

The Development of Pineapple Leave Fibre Composite Material for Marine Application Using Hand Lay-Up Method

Muhammad Iqmal Aizat Majibul Rahman¹, Ahmad Hamdan Ariffin^{1*}

¹ Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 36400, Malaysia

*Corresponding Author: ahmadh@uthm.edu.my

DOI: <https://doi.org/10.30880/rpmme.2024.05.01.008>

Article Info

Received: 10 Jan 2024

Accepted: 20 June 2024

Available online: 15 Sept 2024

Keywords

Pineapple Leaf Fiber (PALF), Reinforcement Material, Marine Applications, Flexural Strength, SEM Analysis.

Abstract

Pineapple leaf fiber (PALF), abundant in Malaysia, holds potential for industrial use, particularly in reinforcing materials. This study focuses on utilizing PALF as reinforcement with epoxy for marine applications. The research explores the impact of layering, orientation, and material volume on flexural strength and water absorption. Samples, composed of 3 layers with 70% epoxy and 30% PALF, undergo a 3-point bending flexural test, evaluating maximum force, stroke, stress, strain, and Young's modulus. Water absorption and SEM analysis complement the study. Results highlight the uni-directional configuration's superior mechanical properties, with the highest flexural strength (735.52 N), ultimate tensile strength (16.17 MPa), and Young's modulus (0.0054 MPa). Notably, the uni-directional sample exhibits excellent water resistance, outperforming multi-directional and inclined directional counterparts. These findings emphasize the promising potential of PALF-epoxy composites for marine applications.

1. Introduction

Pineapple industry in Malaysia is a significant agricultural sector that plays a vital role in the country's economy. Malaysia's tropical climate and fertile soil provide favorable conditions for pineapple and oil palm cultivation [1], making it one of the top pineapple-producing countries in the region [2]. In 2017, Malaysia was ranked number 19 as the top pineapple producing country, and number five as the top exporter of pineapples in the world [3]. Every year Malaysia produces more than 350,000 Mt of pineapples [3]. Around 30% of fresh pineapples and 95% of canned pineapples are exported to many countries [3]. The industry is supported by extensive research and development efforts to improve pineapple varieties, increase productivity, and enhance disease resistance.

Beside than that, pineapple leaves, is also an abundant resource in Malaysia's lush agricultural landscape, have emerged as a valuable asset within the country's industry. With Malaysia being one of the world's largest producers of pineapples [3], the leaves of this tropical fruit have garnered significant attention for their diverse applications and potential economic benefits. These leaves, known scientifically as *Ananas comosus*, possess strong and resilient fibers that can be extracted and utilized in various industries [4][5]

After that, In Malaysia, pineapple leaf fibers are predominantly utilized in the production of textiles and handicrafts. The fibers are carefully extracted and processed, transformed into a durable and eco-friendly alternative to conventional textiles [6]. The resulting pineapple leaf fabrics are highly sought after for their unique properties, including breathability, moisture-wicking capabilities, and resistance to wrinkling. Moreover, Malaysia's artisans have ingeniously incorporated pineapple leaf fibers into traditional handicrafts, creating

intricate and visually stunning products such as bags, baskets, and footwear [7]. The utilization of pineapple leaf fibers in Malaysia not only highlights the country's commitment to sustainable practices but also showcases its rich cultural heritage and creativity in transforming natural resources into valuable and aesthetically pleasing products.

Research shows that Malaysia contains a lot of natural fiber. This natural fiber has a lot of benefits and can be used as a source of income in Malaysia. This will provide small farmers with the opportunity to supplement their income. Natural fiber can be used in many applications, such as aerospace, land, and marine. The strong structure of natural fiber can be obtained by doing some reinforcement. Composite reinforcement can increase the physical and mechanical properties of the natural fiber. A few tests have been done to determine the mechanical properties of the reinforced natural fiber A flexural test; the 3-point bending test has also been tested. The research study was about the effect of the orientation of natural fiber on flexural strength. From the test, it shows that the 45-degree incline orientation of natural fiber has the biggest value for maximum bending stress [9]. Other than that, water absorption percentage has also been studied in past research. The volume ratio of the reinforcement of natural fiber and resin epoxy shows that it will affect the water absorption percentage. According to the study, the higher the volume of resin epoxy, the lower the water absorption percentage of the reinforced natural fiber [10].

2. Experimental setup

2.1 Sample preparation

In the pursuit of evaluating the mechanical properties of reinforced pineapple leaf fibers, meticulous sample preparation is paramount. The materials utilized in this study include pineapple fibers, epoxy resin, and hardener, sourced with precision from Universiti Tun Hussein Onn Malaysia (UTHM). The first step in the preparation process involves readying a 400x400 mm polystyrene foam mold, essential for maintaining the integrity of the samples. A coating of silicone is meticulously applied to the mold, ensuring the easy removal of samples once fabricated. Subsequently, the pineapple leaves fiber, sourced through collaboration with UTHM, undergoes careful preparation and arrangement on the mold. The composition, consisting of 3 layers with a ratio of 70% epoxy and 30% PALF, is then meticulously poured into the mold, setting the foundation for the subsequent testing phases. The composition of the specimens can be observed in table1.

Table 1 *Composition of specimens*

Factor	Level 1	Level 2	Level 3
Layer arrangement	Uni-directional	Multi directional	Inclined directional
Layer quantity	3	3	3
Volume ratio	70% epoxy 30% PALF	70% epoxy 30% PALF	70% epoxy 30% PALF

The composition diversity is a key aspect of the sample preparation, as it enables the exploration of different layer arrangements, adding a layer of complexity to the study. The specific arrangement of pineapple leaf fibers plays a crucial role in influencing the mechanical properties of the resulting composite material. With attention to detail, this study emphasizes the importance of a systematic and controlled sample preparation process, ensuring the reliability and relevance of the subsequent mechanical tests.

2.2 Flexural test

The specimen flexural strength will be test using 3-point bending test. This test will use an all-purpose testing machine with a 3-point bending test-specific fixture. The specimen will be set up on a simply-supported beam and placed beneath the flexural testing machine's application of load equipment. Through the control panel, the load will be applied to the specimen, and the deflection along the specimen will be calculated. For various specimen kinds, the procedure will be repeated. Table 2 shows the mechanical properties of PALF composite from past researches [8]

Table 2 mechanical properties of PALF composite from past researches [8]

Fiber orientation	Maximum load (KN)	Maximum bending stress (Mpa)
Uni-directional	0.226514998	86.60543723
Multi directional	0.278678076	102.855419
Inclined directional	0.286039163	105.5754786

2.3 Water absorption test

To calculate the water absorption percentage, the specimen is divided by three with difference volume of material. First, the weight of the specimen was recorded. After that, the specimens were deep into water for 24 hours for 5 days. Then, the new weight of the specimen will be recorded. For water absorption percentage, some calculation is needed. Equation of water absorption is shown in equation 1. ASTM D-5229 standard was used to prepare the test specimens for water absorption test. The dimensions of the water absorption test were taken as $20 \times 20 \times 6$ mm based on the standard.

$$\text{water absorption percentage \%} = \frac{M_2 - M_1}{M_1} \times 100 \quad (\text{equation 1})$$

M_1 = weight after specimen deep into water, (g)

M_2 = weight of the specimen before deep into water, (g)

2.4 Scanning electron microscopy (SEM) analysis

After conducting flexural tests on the pineapple leaf fibre composites, specimens that exhibited fracture were subjected to Scanning Electron Microscopy (SEM) analysis following the ASTM D5229 standard. The specimens, underwent examination through SEM to investigate the microstructural features and fracture surfaces. The sample were cut into 1cm x 1 cm and adhered on aluminium plate. The image was focussed at 150 times magnifications. This analysis provided detailed insights into the fibre-matrix interface, morphology, and potential failure mechanisms, contributing valuable information to the overall understanding of the material's performance and structural.

3. Result and discussion

The results of the 3-layer configurations in unidirectional, multidirectional, and inclined directional orientations, each comprising 70% epoxy and 30% PALF, were meticulously compiled and illustrated in a comparative graphical representation. The graphical depictions, presented in Figure 4.1.2, Figure 4.1.3, and Figure 4.1.4, provide a clear visual comparison of the maximum force against maximum stroke for the respective samples.

Subsequently, a further comparison was conducted for the maximum stress against maximum strain, as delineated in Figure 4.4, Figure 4.5, and Figure 4.6. From the stress-strain graphs, the Young's modulus was derived, and its representation is presented in the comparison graph found in Figure 4.99. This systematic approach ensures a comprehensive evaluation of the mechanical properties of the composite materials.

3.1 Flexural properties

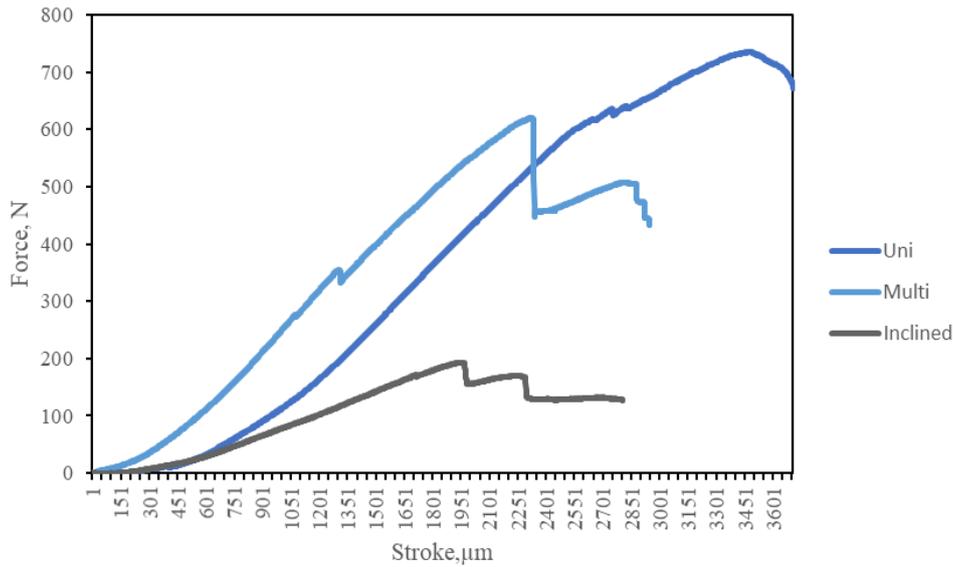


Figure 1 Graph comparison of average Uni, Multi and Inclined maximum force against maximum stroke

In Figure 1, it is observed that the unidirectional configuration, comprising a composition of 3 layers with 70% epoxy and 30% PALF, exhibits the highest recorded maximum force and stroke, measuring 735.5208 N and 3.63 mm, respectively. Conversely, the lowest force and stroke maximum are shown in the inclined directional setup with a composition of 3 layers, 70% epoxy, and 30% PALF, yielding results of 193.2291 N and 2.024 mm. The multi-directional configuration, featuring the same composition, demonstrates intermediate performance with a maximum force of 619.3751 N and a corresponding stroke maximum of 2.024 mm. These findings contribute valuable insights into the varying mechanical responses of the composite materials under consideration, aiding in the assessment of their structural performance.

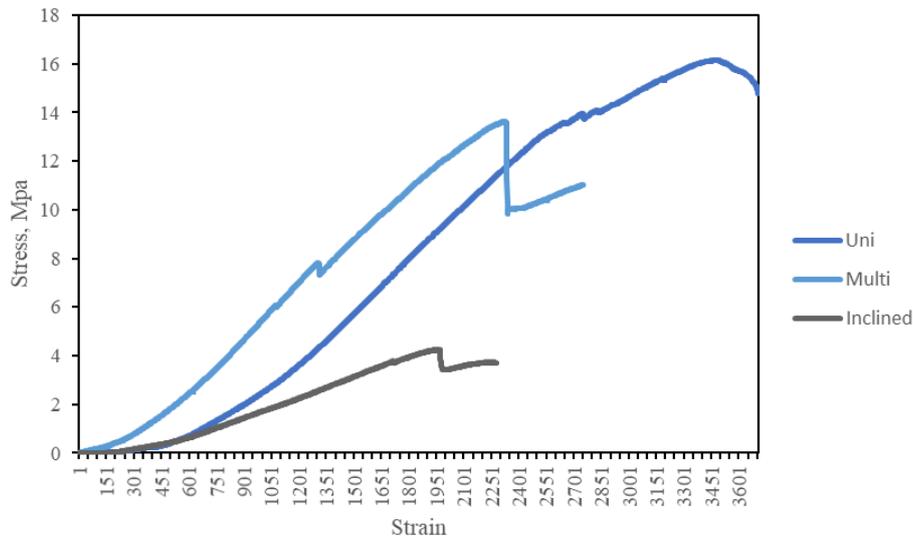


Figure 2 Graph comparison of average Uni, Multi and Inclined stress against strain

From figure 2, it is evident that the unidirectional configuration, characterized by a composition of 3 layers with 70% epoxy and 30% PALF, exhibited the highest stress value at 17.84341 Mpa and a corresponding strain of 0.0237854. In contrast, the inclined directional setup registered the lowest stress value, recording 5.25412 Mpa with a strain of 0.013586. The multidirectional configuration, featuring the same composition, demonstrated an intermediate stress value of 14.9792 Mpa with a strain of 0.015938. These distinct stress-strain profiles underscore the directional dependence of the composite materials' mechanical responses, providing valuable insights into their structural performance under varying loading conditions.

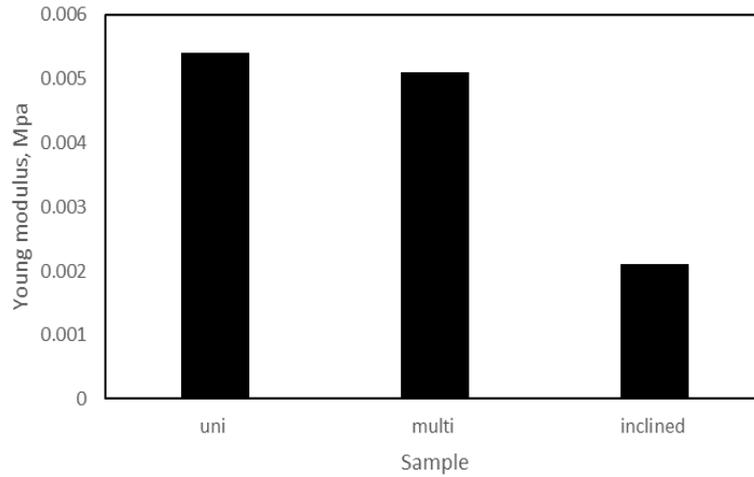


Figure 3 Graph comparison of Uni, Multi and Inclined sample against young modulus

Figure 3 shows the calculated Young's modulus values derived from the stress-strain curves exhibit distinct characteristics for the composite materials with a consistent composition of 3 layers comprising 70% epoxy and 30% PALF. The unidirectional configuration yielded the highest Young's modulus at 0.0054 MPa, emphasizing its superior stiffness. Conversely, the inclined directional setup displayed the lowest Young's modulus, recording 0.0021 MPa, indicative of relatively lower stiffness. The multidirectional configuration, featuring the same composition, demonstrated an intermediate Young's modulus of 0.0051 MPa.

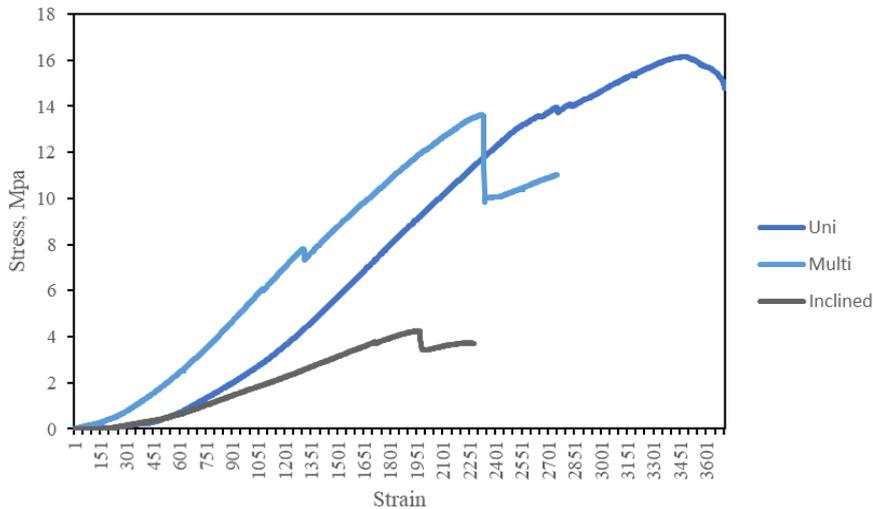


Figure 4 Graph comparison of Uni, Multi and Inclined ultimate tensile strength

Figure 4 shows the stress-strain data extracted from the graphical representation reveals distinctive characteristics in the ultimate tensile strength of composite materials, all sharing a consistent composition of 3 layers with 70% epoxy and 30% PALF. The unidirectional configuration stands out with the highest ultimate tensile strength, reaching 16.16529 MPa, underscoring its superior resistance to tensile forces. In contrast, the inclined directional setup exhibits the lowest ultimate tensile strength at 3.706502 MPa, indicative of a comparatively lower ability to withstand tensile stress. The multidirectional configuration, featuring the same composition, demonstrates an intermediate ultimate tensile strength of 11.0119 MPa. The differences in ultimate tensile strength arise from the varying degrees of fibre alignment in different configurations. Unidirectional setups exhibit superior tensile strength due to aligned fibres, while inclined setups and multidirectional configurations experience reduced strength as a result of misaligned or less efficiently aligned fibres. These insights highlight the crucial role of fibre orientation in determining the mechanical properties of composite materials.

3.2 Water absorption properties

In adherence to ASTM D5229 standards, a comprehensive water absorption test was conducted using specimens sized at 20x20x6 mm. These specimens were submerged in three separate water containers for a duration of five days. Before commencing the experiment, the initial weight of each specimen was meticulously recorded. Throughout the five-day period, daily weight measurements were consistently taken to monitor the extent of water absorption. The detailed results of these weight measurements, along with the corresponding water absorption percentages calculated using Equation 1, were integral components of the study. This methodological approach followed ASTM D5229 guidelines, ensuring a systematic and quantitative assessment of the water absorption characteristics of the specimens under investigation.

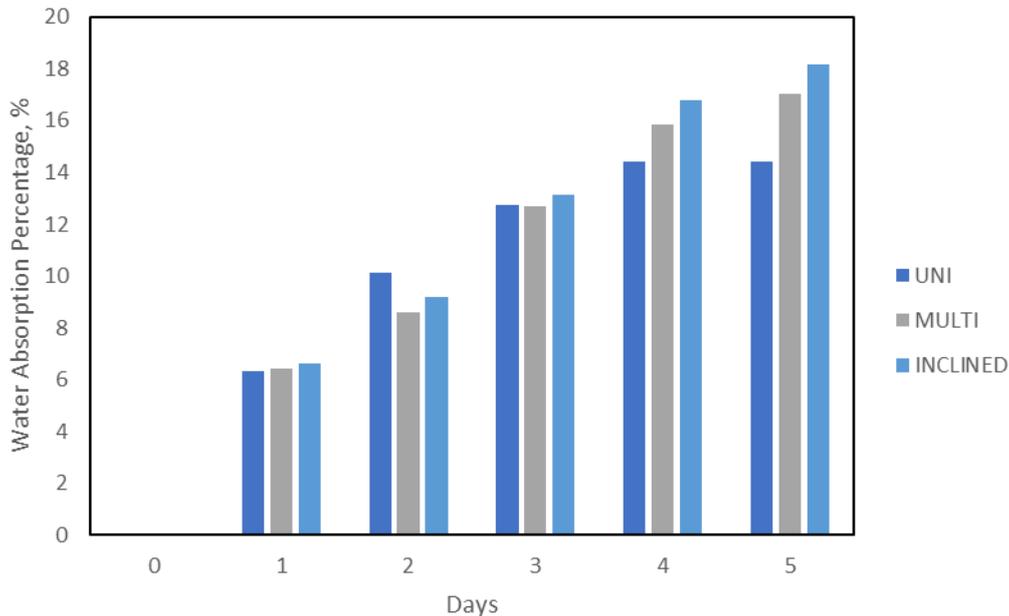


Figure 5 Graph water absorption percentage for 5 days

The graph in Figure 5 depicts the water absorption percentage over a five-day period for each sample. A noticeable trend reveals a significant increase in water absorption as the days progress. On the first day, Uni-directional exhibited the lowest absorption at 6.32%, while inclined directional reached the highest at 6.60%, with multi-directional at 6.40%. Day 2 saw Uni-directional experiencing the highest surge at 10.10%, surpassing inclined directional at 9.17%, and multi-directional at 8.59%. By day 3, inclined directional showed the highest absorption at 13.16%, while Uni-directional recorded the lowest at 12.74%, with multi-directional falling in between at 12.86%. The trend continued on days 4 and 5, with inclined directional consistently exhibiting the highest water absorption percentages at 16.80% and 18.18%, respectively. Uni-directional maintained the lowest percentages at 14.42%, while multi-directional presented intermediate values at 15.82% and 17.02%. This pattern underscores the influence of sample orientation, particularly with inclined directional configurations leading to increased water absorption due to smaller gaps between PALF and epoxy components.

3.3 Scanning electrons microscopic (SEM) analysis

SEM analysis was carried out on three samples of unidirectional, multidirectional, and inclined directional, each consisting of 70% epoxy and 30% PALF. SEM was employed to gain detailed insights into the microstructure of these composite materials. This technique allows for a closer examination of surface morphology, facilitating the identification of fiber distribution, matrix interaction, and potential defects. In this study, SEM helps elucidate the structural characteristics of the composites, providing valuable information on fiber alignment, dispersion, and overall material integrity. A magnification of x150 was utilized for the SEM analysis to ensure a thorough examination of the samples at a microscale level.

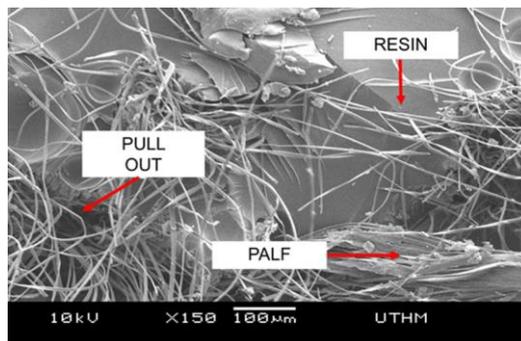


Figure 6 SEM analysis on Uni-directional 70% epoxy 30% PALF sample

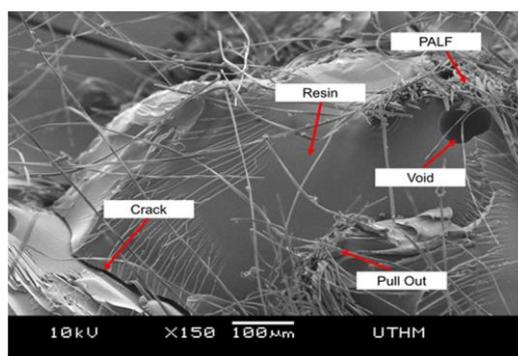


Figure 7 SEM analysis on Multi directional 70% epoxy 30% PALF sample

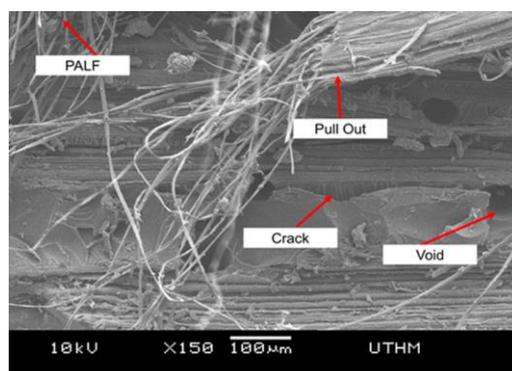


Figure 8 SEM analysis on inclined directional 70% epoxy 30% PALF sample

SEM analysis of the unidirectional sample (Figure 6), comprising 70% epoxy and 30% PALF, revealed minimal defects, showcasing a visually appealing and structurally sound composite. The micrographs emphasized the absence of significant flaws, underscoring the superior quality of the unidirectional sample. The microstructural examination provided valuable insights, displaying instances of fibre pull-out from the flexural test, highlighting the sample's robustness. In direct comparison to multidirectional and inclined directional counterparts, the unidirectional sample demonstrated superior structural integrity, establishing itself as the optimal configuration within the study.

The SEM analysis of the multidirectional sample (Figure 7) exhibited an intermediate level of defects within the microstructure. The examination revealed voids and cracks, indicative of certain structural

imperfections. SEM images highlighted gaps between the epoxy and PALF, offering insights into factors contributing to lower flexural strength. In comparison to inclined directional samples, the multidirectional configuration emerged as a more favourable option, presenting a structural profile superior in quality and integrity.

Figure 8 demonstrates SEM analysis of the inclined directional sample, revealing the highest incidence of defects within its microstructure. The examination displayed numerous voids and cracks, emphasizing substantial structural imperfections. SEM images depicted observable gaps between the epoxy and PALF, contributing to the inclined directional sample's lowest flexural strength. In comparison to unidirectional and multidirectional counterparts, the inclined directional sample exhibited less favourable structural characteristics, highlighting the impact of PALF orientation on overall material performance.

4. Conclusion

In conclusion, the comprehensive analysis of the flexural test results reveals notable variations in the mechanical properties of pineapple leaf fiber composite materials across different orientations. The uni-directional sample emerges as the most favorable, exhibiting the highest flexural strength (735.52 MPa), largest stroke maximum (3.63 mm), and highest Young Modulus (0.0054 MPa). These findings highlight the significant contribution of the uni-directional sample's specific fiber arrangement to its enhanced mechanical properties, making it a promising choice for marine applications where structural integrity is paramount. The study also sheds light on the water absorption characteristics, showcasing the uni-directional sample's remarkable resistance, with a final absorption percentage of 14.4% on day 5, compared to higher rates in multi-directional and inclined samples. In summary, the uni-directional sample demonstrates superior mechanical properties and resistance to water absorption, positioning it as the preferred variant for the development of pineapple leaf fiber composite materials tailored for marine applications. These findings offer crucial insights for advancing the efficiency of composite materials and present a novel concept for enhancing the mechanical attributes of pineapple leaf fiber composites in future marine applications.

Acknowledgment

The authors would like to thank the Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein Onn Malaysia for the support provided throughout the project.

Conflict of Interest

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

Author Contribution

*The authors confirm contribution to the paper as follows: **study conception and design:** Muhammad Iqmal Aizat, Ahmad Hamdan; **data collection:** Muhammad Iqmal Aizat; **analysis and interpretation of results:** Muhammad Iqmal Aizat, Ahmad Hamdan; **draft manuscript preparation:** Muhammad Iqmal Aizat. All authors reviewed the results and approved the final version of the manuscript.*

References

- [1] V. S. Shevade and T. V. Loboda, "Oil palm plantations in Peninsular Malaysia: Determinants and constraints on expansion," *PLoS One*, vol. 14, no. 2, 2019, doi: 10.1371/journal.pone.0210628.
- [2] A. A. MOHD NOH *et al.*, "OBSERVATION ON THE FRUIT DEVELOPMENT, FRUIT RIPENING AND PREFERENCE OF RATS IN DAMAGING PINEAPPLE MD2 BASED ON HORMONAL FLOWER INDUCED DAYS AND PHENOLOGY," *The Planter*, vol. 98, no. 1160, 2022, doi: 10.56333/tp.2022.012.
- [3] "Japan as a New Market for Malaysian Pineapples," *FFTC Journal of Agricultural Policy*, no. 1, 2021, doi: 10.56669/urser7590.

- [4] M. Asim *et al.*, "A review on pineapple leaves fibre and its composites," *International Journal of Polymer Science*, vol. 2015. 2015. doi: 10.1155/2015/950567.
- [5] N. K. Sugianitri and Suhendra, "Addition of the leaf fiber of pineapple (*Ananas comosus* (L) Merr) to the impact strength test of heat cured acrylic resin," *Makassar Dental Journal*, vol. 10, no. 3, 2021, doi: 10.35856/mdj.v10i3.449.
- [6] M. F. Azuan, M. A. Samin, and R. Legino, "Natural Fabric with Pineapple Fibres used as a Batik Medium," *Environment-Behaviour Proceedings Journal*, vol. 7, no. SI8, 2022, doi: 10.21834/ebpj.v7isi8.3923.
- [7] A. V. Soocheta and S. Rajeswaree, "Extraction and Processing of Pineapple Leaf Fibres," *University of Mauritius Research Journal*, vol. 23, 2017.
- [8] P. K. Jena, J. R. Mohanty, and S. Nayak, "Effect of Surface Modification of Vetiver Fibers on Their Physical and Thermal Properties," *Journal of Natural Fibers*, vol. 19, no. 1, 2022, doi: 10.1080/15440478.2020.1726249.
- [9] A. E. Hadi *et al.*, "Potentiality of Utilizing Woven Pineapple Leaf Fibre for Polymer Composites," *Polymers (Basel)*, vol. 14, no. 13, 2022, doi: 10.3390/polym14132744. Nicholl, K. (2020, May). A royal spark. *Vanity Fair*, 62(5), 56–65, 100.
- [10] A. M. Noor Azammi *et al.*, "Characterization studies of biopolymeric matrix and cellulose fibres based composites related to functionalized fibre-matrix interface," in *Interfaces in Particle and Fibre Reinforced Composites: Current Perspectives on*