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Research Article

Evaluation of Mechanical Properties of Alkaline-Treated Indigenous Fibers Reinforced Epoxy Composites

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ABSTRACT

This study evaluates the mechanical and thermal properties of epoxy composites reinforced with indigenous fibers—raffia, abaca, and coconut—treated with varying concentrations of sodium hydroxide (NaOH). Indigenous fibers are gaining attention as sustainable alternatives to synthetic reinforcements in composite materials due to their availability, cost-effectiveness, and environmental compatibility. The research investigates the impact of alkaline treatment on fiber properties, tensile strength, Young's modulus, and thermal conductivity, with fiber loadings of one gram and two grams. The results demonstrate that alkaline treatment improves fiber-matrix adhesion, leading to enhanced mechanical and thermal properties. Raffia fiber composites achieved a maximum tensile strength of 9.93 MPa and a Young's modulus of 9268 MPa at 3% NaOH concentration. Abaca composites exhibited superior mechanical performance, with a tensile strength of 18.13 MPa and Young's modulus of 14,556 MPa under similar conditions. Coconut composites recorded a tensile strength of 14.32 MPa and Young's modulus of 9431 MPa at 2% NaOH concentration. However, increasing fiber loading to 2 grams reduced tensile strength and thermal conductivity due to agglomeration and reduced matrix uniformity. Thermal conductivity improved with higher NaOH concentrations, peaking at 3% for all fiber types, consistent with literature on the benefits of alkali treatments. These findings align with studies by Patel et al. (2023) and Ramli et al. (2020), confirming that chemical treatments enhance fiber compatibility and overall composite performance. This research underscores the potential of indigenous fibers as viable reinforcements in sustainable composite materials, promoting advancements in eco-friendly engineering practice.

Key Words: Alkaline treatment, epoxy composites, indigenous fibers, tensile strength, heat conductivity.

1. INTRODUCTION

The integration of indigenous fiber reinforcements into epoxy composites presents a promising avenue for enhancing the sustainability and environmental compatibility of engineered materials. With increasing concerns over the environmental impact of conventional composite materials, there is a growing interest in exploring alternative solutions that utilize renewable and biodegradable resources. By assessing the mechanical properties of epoxy composites reinforced with indigenous fibers and evaluating the associated manufacturing processes, this study seeks to contribute to the development of eco-friendly composite materials that align with the principles of sustainable engineering. This optimization not only holds potential for improving the performance and quality of epoxy composites but also for reducing production costs and resource consumption, thereby advancing sustainable manufacturing practices.

A. Objectives

1. To create a fiber composite material using locally available fibers here in Mindanao - abaca, coconut, and raffia fibers.
2. To subject the fiber composites under varying concentrations of alkali treatment and constant resin application ratio.

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3. To test the produced materials with regards to the following factors:
i. Tensile Strength
ii. Heat Conductivity
4. To create a baseline for future research and industrial applications through profiling of mechanical characteristics of indigenous fiber reinforced epoxy composites.

B. Conceptual Framework

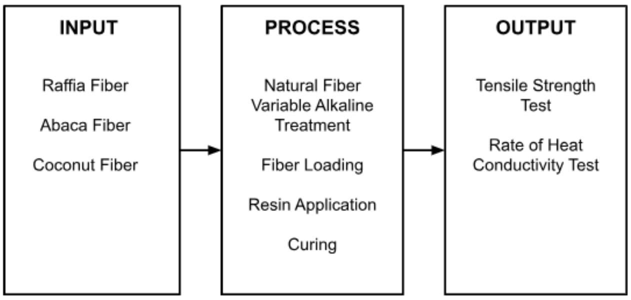

Figure 1: Conceptual Framework of the Process

The indigenous fibers will be treated/cured and will then undergo the same process as manufacturing of epoxy composites. After this phase, the produced indigenous fiber composites will undergo experiments and tests for the analysis of their respective mechanical properties, as well as a feasibility study for their economic and industrial viability from then on, the results will be recorded to obtain the highest performing and efficient fiber composite.

C. Significance of the Study

Epoxy composites are an indispensable material in mechanical and industrial engineering applications. It is used as a lightweight and sturdy alternative for casing, insulation, and structural components due to their unique properties, including high strength, durability, thermal insulating capabilities, and high resistance to corrosion. This research will be critically beneficial for pioneering the indigenous fiber and epoxy industry by promoting information in its manufacturing processes.

D. Scope and Limitations

The composites will undergo tests using specified machines and experiments, which will only consider factors including weight, structural integrity, stress-strain characteristics, and strength to weight ratio. To create a baseline quality, the researchers regulated the fiber loading and fiber orientation as uniform among the materials.

2. METHODOLOGY

The raw indigenous fibers are first subjected to a varied alkaline treatment in 1%, 2%, and 3% concentrations, and soaked for eight hours. After which, the indigenous fibers are washed and air-dried for one to two days, before loading them into 1 and 2 grams of fiber. The resin and hardener ratio are at 10:2, specifically 10mL and 2mL mixture, and therefore applied to the fiber-loaded indigenous fibers with at least three samples per gram per percentage of alkaline-treated fibers. Collectively, there are a total of 54 specimens across the abaca, coconut, and raffia fibers that will then be subjected to the tensile strength test and heat conductivity test. The tensile strength test utilized the usage of a Universal Testing Machine, and the heat conductivity test was measured using the temperature difference of the specimen subjected to heat.

A. Research Design

The research will employ an experimental design approach on determining the mechanical properties of indigenous fiber resin composites. This study aims to systematically assess key mechanical characteristics such as tensile strength and heat conductivity of composite materials fabricated using different types of indigenous fibers and resin matrices. Through experimental testing following standardized procedures, the research will investigate the influence of fiber type, variable fiber treatment, fiber orientation, fiber loading, and resin application on the mechanical behavior of the indigenous fiber composites.
In this research, the Gunt Hamburg WP300 Universal Testing Machine (see Figure 1) is utilized for testing the indigenous fiber reinforced epoxy composite materials. The machine operates within a testing speed range of 0.001

Journal of Information Systems Engineering and Management
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to 100 mm/min, enabling fine control over the testing process. This apparatus is used for determining material properties such as tensile strength, modulus of elasticity, and fracture resistance.

Figure 2: Gunt Hamburg WP300 Universal Testing Machine

B. Alkaline Treatment and Drying Procedures of Indigenous Fibers

The indigenous fibers (see Figure 2) will be chemically treated through alkaline treatment using NaOH (Sodium Hydroxide) solution at varying concentration levels. The purpose of the alkaline treatment is to diminish the moisture-related hydroxyl groups and thus weaken the hydrophilic nature - having a strong affinity for water; tending to dissolve in, mix with, or be wetted by water - of the indigenous fibers as well as impurities. This improves the adhesion between the fiber and epoxy, therefore increasing their mechanical capabilities.

(a) Raffia fibers

(b) Abaca fibers

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/ **Research Article**

(c) Coconut fibers
Figure 3: Alkaline Treatment of Indigenous Fibers

The above figures labeled (a), (b), and (c) represent indigenous Raffia, Abaca, and Coconut fibers with Alkaline treatment at 1%, 2%, and 3%, respectively.

(a) Raffia fibers

(b) Abaca fibers

(c)Coconut fibers
Figure 4: Drying Procedure of Indigenous Fibers

The above figures labeled (a), (b), and (c) depict indigenous Raffia, Abaca, and Coconut fibers, respectively, dried using the room temperature method. This was implemented in the Mechanical Engineering Annex building, Xavier University main campus. The fibers where hung using the plastic hunger, separated at a designted distances to make room air circulated naturally.

Journal of Information Systems Engineering and Management
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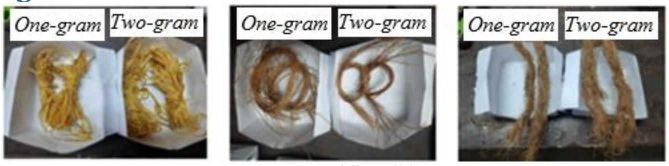
https://www.jisem-journal.com/ **Research Article**

C. Fiber Loading of Indigenous Fibers



(a) Raffia fibers

(b) Abaca fibers

(c) Coconut fibers

Figure 5: One-gram and Two-gram Fiber Loading Procedure of Inidgenous Fibers

To create a baseline data for the juxtaposition of the mechanical properties for each indigenous fiber-based epoxy composites, specimens were made with varying fiber loading for each alkaline treatment parameter of one-gram and two-gram fiber loading under constant fiber to epoxy ratio at 10:2. Loading will be different for each mechanical property included in this study. A cylindrical-straw structure will be used for determining the tensile strength properties of each indigenous fiber-based epoxy composite, while circular disks will be used in deducing their corresponding rate of heat conductivity.

D. Post-Processing and Validation

After the fiber loading, the fiber materials were prepared for curing. The endpoints of the cylindrical-straw provided additional lengths that make it hold during the tensile testing (as seen in the figures below).

(a) Raffia fibers

Journal of Information Systems Engineering and Management
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(b) Abaca fibers

(c) Coconut fibers

Figure 6: Fiber Curing Procedure of Indigenous Fibers

Post-processing involves scrutinizing the collected data, ensuring accuracy and consistency, and addressing any outliers or anomalies through data cleaning techniques. Validation of the results will involve cross-referencing them with existing literature and empirical evidence to confirm their reliability and relevance. It should also be noted that three specimens for each indigenous fiber will be made and tested for data reliability. Figure 7 illustrates the testing setup and procedure using the Gunt Hamburg WP300 Universal Testing Machine.

Figure 7: Indigenous Fiber Reinforced Epoxy under Universal Testing Machine

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/ **Research Article**

3. RESULTS AND DISCUSSION

Presenting the results and discussion and focusing on the analysis of the mechanical properties of indigenous fiber reinforced epoxy composites, this chapter interprets the data obtained from various tests, highlighting key findings and comparing them with existing literature. The discussion addresses the implications of these results, providing insights into the performance and potential applications of the studied composites.

A. Physical Properties of Indigenous Fibers

Table 1. Physical Properties of Indigenous Fibers

Natural Fiber	Physical Appearance	Texture and Malleability	Density (g/µm3)	Diameter (µm)
Raffia	Silky-White	Soft and Flexible	43402	163
Abaca	Medium Brown	Rigid and Flexible	19495	159
Coconut	Dark Brown	Rough and Brittle	122393	109.56

These fibers are examined as potential reinforcements for epoxy, the following values reflecting are from the raw indigenous fibers that has not yet undergone alkaline treatment. Among the three fibers studied, coconut fibers possess the highest density, at 122,393 g/µm³, and the smallest diameter of 109.56 µm. These characteristics suggest that coconut fibers may provide improved compressive strength and durability when incorporated into epoxy composites. However, their brittleness could limit their use in applications requiring significant flexibility or elongation.

B. Physical Properties of Indigenous Fibers after Alkaline Treatment

Table 2. Physical Properties of Indigenous Fibers after Alkaline Treatment

Natural Fiber	Alkaline Solution	Physical Appearance	Texture and Malleability	Density (g/µm³)	Diameter (µm)
Raffia	1%	Light Yellow	Soft and Flexible	25685	146.67
Raffia	2%	Dark Yellow	Perforated, Wilted Texture	37413	131.67
Raffia	3%	Brown	Dry and Brittle	51056	128.33
Abaca	1%	Medium Brown	Rigid and Flexible	16069	151.67
Abaca	2%	Light Brown	Light and Stiff	22536	135
Abaca	3%	Golden Brown	Light and Brittle	26060	131.67
Coconut	1%	Dark Brown	Rough and Brittle	08475	107.5
Coconut	2%	Dark Brown	Malleable	9110	106.25
Coconut	3%	Dark Brown	Smooth	19108	101.25

The alkaline treatment of raffia, abaca, and coconut fibers significantly altered their physical properties, enhancing their suitability for composite applications. Across all fiber types, density increased with higher NaOH concentrations due to the removal of non-cellulosic components like lignin and hemicellulose, which reduced impurities and enhanced fiber-matrix adhesion. Conversely, fiber diameter decreased, indicating a more compact structure conducive to better mechanical performance. These results align with the findings of Patel et al. (2023), who reported that alkaline treatment improves mechanical properties by removing impurities and enhancing fiber-matrix bonding [1]. Similarly, Saju and Gupta (2020) noted that NaOH treatments reduce fiber hydrophilicity and increase interfacial adhesion. These enhancements underscore the potential of alkaline-treated fibers for developing high-performance, sustainable composites [2].

C. Tensile Strength Characteristics of Raffia Fiber- Based Epoxy Composites

Journal of Information Systems Engineering and Management
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https://www.jisem-journal.com/ **Research Article**

Table 3. Tensile Strength of Raffia Fiber-Based Epoxy Composites

Variables	Maximum Tensile Strength (Mpa)	Maximum Elongation (mm)	Area (mm2)	Density (g/mm3)	Young's Modulus
1 % solution, 1 gram loading	14.14710605	0.105	28.27433388	0.001313659848	9431.404035
1 % solution, 2 grams loading	9.880869384	0.15	50.26548246	0.001193662073	4610.764995
2 % solution, 1 gram loading	14.32394488	0.125	28.27433388	0.001313659848	8020.125912
2 % solution, 2 grams loading	9.900763752	0.15	50.26548246	0.001193662073	4620.048414
3 % solution, 1 gram loading	14.14710605	0.145	28.27433388	0.001313659848	6831.050726
3 % solution, 2 grams loading	9.748240264	0.155	50.26548246	0.001193662073	4456.041337

At lower NaOH concentrations (1%), composites exhibited moderate tensile strength, with a maximum value of 8.66 MPa at a one-gram fiber loading. Increasing the NaOH concentration to 3% led to the highest tensile strength recorded, 9.93 MPa, for a one-gram fiber loading. However, increasing the fiber loading to two grams generally resulted in a decrease in tensile strength, with the 3% NaOH-treated composite reaching 8.92 MPa. This trend suggests that while higher NaOH concentrations improve fiber-matrix adhesion, excessive fiber content may lead to agglomeration or insufficient matrix encapsulation, thereby reducing the composite's tensile strength.

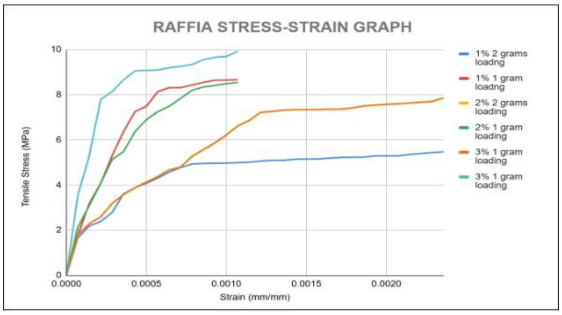

Figure 8: Tensile Strength of Raffia Fiber-Based Epoxy Composites

D. Tensile Strength Characteristics of Abaca Fiber- Based Epoxy Composites

Table 4. Tensile Strength of Abaca Fiber-Based Epoxy Composites

Variables	Maximum Tensile Strength (Mpa)	Maximum Elongation (mm)	Area (mm2)	Density (g/mm3)	Young's Modulus
1 % solution, 1 gram loading	18.12597963	0.11	28.27433388	0.001313659848	11537.861
1 % solution, 2 grams loading	10.36496567	0.165	50.26548246	0.001193662073	4397.524679
2 % solution, 1 gram loading	17.86072139	0.1	28.27433388	0.001313659848	12498.75535
2 % solution, 2 grams loading	10.04002433	0.11	50.26548246	0.001193662073	6390.849349
3 % solution, 1 gram loading	17.67209331	0.085	28.27433388	0.001313659848	14556.91377
3 % solution, 2 grams loading	9.880869384	0.105	50.26548246	0.001193662073	6587.246256

Journal of Information Systems Engineering and Management
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The tensile strength of abaca fiber-based epoxy composites (see Figure 9) demonstrates a clear relationship with the NaOH concentration and fiber loading. At a 1% NaOH treatment, the tensile strength peaked at 18.13 MPa with a one-gram fiber loading, while a two-gram fiber loading reduced the tensile strength to 10.36 MPa. Similarly, at a 3% NaOH treatment, the highest tensile strength observed was 17.67 MPa for one-gram fiber loading, dropping to 9.88 MPa for two-gram loading. The general trend indicates that while alkaline treatment enhances fiber-matrix adhesion, excessive fiber content disrupts stress distribution, leading to reduced tensile strength.

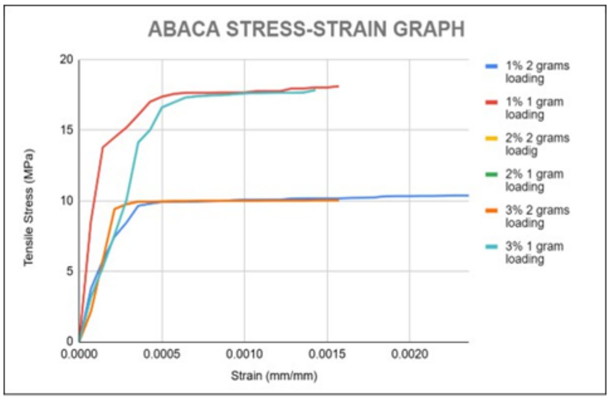

Figure 9: Tensile Strength of Abaca Fiber-Based Epoxy Composites

E. Tensile Strength Characteristics of Coconut Fiber- Based Epoxy Composites

Table 5. Tensile Strength of Coconut Fiber-Based Epoxy Composites

Variables	Maximum Tensile Strength (Mpa)	Maximum Elongation (mm)	Area (mm2)	Density (g/mm3)	Young's Modulus
1 % solution, 1 gram loading	8.66510246	0.075	28.27433388	0.001313659848	8090.66523
1 % solution, 2 grams loading	5.470951169	0.165	50.26548246	0.001193662073	2321.150263
2 % solution, 1 gram loading	8.547209907	0.075	28.27433388	0.001313659848	7980.588148
2 % solution,2 grams loading	8.156690833	0.165	50.26548246	0.001193662073	3460.624028
3 % solution, 1 gram loading	9.926552747	0.075	28.27433388	0.001313659848	9268.48996
3 % solution, 2 grams loading	8.919308269	0.15	50.26548246	0.001193662073	4200.872067

The tensile strength of coconut fiber-based epoxy composites (see Figure 10) varied depending on the NaOH concentration and fiber loading. At a 1% NaOH treatment, the tensile strength reached 14.15 MPa for one-gram fiber loading but dropped to 9.88 MPa when the fiber loading increased to 2 grams.

Journal of Information Systems Engineering and Management
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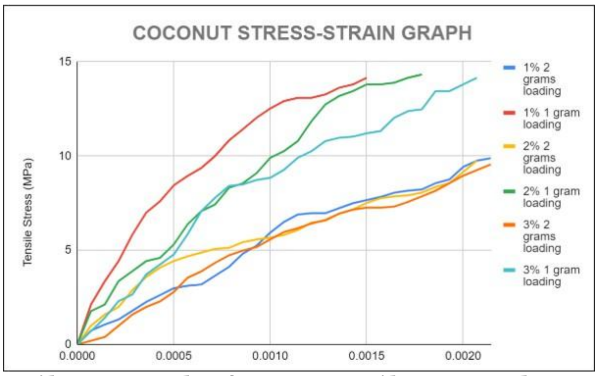

Figure 10: Tensile Strength of Coconut Fiber-Based Epoxy Composites

Similarly, at 3% NaOH treatment, the maximum tensile strength was 14.14 MPa for one-gram fiber loading, while two-gram loading resulted in a reduced value of 9.75 MPa. These results suggest that higher NaOH concentrations improve fiber-matrix adhesion by removing impurities and enhancing interfacial bonding, while excessive fiber content may hinder stress transfer and reduce composite strength.

F. Overall Tensile Strength Characteristics of Indigenous Fibers

Table 6. Overall Tensile Strength Characteristics for One Gram Loading

COMPILATION OF DATA FOR 1 GRAM INDIGENOUS FIBER-REINFORCED EPOXY COMPOSITES

Indigenous Fiber	Alkaline Treatment	Maximum Tensile Strength (MPa)	Maximum Elongation (mm/mm)	Young's Modulus
Raffia	1%	8.66510246	0.075	8090.66523
Raffia	2%	8.547209907	0.075	7980.588148
Raffia	3%	9.926552747	0.075	9268.48996
Abaca	1%	18.12597963	0.11	11537.861
Abaca	2%	17.86072139	0.1	12498.75535
Abaca	3%	17.67209331	0.085	14556.91377
Coconut	1%	14.14710605	0.105	9431.404035
Coconut	2%	14.32394488	0.125	8020.125912
Coconut	3%	14.14710605	0.145	6831.050726

Abaca composites demonstrated the highest tensile strength and stiffness, achieving a peak tensile strength of 18.13 MPa and Young's modulus of 14,556 MPa at one-gram fiber loading with 3% NaOH treatment. These results highlight the superior mechanical properties of abaca fibers, attributed to their higher cellulose content and better fiber-matrix adhesion after alkaline treatment. Coconut composites followed, with a maximum tensile strength of 14.32 MPa and Young's modulus of 9431 MPa at one-gram fiber loading with 2% NaOH treatment. Raffia composites exhibited the lowest values, with a maximum tensile strength of 9.93 MPa and Young's modulus of 9268 MPa at one-gram fiber loading and 3% NaOH treatment.

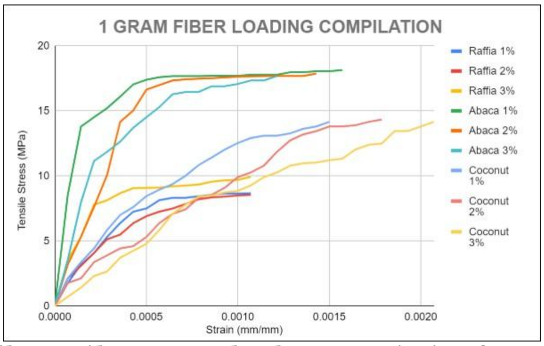

Figure 11: Overall Tensile Strength Characteristics for One Gram Loading

Journal of Information Systems Engineering and Management
2025, 10(43s)
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Table 7. Overall Tensile Strength Characteristics for Two Gram Loading

COMPILATION OF DATA FOR 2 GRAM INDIGENOUS FIBER-REINFORCED EPOXY COMPOSITES

Indigenous Fiber	Alkaline Treatment	Maximum Tensile Strength (MPa)	Maximum Elongation (mm/mm)	Young's Modulus
Raffia	1%	5.470951169	0.165	2321.150263
Raffia	2%	8.156690833	0.165	3460.624028
Raffia	3%	8.919308269	0.15	4200.872067
Abaca	1%	10.36496567	0.165	4397.524679
Abaca	2%	10.04002433	0.11	6390.849349
Abaca	3%	10.36496567	0.165	4397.524679
Coconut	1%	9.880869384	0.15	4610.764995
Coconut	2%	9.900763752	0.15	4620.048414
Coconut	3%	9.748240264	0.155	4402.999216

In abaca, increasing fiber loading to 2 grams reduced the tensile strength to 9.88 MPa and Young's modulus to 6587 MPa, indicating that excessive fiber content disrupted stress distribution. Coconut fiber at two-gram fiber loading, the tensile strength dropped to 9.75 MPa, and Young's modulus decreased to 4,456 MPa, suggesting that increased fiber content led to agglomeration, reducing matrix uniformity and overall mechanical performance. Raffia's reduction in tensile strength to 8.92 MPa and Young's modulus to 4,200 MPa at two-gram fiber loading indicates that raffia fibers are less effective at maintaining structural integrity under higher fiber content.

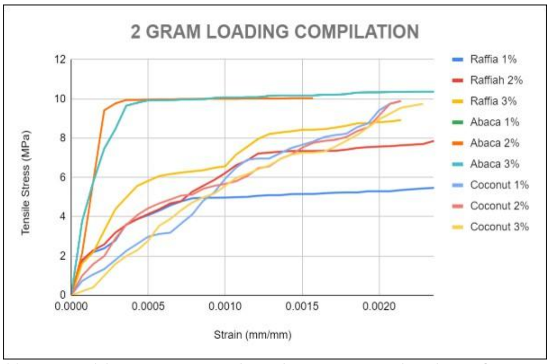

Figure 12: Overall Tensile Strength Characteristics for Two Gram Loading

G. Conductive Heat Flow Characteristics of Raffia Fiber-Based Epoxy Composites

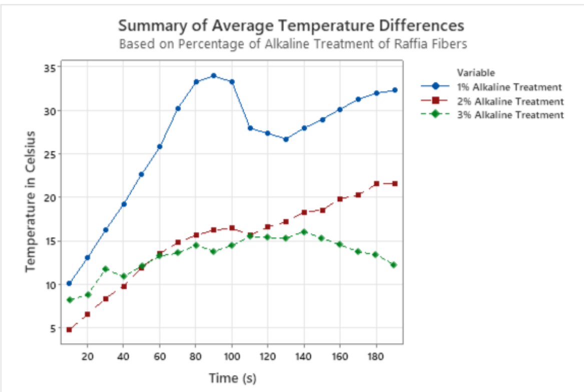

Figure 13: Conductive Heat Flow Characteristics of Raffia Fiber-Based Epoxy Composites

The results for conductive heat flow characteristics of raffia fiber-based epoxy composites indicate that the heat conductivity improved with higher concentrations of alkaline treatment. This trend demonstrates the material's increasing capability to dissipate heat with enhanced fiber-matrix bonding due to the removal of lignin and other impurities, which typically inhibit heat flow. Notably, composites treated with 3% NaOH displayed the highest

Journal of Information Systems Engineering and Management
2025, 10(43s)
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https://www.jisem-journal.com/ **Research Article**

thermal conductivity, attributed to the improved crystalline alignment of cellulose fibers, which promotes effective heat transfer pathways. In contrast, higher fiber loading slightly diminished thermal conductivity, emphasizing the need for a balanced approach. Excessive fiber content can introduce structural inconsistencies, such as voids or uneven distribution, which impede the uniform heat flow across the material. Sahu and Gupta (2020) highlighted that alkaline treatments enhance fiber-matrix bonding by removing impurities such as lignin and hemicellulose, which aligns with the observed improvement in thermal conductivity at higher NaOH concentrations in this study [2].

H. Conductive Heat Flow Characteristics of Abaca Fiber-Based Epoxy Composites

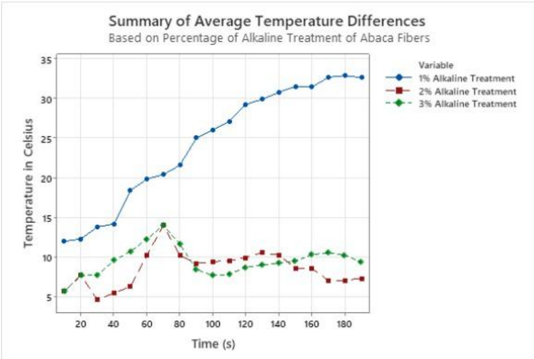

Figure 14: Conductive Heat Flow Characteristics of Abaca Fiber-Based Epoxy Composites

The data presented highlights the conductive heat flow characteristics of abaca fiber-based epoxy composites under varying alkaline treatment concentrations and fiber loadings. The results reveal that higher NaOH concentrations, specifically 3%, lead to improved thermal conductivity due to the enhanced fiber-matrix bonding resulting from the removal of lignin and impurities. The optimal performance was observed at one-gram fiber loading, where the uniform distribution of fibers within the matrix promoted efficient heat transfer pathways. Conversely, increasing the fiber loading to two grams slightly reduced thermal conductivity, likely due to agglomeration and reduced matrix integrity.

I. Conductive Heat Flow Characteristics of Coconut Fiber-Based Epoxy Composites

The findings presented for coconut fiber-based epoxy composites show similar trends to those observed in the raffia and abaca fiber-based composites regarding the effects of NaOH concentration and fiber loading on thermal conductivity. The thermal conductivity of the coconut fiber composites improved with increasing NaOH concentration, with the highest values observed at 3% NaOH treatment. This enhancement can be attributed to the improved fiber-matrix adhesion achieved by removing impurities like lignin and hemicellulose, which facilitate better alignment of the fibers and more efficient heat transfer [9]. The optimal performance was recorded at one-gram fiber loading, where the composite structure was uniform, and the heat pathways were well-distributed. However, when the fiber loading increased to two grams, a slight decrease in thermal conductivity was observed, similar to the trends seen in the raffia and abaca composites. This reduction suggests that excessive fiber content may disrupt the uniformity of the matrix, forming voids or agglomerations that hinder heat flow.

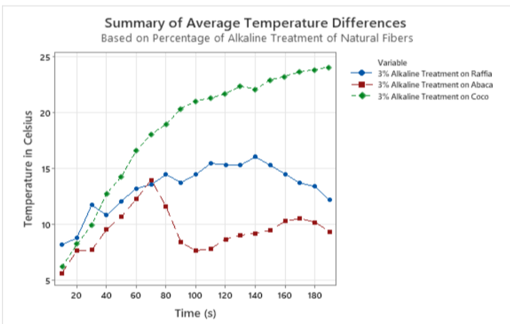

Figure 15: Conductive Heat Flow Characteristics of Coconut Fiber-Based Epoxy Composites

Journal of Information Systems Engineering and Management
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J. Overall Conductive Heat Flow Characteristics of Indigenous Fibers

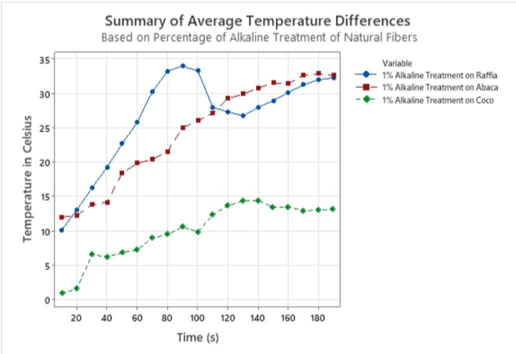

Figure 16. Overall Conductive Heat Flow Characteristics of Indigenous Fibers at 1% Alkaline Treatment

The overall results reveal that the thermal conductivity of all three composites improved with increasing NaOH concentration. For each fiber type, composites treated with 3% NaOH exhibited the highest thermal conductivity, indicating that the alkali treatment significantly enhances heat transfer properties. This improvement is due to the removal of impurities like lignin and hemicellulose, which improves fiber-matrix adhesion and facilitates the formation of a more uniform heat transfer network. At one-gram fiber loading, the thermal conductivity for raffia, abaca, and coconut composites treated with 3% NaOH was at its highest. For example, raffia composites treated with 3% NaOH showed the highest conductivity, which was significantly higher than that observed in composites with two-gram fiber loading. The decrease in conductivity at higher fiber loadings can be attributed to the potential formation of fiber agglomerates and the reduction of matrix continuity, which disrupts efficient heat flow. The study by Dev et al. (2023), "Recent progress in thermal and acoustic properties of natural fiber-reinforced polymer composites," also supports these results by observing that excessive fiber content tends to reduce thermal conductivity, as fiber agglomeration and poor matrix encapsulation lead to a decrease in heat transfer efficiency [3]. This mirrors the slight reduction in conductivity observed in the present study when the fiber loading was increased to two grams.

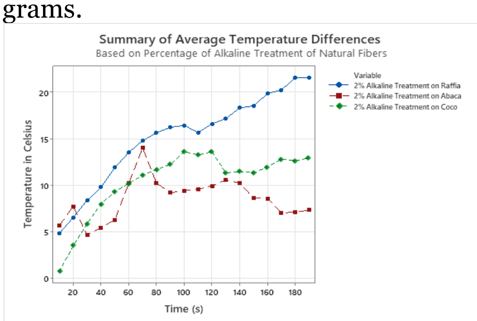

Figure 17: Overall Conductive Heat Flow Characteristics of Indigenous Fibers at 2% Alkaline Treatment

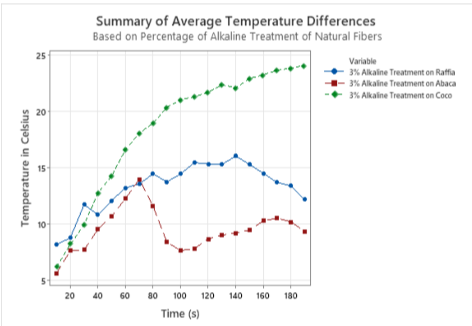

Figure 18: Overall Conductive Heat Flow Characteristics of Indigenous Fibers at 3% Alkaline Treatment

4. CONCLUSION

Indigenous fibers are hydrophilic in nature, and their poor adhesion with hydrophobic polymer matrix is one of the major issues [8]. On research by Karthi et al., it is found, for the natural fibers, that the most suitable method of chemical modification is the alkaline treatment [10]. The alkaline treatment significantly improved the interfacial bonding between the fibers and epoxy matrix. This improvement was evident in the enhanced tensile strength and Young's modulus observed for all three fiber types. Higher concentrations of NaOH (3%) provided the best results, optimizing fiber-matrix adhesion by removing impurities and increasing surface roughness, which enhanced load transfer. Chemically treated indigenous fiber composites displayed higher tensile strengths compared to untreated fibers, highlighting the importance of alkaline treatment [7].

In terms of fiber type impact, Abaca fibers showed the highest mechanical strength and stiffness, with a peak tensile strength of 18.13 MPa and Young's modulus of 14,556 MPa under one-gram fiber loading with 3% NaOH treatment. The role of chemical treatments enhanced both the mechanical and thermal properties of indigenous fiber composites [6]. This makes abaca an ideal choice for structural and load-bearing applications. Coconut fibers followed, with moderate strength and stiffness, showing good potential for applications requiring compressive strength but not high flexibility. Raffia fibers, while exhibiting lower tensile strength (9.93 MPa) and stiffness (9268 MPa), displayed significant flexibility, making them suitable for applications where lightweight and flexibility are paramount. Mahjoub et al. verified a decrease in the tensile strength for higher values of NaOH solution concentration [11].

Thermal conductivity improved with increasing NaOH concentrations across all fiber types, aligning with findings in the literature that alkaline treatment enhances the matrix's thermal properties. There is a positive relationship between the thermal conductivity and density indigenous fibers [4], and there is an achieved enhanced stiffness in indigenous fiber composites after chemical treatment [5]. However, higher fiber loading led to a decrease in thermal conductivity due to structural inconsistencies and void formation, which hindered the effective transfer of heat. The decline in conductivity with higher fiber loading echoes Kumar et al.'s findings, where excessive fiber content disrupted homogeneity, impairing heat transfer efficiency [6]. Furthermore, excessive fiber content compromises stiffness due to agglomeration and irregular stress distribution. The combination of one-gram fiber loading and 3% NaOH treatment provided the best overall mechanical and thermal properties for all fiber types. This combination offered the optimal balance between tensile strength, Young's modulus, and thermal conductivity, making it the most suitable for composite applications.

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