 https://doi.org/10.24191/jeesr.v27i1.008

# Dielectric Characterization of Pineapple Leaf Fibre (PALF) Reinforced Polydimethylsiloxane (PDMS) Composites with Varying Fibre Loading

Nur Hidayah Abu Bakar, Aslina Abu Bakar*, Amirudin Ibrahim, Aiza Mahyuni Mozi, Rosfariza Radzali, Alhan Farhanah Abd Rahim, Najwa Mohd Faudzi and Azlina Idris

***Abstract*— This study investigates the dielectric properties of biofibre-reinforced polymer composites composed of Pineapple Leaf Fibre (PALF) and Polydimethylsiloxane (PDMS), with a focus on varying fibre loadings and the effects of alkaline treatment. Conventional dielectric substrates such as FR4 suffer from rigidity, environmental concerns, and limited tunability. In contrast, PALF-PDMS composites offer a sustainable alternative with adjustable dielectric characteristics. Composites were fabricated via manual mixing, incorporating PALF loadings from 10 wt% to 90 wt%. Alkaline treatment using NaOH enhanced fibre-matrix compatibility by reducing moisture absorption and increasing interfacial polarisation. Results show that treated composites exhibit lower dielectric constants at low fibre loadings but outperform untreated variants at higher loadings. These findings highlight the potential of PALF-PDMS composites as eco-friendly, tunable substrates for flexible electronics and antenna applications.**

***Index Terms*—Alkaline treatment, biofibre-reinforced composites, dielectric characterization, fibre loading, Pineapple Leaf Fibre (PALF), Polydimethylsiloxane (PDMS),**

## I. INTRODUCTION

Natural fibres, known for their excellent mechanical properties, biodegradability, and environmental friendliness, have gained popularity as reinforcement materials. Traditional substrates such as FR4 and Rogers RT/duroid 5880 despite their widespread use, have limitations including rigidity, environmental impact, high cost, and non- biodegradability [1, 2]. A key drawback of these conventional materials is their fixed dielectric constant, which cannot be tuned. Natural fibres have the potential to overcome this issue. Biofibre-reinforced polymer composites have emerged as viable alternatives due to their mechanical strength, flexibility, and biodegradability.

Notably, the dielectric properties of biofibres, particularly their low dielectric constant and dielectric loss, can be tailored by adjusting the fibre weight percentage. Although the potential of bio-based materials for electronic applications has been demonstrated in previous studies, detailed investigations into their dielectric characterisation for use as substrate materials remain limited [3, 4].

A study [5] demonstrated that varying filler percentages result in different tangent loss performances and dielectric constant values. Moreover, different types of agricultural waste materials, such as rice straw, rice husk, sugarcane bagasse, and banana leaves, when reinforced with Epoxy 331, produce varied dielectric characteristics. A high dielectric constant is generally advantageous for substrate materials, while a high loss tangent value is more suitable for microwave absorbers. In addition, studies [6, 7] have shown that increasing the fibre weight percentage in hybrid composites leads to higher dielectric constant, dissipation factor, and loss factor. It is evident that the type of polymer has minimal influence on the dielectric properties of hybrid composites. Interestingly, composites with fibres subjected to alkaline treatment exhibited a lower dielectric constant due to the increased hydrophobicity of the fibres.

Biofibre-reinforced polymer composites, such as those reinforced with pineapple leaf fibre (PALF) and polydimethylsiloxane (PDMS), offer promising alternatives due to their mechanical strength, flexibility, biodegradability, and adjustable dielectric properties. This study aims to investigate the dielectric properties of PALF-reinforced PDMS composites, with a focus on the impact of varying fibre loadings and alkaline treatment on material performance. PALF provides a low dielectric constant and good thermal stability, which, when combined with the flexibility offered by PDMS, presents a viable option for advanced substrate applications. By analysing how changes in fibre content and surface treatment affect dielectric behaviour, this study seeks to develop a high-performance, environmentally friendly substrate material. Addressing limitations of traditional materials, such as limited flexibility and environmental concerns, could lead to the development of more efficient, sustainable, and adaptable substrate materials for advanced electronic applications

This manuscript is submitted on 1st May 2025, revised on 14th July 2025, accepted on 28th August 2025 and published on 31st October 2025. Nur Hidayah Abu Bakar, Aslina Abu Bakar, Amirudin Ibrahim, Aiza Mahyuni Mozi1a, Rosfariza Radzali, Alhan Farhanah Abd Rahim, Najwa Mohd Faudzi are with the Electrical Engineering Studies, Universiti Teknologi MARA, Cawangan Pulau Pinang. Azlina Idris was with Wireless Communication Technology Group from Universiti Teknologi MARA, Shah Alam

*Corresponding author
Email address: aslina060@uitm.edu.my

## II. MATERIALS AND METHODS

### A. *Materials*

Pineapple Leaf Fibre (PALF) was selected for its high cellulose content and mechanical integrity. Polydimethylsiloxane (PDMS), known for its flexibility and biocompatibility, served as the polymer matrix. Sodium hydroxide (NaOH) was used for alkaline treatment to enhance fibre-matrix adhesion. Polydimethylsiloxane (PDMS) was chosen as the polymer matrix for this composite material due to its well-known flexibility, transparency, and biocompatibility [8]. Furthermore, alkaline treatment using sodium hydroxide (NaOH) is an effective technique for enhancing fibre–matrix compatibility, improving fibre characteristics, and contributing to the development of high-performance composite materials [9, 10].Figure 1(a) shows the fibre after alkaline treatment, while Figure 1(b) displays the untreated (pure) pineapple leaf fibre (PALF).

(a) (b)

**Fig. 1.** PALF (a)Treated (b) Pure

### B. *Fibre Treatment*

The alkaline treatment process followed procedures adapted from established studies [9, 10], with the sodium hydroxide (NaOH) concentration and treatment duration selected in accordance with common practices for fibre surface modification. PALF underwent surface modification via alkaline treatment using 1.5 M NaOH. Fibres were soaked for 3 hours at room temperature, rinsed until neutral pH, and oven-dried at 80 °C for 48 hours. This process removed non-cellulosic components, improving fibre compatibility and reducing moisture absorption. They were then oven-dried at 80 °C for 48 hours, as illustrated in Fig. 1(a).

### C. *Composite Preparation*

The treated pineapple leaf fibres (PALF) were cut into short lengths of approximately 10 mm, while the untreated fibres were blended into small particles. Polydimethylsiloxane (PDMS) was mixed with its curing agent in a 10:1 ratio and gradually combined with the fibres to ensure uniform dispersion. The PALF–PDMS mixture was stirred thoroughly for five to ten minutes to achieve an even distribution. It was then poured slowly into a mould and spread uniformly, with weights applied to maintain consistent thickness and minimise air bubble formation. The mixture was gently tapped to release trapped air. Fig. 2 shows the PALF–PDMS composite being evenly spread in the mould during the fabrication process. This manual polymer mixing technique promotes strong bonding between the fibres and the matrix, enhancing the composite's mechanical strength, fibre–matrix compatibility, and environmental resistance.

**Fig. 2**. PALF-PDMS mixture spread in mold

### D. *Composite Formulation*

For consistency, the material thickness was maintained within the range of approximately 3 to 7 mm. Achieving a perfectly uniform thickness is challenging due to the manual fabrication process, variability in fibre dispersion, and uneven pressure distribution during moulding. Despite these limitations, the selected thickness range offers a balance between mechanical stability and flexibility, while minimising significant dielectric variation across the composite. Various fibre loadings were prepared by adjusting the weight percentage of PALF in the composite. The loadings were 10 wt%, 20 wt%, 30 wt%, 40 wt%, 50 wt%, 60 wt%, 70 wt%, 80 wt%, and 90 wt%. These percentages were applied to both untreated and treated fibres.

### E. *Testing (Dielectric Measurement)*

The dielectric properties were tested across the frequency range of 2 GHz to 20 GHz using a Vector Network Analyzer (VNA) to simulate typical wireless communication bands. The dielectric constant, often referred to as relative permittivity (εr), is a crucial parameter that influences the impedance, bandwidth, and radiation efficiency of antennas by determining the speed at which electromagnetic waves propagate through the material. Accurate measurement of the dielectric constant is essential for effective wearable antenna design [3, 11]. This measurement can be carried out using a Vector Network Analyzer, as illustrated in Fig. 3.

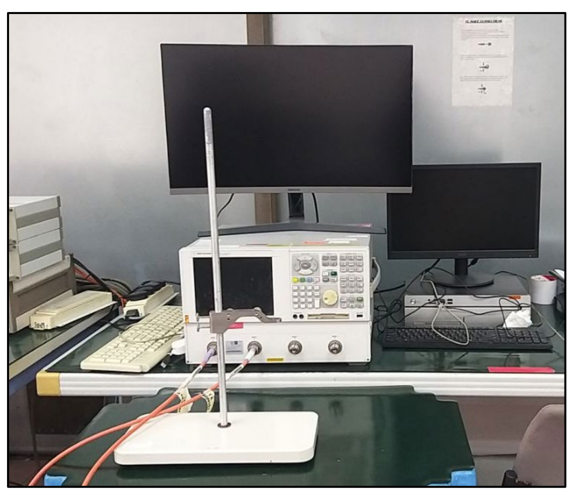


**Fig. 3**. KEYSIGHT 5080B Vector Network Analyzer (VNA)

TABLE I. PURE FIBRE DIELECTRIC PROPERTIES

| Parameter \ Weight Percentage, wt% | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|---|
| Dielectric Constant, $\varepsilon_r$ | 1.65 | 1.67 | 1.89 | 1.92 | 1.94 | 1.95 | 2.18 | 2.6 | 2.63 |
| Tangent Loss, tan δ | 0.04 | 0.18 | 0.19 | 0.2 | 0.2 | 0.23 | 0.25 | 0.38 | 0.41 |

TABLE II. TREATED FIBRE DIELECTRIC PROPERTIES

| Parameter \ Weight Percentage, wt% | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 |
|---|---|---|---|---|---|---|---|---|---|
| Dielectric Constant, $\varepsilon_r$ | 1.58 | 1.59 | 1.71 | 1.78 | 1.85 | 2.14 | 2.59 | 2.7 | 2.98 |
| Tangent Loss, tan δ | 0.14 | 0.16 | 0.18 | 0.25 | 0.25 | 0.31 | 0.34 | 0.43 | 0.44 |

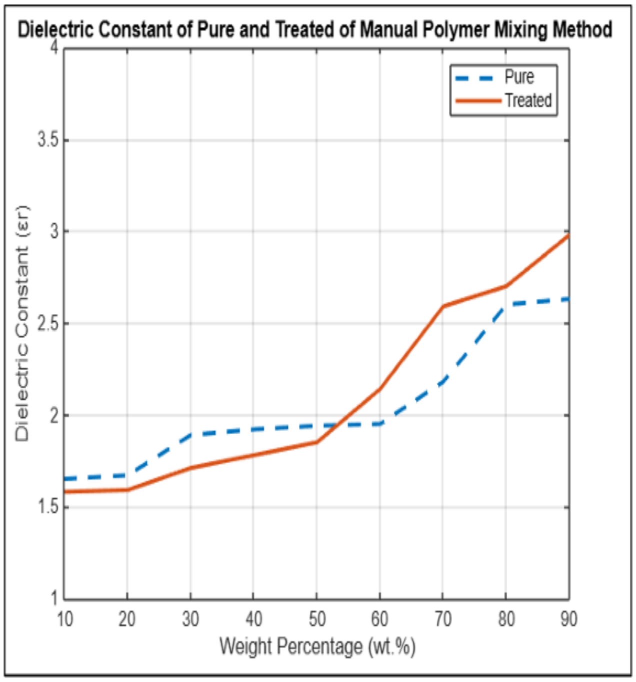



**Fig. 4.** Comparison Dielectric Constant (Pure and Treatment Fibre).

## III. Result And Discussion

This study successfully demonstrates the potential of biofibre-reinforced composites, specifically pineapple leaf fibre (PALF) and polydimethylsiloxane (PDMS), as viable substrate materials. The dielectric properties of both untreated and treated fibres are summarised in Tables I and II. From these tables, it can be concluded that the dielectric constant of both fibre types increases with the weight percentage of fibre loading. The results, as presented in the tables and illustrated in Fig. 4, highlight the key trends and relationships observed, providing a clear visual summary of the data. Further explanation of these findings is provided in the discussion section, which elaborates on the impact of alkaline treatment on dielectric performance, particularly the effect of reduced hydrophilicity following NaOH treatment. This surface modification enhances the interaction between PALF and PDMS, leading to improved dielectric properties at higher fibre loadings, as evidenced by the sharp increase in the dielectric constant at 70 wt% and above.

This study successfully demonstrates the potential of biofibre-reinforced composites, specifically pineapple leaf fibre (PALF) and polydimethylsiloxane (PDMS), as viable substrate materials. The dielectric properties of both untreated and treated fibres are summarised in Tables I and II. From these tables, it can be concluded that the dielectric constant of both fibre types increases with the weight percentage of fibre loading. The results, as presented in the tables and illustrated in Fig. 4, highlight the key trends and relationships observed, providing a clear visual summary of the data. Further explanation of these findings is provided in the discussion section, which elaborates on the impact of alkaline treatment on dielectric performance, particularly the effect of reduced hydrophilicity following NaOH treatment. This surface modification enhances the interaction between PALF and PDMS, leading to improved dielectric properties at higher fibre loadings, as evidenced by the sharp increase in the dielectric constant at 70 wt% and above.

### *3.1 Effect of Fibre Loading on Dielectric Constant*

Fig. 4 illustrates the effect of fibre loading on the dielectric constant of polydimethylsiloxane (PDMS) composites reinforced with pineapple leaf fibre (PALF). It is evident that fibre loading significantly influences the dielectric properties of the composite. As the fibre loading increases, the dielectric constant also rises, as shown in Figure 4. PALF typically exhibits a dielectric constant ranging from 3.0 to 3.5 [3, 11], while PDMS has a dielectric constant of 2.69 [1]. The composite's dielectric constant is influenced by interfacial, orientation, atomic, and electronic polarisations, which depend on the interfacial characteristics and the inherent properties of both the matrix and the fibres. Interfacial polarisation, in particular, arises due to differences in conductivity and polarisation between the matrix and the reinforcing fibres [12]

As shown in Fig. 4, treated composites initially exhibit lower dielectric constants due to reduced moisture content. However, at higher loadings, the improved interfacial bonding enhances polarisation mechanisms, resulting in a steeper increase in dielectric constant compared to untreated composites. This demonstrates that NaOH treatment not only improves mechanical compatibility but also optimizes dielectric performance, especially in composites with high fibre content.This trend is attributed to stronger interfacial polarisation and the higher cellulose content in the treated fibres [7], which enhances polarisation mechanisms within the composite.

### *3.2 Effect of alkali treatment on dielectric constant*

Fig. 4 illustrates the impact of alkaline treatment on the dielectric constant of PALF–PDMS composites, particularly in relation to hydrophobicity. Sodium hydroxide (NaOH) treatment removes non-cellulosic components such as lignin, hemicellulose, and waxes from the surface of the PALF fibres [13], thereby increasing cellulose exposure. This process reduces the hydrophobicity of the fibres, making them more hydrophilic [14]. The treated fibres exhibit improved interfacial bonding with the PDMS matrix, which contributes to enhanced interfacial polarisation. This effect becomes more pronounced at higher fibre loadings, resulting in a noticeable increase in dielectric constant beyond 70 wt%, as shown in Figure 4.

The reduction in hydrophobicity due to NaOH treatment enhances the compatibility between the fibres and the matrix, leading to better fibre orientation and interaction within the polymer [15]. This improved alignment and bonding result in superior dielectric properties at higher fibre loadings, as indicated by the higher dielectric constant in treated PALF–PDMS compared to the untreated form. Thus, NaOH treatment plays a critical role in modifying the fibre surface, positively influencing the dielectric behaviour, particularly for applications requiring high dielectric constants and improved material performance.

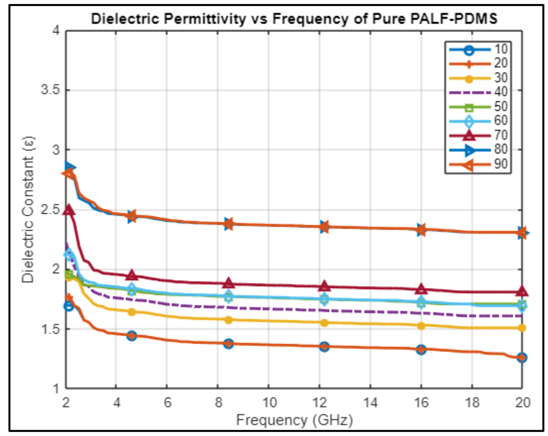
### *3.3 Effect of Frequency on Dielectric Properties*

Fig. 5 illustrates that the dielectric constant of both untreated and treated PALF–PDMS composites decreases with increasing frequency. This is typical behaviour in dielectric materials, as higher frequencies reduce the material's ability to respond to polarisation mechanisms [14]. At certain frequencies, the treated PALF–PDMS exhibits lower dielectric constants than the untreated counterpart, indicating improved dielectric stability and reduced polarisation variation across the frequency range, rather than a decline in overall polarisability.

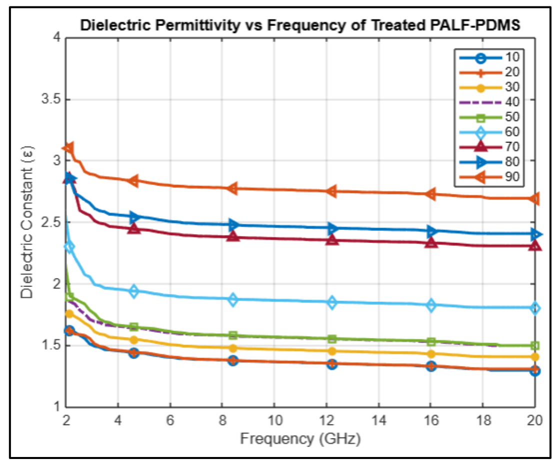
Both composites demonstrate higher dielectric constants at lower frequencies (2 to 4 GHz), attributed to increased dipole alignment with the applied electric field. The untreated PALF–PDMS shows higher dielectric constants at higher fibre loadings, whereas the treated composite exhibits a more uniform response. At higher frequencies (above 10 GHz), the dielectric constant stabilises for both materials. Overall, the treated PALF–PDMS composite demonstrates greater consistency in dielectric performance across the frequency spectrum.

### *3.4 Effect of fibre loading on dissipation factor*

Fig. 6 shows the dissipation factor (tan δ) across the frequency range for both composite types. At lower frequencies (2–4 GHz), a sharp decline in tan δ is observed, followed by stabilization at higher frequencies. Untreated composites, particularly at 90 wt% fibre loading, exhibit higher dissipation factors, indicating greater energy loss due to poor fibre-matrix interaction. In contrast, treated composites consistently show lower tan δ values, reflecting improved bonding and reduced dielectric losses. This reduction in energy dissipation makes treated PALF-PDMS composites more efficient for applications requiring minimal signal attenuation and high dielectric integrity.In contrast, the treated PALF–PDMS consistently demonstrates lower dissipation factors across the frequency range, suggesting that sodium hydroxide (NaOH) treatment effectively reduces energy loss by enhancing fibre–matrix interaction. This improved performance makes treated PALF–PDMS more efficient and better suited for applications requiring minimal energy dissipation and higher overall efficiency.

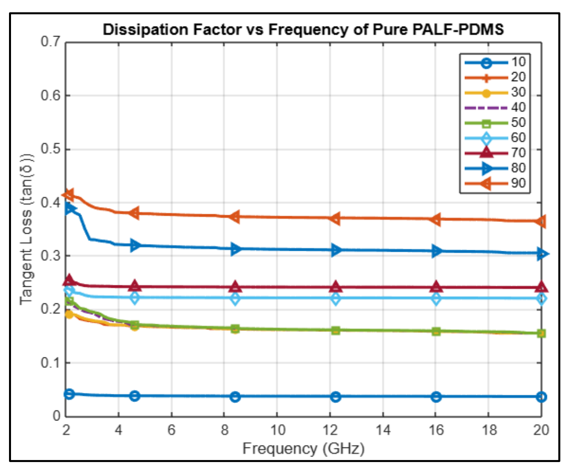



(a)

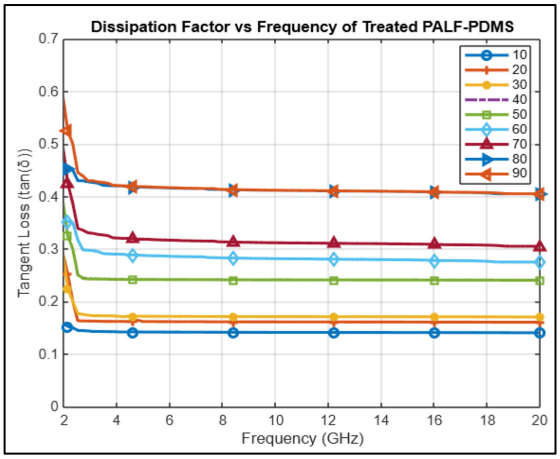



(b)

**Fig. 5**. Dielectric permittivity vs frequency (a) pure (b) treated of PALF-PDMS.




(a)




(b)

**Fig. 6.** Dissipation factor vs frequency of (a) pure (b) treated of PALF-PDMS)

## IV. Conclusion

This study demonstrates the viability of PALF-reinforced PDMS composites as flexible dielectric substrates, offering tunable dielectric properties through controlled fibre loading and alkaline treatment. Treated fibres exhibit superior dielectric performance at higher loadings due to enhanced interfacial polarisation and reduced moisture content. The composites show consistent dielectric behavior across the 2–20 GHz range, with lower dissipation factors indicating minimal energy loss. These attributes make PALF-PDMS composites promising candidates for sustainable, high-performance substrates in flexible antenna and electronic applications. Future work may include experimental validation in antenna prototypes and long-term environmental stability assessments.

## Acknowledgments

The authors gratefully acknowledged Universiti Teknologi MARA, Cawangan Pulau Pinang, Malaysia for the financial support.

## References

[1] C. Huang et al., "Electrical and mechanical properties of flexible FR4 substrates," *Materials Science Forum*, vol. 745, pp. 87–92, 2013.
[2] N. Engheta, "Rogers RT/duroid 5880 substrates for microwave applications," IEEE Transactions on Microwave Theory and Techniques, vol. 53, no. 1, pp. 210–218, 2005.
[3] R. K. Mishra and P. Rajput, "Sustainable materials for flexible antennas," Materials Today: Proceedings, vol. 26, pp. 3023–3032, 2020.
[4] C. Y. Lee, & Chou, Y. J., "Dielectric Characterization of Biodegradable Polymer Composites.," Polymer Testing, vol. 58, pp. 56-64, 2017.
[5] N. Zulkifli et al., "Analysis of dielectric properties on agricultural waste for microwave communication application," MATEC Web of Conferences, vol. 140, p. 01013, 2017.
[6] S. Kulandaisamy and P. Govindasamy, "Electrical properties of alkali treated acacia and cactus fiber reinforced hybrid polyester composites," Journal of Electrical Engineering, vol. 20, p. 76, Mar. 2020.
[7] E. Jayamani, S. B. Hamdan, R. Rahman, and M. K. B. Bakri, "Comparative study of dielectric properties of hybrid natural fiber composites," Procedia Engineering, vol. 97, pp. 536–544, 2014.
[8] O. Gbotemi et al., "Characterization of PMMA/BaTiO<sub>3</sub> Composite Layers Through Printed Capacitor Structures for Microwave Frequency Applications," IEEE Transactions on Microwave Theory and Techniques, vol. 66, no. 4, pp. 1736-1743, 2018, doi: 10.1109/TMTT.2017.2781694.
[9] A. Bekele, H. Lemu, and M. Jiru, "Study of the effects of alkali treatment and fiber orientation on mechanical properties of enset/sisal polymer hybrid composite," Journal of Composites Science, vol. 7, no. 1, p. 37, Jan. 2023.
[10] J. Kaima, I. Preechawuttipong, R. Peyroux, P. Jongchansitto, and T. Kaima, "Experimental investigation of alkaline treatment processes (NaOH, KOH and ash) on tensile strength of the bamboo fiber bundle," Results in Engineering, vol. 18, p. 101186, June 2023.
[11] M. J. John and S. Thomas, "Biofibers and biocomposites," Carbohydrate Polymers, vol. 71, no. 3, pp. 343-364, 2008.
[12] E. Jayamani and M. K. Bakri, "Preliminary study on the acoustical, dielectric and mechanical properties of sugarcane bagasse reinforced unsaturated polyester composites," Materials Science Forum, vol. 890, pp. 12–15, Mar. 2017.
[13] R. Thandavamoorthy, Y. Devarajan, and S. Thanappan, "Analysis of the characterization of NaOH-treated natural cellulose fibre extracted from banyan aerial roots," Scientific Reports, vol. 13, no. 1, p. 12579, Aug. 2023.
[14] D.-C. Wang, S.-N. Lei, S. Zhong, X. Xiao, and Q.-H. Guo, "Cellulose-based conductive materials for energy and sensing applications," Polymers, vol. 15, no. 20.
[15] M. R. Mohammed, A.R. Muhana, Aeshah Adam, Tijjani Betar, Bashir , A. F. Osman, and O. Dahham, "Surface treatment to improve water repellence and compatibility of natural fiber with polymer matrix: Recent advancement," Polymer Testing, vol. 115, p. 107707, Nov. 2022.