topography (surface roughening), increasing the specific contact area for mechanical interlocking mechanisms with the epoxy resin without damaging the fiber core. This combination allows optimal stress transfer from the matrix to the fiber, minimizing fiber pull-out and maximizing composite strength.

Regarding the salt electrolyte treatment, the 10% NaCl treatment (S2) resulted in a tensile strength of 5.08 MPa, which is statistically comparable to the untreated control. Physically, NaCl acts as an electrolyte, stabilizing the plasma discharge and preventing the aggressive degradation observed in the distilled water group. However, unlike NaOH, NaCl is chemically neutral and lacks the delignification capacity to strip lignin effectively. Thus, NaCl provides plasma stability but limited surface activation, which is insufficient to produce a significant increase in fiber tensile strength beyond the baseline. This confirms that ionic conductivity alone, without proper chemical reactivity (pH), yields only mild adhesion improvements [8,13].

Interestingly, the tensile stress of untreated fibers was higher than that of fibers treated with NaCl or distilled water. This indicates that the natural fiber structure retains its intrinsic strength as long as it is not chemically or physically degraded. According to Kocaman [14], lignin acts as a natural binder that maintains the fiber's base strength. Therefore, when NaCl and distilled water treatments fail to produce significant positive modifications, the original lignin-rich fiber strength remains superior.

Overall, these results are consistent with scientific findings indicating that alkali-based chemical treatment is the most effective method for improving the mechanical properties of natural fibers. These results also reaffirm the urgency of exploring combined NaCl–plasma or NaOH–plasma treatments, suggesting that integrating chemical and plasma treatments could yield much stronger morphological and adhesion improvements than either method alone (Fig. 6). The tensile fracture morphology of the distilled-water-treated specimens is shown in Fig. 7.

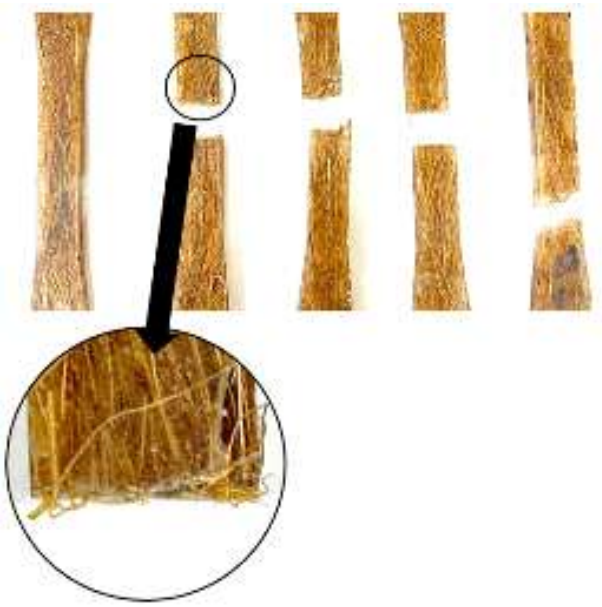

Fig. 6. Tensile test results of untreated specimens

Chemically, coconut coir fibers are composed of cellulose, hemicellulose, and lignin, which possess hydroxyl groups (–OH).

These groups can form hydrogen bonds with epoxy resin molecules and, during resin curing (cross-linking), react covalently with active epoxides in the resin, thereby producing strong interfacial bonds. In the context of our study, this chemical mechanism directly explains the superior tensile strength of the NaOH-treated group (S3). The removal of surface impurities by NaOH exposed these active hydroxyl sites, allowing the chemical bonding potential to be fully realized and resulting in the peak strength of 5.70 MPa (Fig. 8).

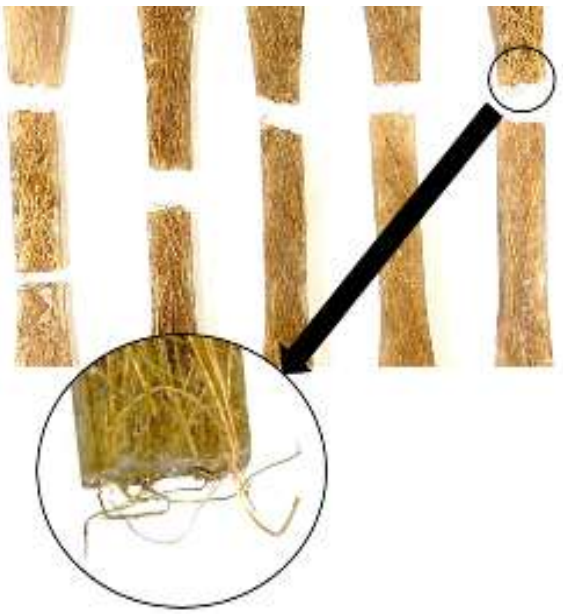

Fig. 7. Tensile test results of distilled water-treated specimens

Beyond chemical bonding, physical factors such as fiber surface roughness are also pivotal. A rough surface supports the mechanical interlocking mechanism, where the resin mechanically penetrates and grips the fiber structure. This theoretical mechanism is clearly supported by the failure morphology observed in our S3 samples (Fig. 8), where fiber fracture is dominant. This visual evidence confirms that the combination of chemical bonding and physical interlocking successfully shifted the failure point from the weak interface to the stronger fiber core.

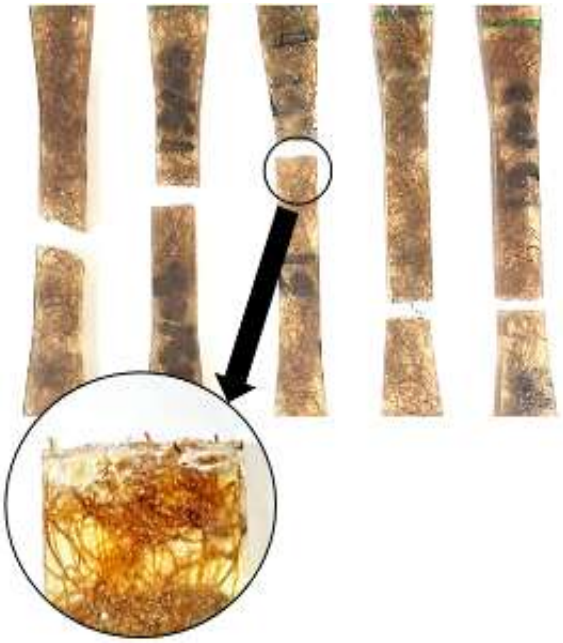

Fig. 8. Tensile test results of 10% NaOH-treated specimens

When coconut coir–epoxy composites are exposed to corrosive environments (Fig. 9), Na^+ and Cl^- ions can penetrate the interface. These ions are hygroscopic and promote water absorption, disrupting hydrogen bonds and weakening adhesion. This degradation mechanism accounts for the moderate performance of the NaCl-treated group (5.08 MPa) compared to the NaOH group. However, plasma stabilized the surface; the presence of salt ions likely introduced moisture traps at the interface, preventing the composite from reaching its maximum potential strength.

To counter this degradation, the synergistic effect of the dual treatment is essential. The NaOH treatment effectively removes lignin and wax, exposing the cellulose backbone, while the plasma treatment activates the surface energy.

Fig. 9. Tensile test results of 10% NaCl-treated specimens

To counter this degradation, the synergistic effect of the dual treatment is essential. The NaOH treatment effectively removes lignin and wax, exposing the cellulose backbone, while the plasma treatment activates the surface energy. Our results confirm that this specific combination (S3) produces an interface that is chemically and mechanically robust enough to resist degradation. Consequently, more energy from tensile loads is transferred through the interfacial bonds, causing fibers to break together with the matrix rather than being pulled out. This suggests that the NaOH–Plasma combination is a superior strategy compared to single treatments alone for developing durable natural fiber composites.

Based on observations in Fig. 6 to Fig. 9, untreated specimens and those soaked only in distilled water exhibited significant fiber pull-out. This indicates weak adhesion due to impurity layers (lignin, hemicellulose, wax) blocking resin penetration. Stress transfer was suboptimal, leading to dominant interfacial failure. Conversely, in specimens treated with 10% NaOH + plasma, very minimal fiber pull-out was observed; instead, the fibers broke simultaneously with the matrix. This failure pattern indicates significantly improved interfacial adhesion, supported by strong chemical and mechanical bonds formed by surface modification.

Based on macroscopic fracture observations obtained using optical visualization, untreated specimens and those treated with distilled water exhibited a dominant fiber pull-out mechanism, indicating weak interfacial bonding between the coconut coir fibers and the epoxy matrix. This failure mode suggests that stress transfer was primarily limited by the fiber–matrix interface rather than the fiber itself. In contrast, specimens treated with 10% NaOH and plasma showed a clear transition in failure behavior, with fiber fracture occurring more frequently than interfacial debonding. This macroscopic failure morphology indicates a significant improvement in interfacial adhesion and load transfer efficiency. Such a transition from fiber pull-out to fiber fracture is widely recognized as a hallmark of enhanced interfacial bonding in natural fiber–reinforced polymer composites and is consistent with trends reported in previous studies on alkali- and plasma-modified natural fibers [15,16,17].

The transition from interfacial failure (pull-out) to fiber fracture observed in the NaOH-treated group provides direct physical evidence of improved bonding quality. By effectively removing the

weak boundary layers (lignin and wax) and increasing surface roughness, the treatment enabled the epoxy resin to interlock with the stronger cellulose backbone mechanically. This observation confirms that surface cleanliness and morphology are prerequisites for maximizing stress transfer in coir-based composites, a principle well-supported by Zulkifli & Dharmawan [4] and Renreng et al. [18]. These studies similarly highlighted that alkalization is essential to prepare natural fibers before secondary processing (such as microwave or plasma) to achieve optimal stiffness and strength [6].

Ultimately, this study demonstrates that relying on a single treatment method may be insufficient for high-performance applications. While alkali treatment provides the necessary surface purity [7], the addition of plasma introduces critical surface energy activation. The resulting dual modification creates a robust fiber–resin interface that is highly resistant to degradation, even when exposed to corrosive ions such as NaCl. This suggests that the NaOH–Plasma combination is a superior strategy for enhancing the mechanical stability of coconut coir–epoxy composites compared to chemical or physical treatments in isolation, offering a viable solution for developing durable natural fiber composites.

4 Conclusion

This study demonstrates that the type of liquid medium in microwave-induced plasma treatment significantly affects the tensile performance of coconut coir–epoxy composites. The results indicate that a 10% NaOH electrolyte medium yields the highest tensile strength (5.70 MPa), corresponding to a 9.2% improvement over untreated fibers. The observed enhancement is likely due to the combined effects of the alkaline environment and plasma exposure, which may improve fiber–matrix mechanical interlocking. In contrast, plasma treatment in distilled water resulted in a 21.6% reduction in tensile strength (4.08 MPa), possibly due to unfavorable effects on fiber integrity rather than effective surface modification. These findings highlight the importance of selecting a conductive alkaline medium to optimize liquid plasma treatment for natural fiber–reinforced composites. Further microstructural characterization is recommended to verify the proposed interpretations.

Acknowledgments

This study was carried out with support from the Department of Mechanical Engineering, Faculty of Engineering, and with additional guidance and program assistance from the Institute for Research and Community Service (LP2M) at the University of Borneo Tarakan.

References

[1] M. Sood and G. Dwivedi, "Effect of fiber treatment on flexural properties of natural fiber reinforced composites: A review," *Egypt. J. Pet.*, vol. 27, no. 4, pp. 775–783, Dec. 2018, doi: 10.1016/j.ejpe.2017.11.005.

[2] I. Mawardi, A. Azwar, and A. Rizal, "Kajian perlakuan serat sabut kelapa terhadap sifat mekanis komposit epoksi serat sabut kelapa," *J. Polimesin*, vol. 15, no. 1, p. 22, Feb. 2017, doi: 10.30811/jpl.v15i1.369.

[3] S. Junus *et al.*, "Tensile and morphological properties of carbon-coir fiber reinforced epoxy hybrid composites," *J. Polimesin*, vol. 23, no. 1, p. 47, Feb. 2025, doi: 10.30811/jpl.v23i1.5523.

[4] Zulkifli, I. B. Dharmawan, and W. Anhar, "Analisa pengaruh perlakuan kimia pada serat terhadap kekuatan impak charpy komposit serat sabut kelapa bermatriks epoxy Effect of chemical treatment of composite coir fiber with epoxy matrix on the Charpy impact strength," *J. Polimesin*, vol. 18, no. 1, pp. 47–52, 2020, doi: 10.30811/jpl.v18i1.1583.

[5] D. A. Farrel, Yuliyanto, and Zulfitriyanto, "Pengaruh sifat mekanik komposit serat sabut kelapa bermatrik polyester terhadap pengujian tarik," *J. Indones. Sos. Teknol.*, vol. 3, no. 2, pp. 219–230, 2022, doi: https://doi.org/10.59141/jist.v3i02.360.

[6] N. H. Sari and J. Fajrin, "Sifat mekanik dari komposit poliester-serat pelepah kelapa: Efek perendaman serat dalam larutan kimia alkali," *J. Tek. Mesin*, vol. 7, no. 2, p. 57, Oct. 2018, doi: 10.22441/jtm.v7i2.2373.

[7] H. Hestiawan, D. Ariawan, K. Amri, A. Nuramal, A. Afrizal, and S. Sudibyo, "Pengaruh perlakuan alkali terhadap sifat fisis dan mekanis serat lantung (artocarpus elasticus)," *J. Rekayasa Mesin*, vol. 13, no. 3, pp. 819–826, Dec. 2022, doi: 10.21776/jrm.v13i3.1220.

[8] P. Valášek, M. Müller, and V. Šleger, "Influence of plasma treatment on mechanical properties of cellulose-based fibres and their interfacial interaction in composite systems," *BioResources*, vol. 12, no. 3, pp. 5449–5461, Jun. 2017, doi: 10.15376/biores.12.3.5449-5461.

[9] A. Pavlovic, L. Valzania, and G. Minak, "Effects of moisture absorption on the mechanical and fatigue properties of natural fiber composites: A review," *Polymers (Basel).*, vol. 17, no. 14, p. 1996, Jul. 2025, doi: 10.3390/polym17141996.

[10] R. R. Pillai and V. Thomas, "Plasma surface engineering of natural and sustainable polymeric derivatives and their Potential Applications," *Polymers (Basel).*, vol. 15, no. 2, p. 400, Jan. 2023, doi: 10.3390/polym15020400.

[11] D. K. Bisoyi, R. Das, and C. Dash, "A Review of cold plasma treatment on textile fibre," *Trends Text. Eng. Fash. Technol.*, vol. 7, no. 5, pp. 4–6, Jan. 2023, doi: 10.31031/TTEFT.2023.07.000675.

[12] U. S. Gupta *et al.*, "Plasma modification of natural fiber: A review," *Mater. Today Proc.*, vol. 43, pp. 451–457, 2021, doi: 10.1016/j.matpr.2020.11.973.

[13] A. E. E. Putra, I. Renreng, H. Arsyad, and B. Bakri, "Investigating the effects of liquid-plasma treatment on tensile strength of coir fibers and interfacial fiber-matrix adhesion of composites," *Compos. Part B Eng.*, vol. 183, no. December 2019, p. 107722, Feb. 2020, doi: 10.1016/j.compositesb.2019.107722.

[14] S. Kocaman, M. Karaman, M. Gursoy, and G. Ahmetli, "Chemical and plasma surface modification of lignocellulose coconut waste for the preparation of advanced biobased composite materials," *Carbohydr. Polym.*, vol. 159, pp. 48–57, Mar. 2017, doi: 10.1016/j.carbpol.2016.12.016.

[15] Z. Al Mahmud *et al.*, "The mechanical and microstructure investigations of jute fabric epoxy reinforced with microfibers from banana and coconut," *SPE Polym.*, vol. 5, no. 4, pp. 693–708, Oct. 2024, doi: 10.1002/pls2.10154.

[16] A. Aminur, J. S. D. Saputra, and C. Y. Syah, "Analysis of tensile and bending strength of coconut fiber reinforcement composite on quasi isotropic laminates stacking sequence," *J. Metall. Eng. Process. Technol.*, vol. 4, no. 2, p. 67, Feb. 2024, doi: 10.31315/jmept.v4i2.11350.

[17] T. P. Kasih and J. Nasution, "Pengembangan teknologi plasma dingin untuk modifikasi karakteristik permukaan material tanpa mengubah sifat dasar material," vol. 32, no. 3, pp. 167–186, 2021, [Online]. Available: https://publikasi.mercubuana.ac.id/index.php/pasti/article/view/1720/1319

[18] I. Renreng, B. Bakri, S. Chandrabakty, and Naharuddin, "Evaluation of mechanical and physical properties of pressed coir fiber/epoxy composite with NaOH and microwave treatment of fiber," *J. Renew. Mater.*, vol. 9, no. 2, pp. 325–335, 2021, doi: 10.32604/jrm.2021.012774.