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The Effect of Partial Replacement of Fiber Glass in Epoxy Composite by Using Dates Palm Fiber for Mechanical Properties

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ABSTRACT

In the field of hybrid composites, the combination of date palm fiber(natural fiber) with fiberglass (synthetic fiber) provides an alternative approach that emphasises on the advantages of both materials to create a composite with unique properties and applications. In this experimental study, hybrid composites were fabricated using different mixing ratio of the epoxy, fiberglass and date palm fiber. Every sample have different mixing ratio of glass fiber and date palm fiber but same epoxy with weight fraction 70% of matrix ratio while 30% balanced consist of glass fiber and dates palm fiber. The study evaluates the impact of this substitution on the overall performance of the hybrid epoxy composites, including aspects like tensile strength, flexural, impact test and morphological structure. For the tensile strength, sample A1(26% Glass Fiber, 4% Dates Palm Fiber) obtained the highest value 87.7MPa. Sample A4(30% Glass Fiber) is the highest value of flexural strength with 218.0MPa while Sample A2 with 101.4KJ/m2 for highest value of the impact test. Then, different structures such as fiber breakage, delamination and debonding are also observed by using Scaning Electron Microscope (SEM). However, the results offer valuable guidance for optimizing the mechanical performance of these composites in various applications It delves into the potential advantages and limitations of using date palm fiber as an alternative to conventional fiber glass in composite materials, aiming to assess the feasibility and efficiency of this substitution in various applications.

Keywords: Hybrid composites; date palm fiber; fiber glass; epoxy matrix; mechanical properties; tensile strength, flexural strength; morphological analysis

INTRODUCTION

The use of glass fiber in manufacturing has seen a notable increase in Malaysia. Glass Fiber Reinforced Polymer (GFRP) composites have been utilized in crossarm manufacturing, demonstrating their effectiveness in 275 kV lines over several decades (Rahman et al. 2021). Pultruded glass fiber-reinforced polymer composite (PGFRPC) cross-arms have also been installed in Malaysia as part of a pilot project (Amir et al. 2021). Epoxy glass-reinforced composites are particularly favored in Malaysian industries such as construction, aviation and maritime due to their favorable mechanical properties, light weight, resistance to atmospheric conditions and affordability (Matykiewicz 2020). The utilization of natural fibers in conjunction with glass fibers for boat structures has also gained traction driven by the cost-effectiveness of natural fibers (Suriani et al. 2021). Furthermore, glass fiber composites have found applications in diverse fields including dentistry, wind energy and the wood industry in Malaysia (Purnama et al. 2022; Romani et al. 2020; Guo et al. 2016). In the automotive sector, glass fiber composites are employed in the production of items like field hockey sticks and automobile bumpers (Khalid et al. 2021; Batista et al. 2019). The enhancement of mechanical properties in hybrid composites has been achieved through the combination of glass fiber with jute, carbon, and other natural fibers (Sezgin & Berkalp, 2016; Shadhin et al. 2021; Olszewski et al. 2021). The mechanical properties of glass fiber composites, including impact resistance, tensile strength, bending properties and interlaminar shear properties have been the subject of extensive research (Amir et al. 2021; Suriani et al. 2021; Sezgin & Berkalp, 2016; Ren, 2023; Batista et al. 2019).

The manufacturing process generates waste including materials processed from raw ingredients. Date fruit processing for instance, yields by-products like cull dates, date stones and sugar-extracted date pulp (Attia et al. 2021). These by-products are rich in fiber, making dates a high-fiber-yielding fruit. Additionally, date palm trees generate waste such as leaflets, rachis, fruit pruning, and trunks which have an energy potential of 87 thousand tonnes per annum (Kumar et al. 2019). Date palm fiber a natural fiber derived from the date palm tree (Phoenix dactylifera L.), is attracting interest for use in various manufacturing processes due to its unique properties and potential applications. Date palm fiber has been utilized as a reinforcement material in composite materials, including biopolymer composites (Gokulkumar et al. 2023), epoxy composites (Fiore et al. 2016) and cement composites (Labib, 2022). Combining date palm fibers with different polymers can enhance the properties of the resulting composites (Gokulkumar et al. 2023). Chemical treatments like NaOH and silane are used to improve the surface characteristics of date palm fibers and address their hygroscopic tendencies (Gokulkumar et al. 2023). The mechanical properties of date palm fibers have been studied with research indicating that tensile strength can be improved through chemical treatments like NaOH treatment (Bourmaud et al. 2017). However, increasing NaOH concentration can negatively affect tensile properties (Fiore et al. 2016). The bending resistance of composite materials is influenced by the length and volume fraction of date palm fibers (Labib, 2022). Surface modification techniques such as removing cellulose, lignin, wax and oil content can enhance the mechanical interlocking of date palm fibers by increasing their surface roughness (Zalinawati et al. 2020). Furthermore, research on hybrid composites with natural additives including date palm fibers, has shown increased compression strength when incorporated into epoxy (Chlob & Fenjan 2022). The potential of using date palm fibers in hybrid composite plates for ballistic protection has also been explored with the expectation of improved ballistic properties and economic and environmental benefits (Alkhatib et al. 2021). The incorporation of natural fibers like date palm fibers in composite materials has been demonstrated to enhance the mechanical and thermal properties of the resulting hybrid composites (Jawaid et al. 2021; Boubaaya et al. 2023).

METHODOLOGY

RAW MATERIALS

The research is structured to first discuss the preparation of raw materials and the matrix used. Subsequently, it details the process of combining epoxy and fibreglass in product creation, followed by the testing and characterization techniques utilized for the final products. A procedural flowchart, presented in Figure 1, was developed to guide the analysis of the partial replacement of glass fibre by date palm fibre on the mechanical properties of hybrid epoxy composites.

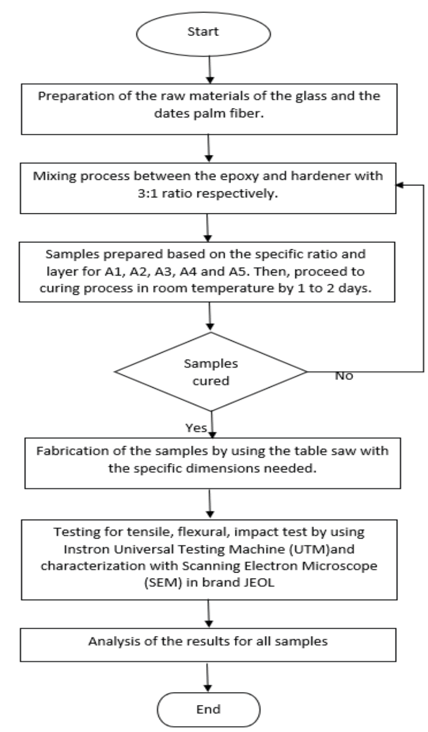

FIGURE 1. The simple flowchart for the procedure during this study

The raw components used in this study include date palm fiber, fiberglass, and epoxy hardener. Each component serves a distinct purpose. For instance, epoxy resin functions as the matrix material, surrounding and binding the reinforcement material (fibers or particles). Epoxy resin was chosen for its high strength-to-weight ratio, corrosion resistance, and durability.

Date palm fiber was used as reinforcement in Polymer Composites. The fibers were incorporated into polymer matrices, such as epoxy, to reinforce the composite materials.

TYPES OF SAMPLES

The preparation of samples for hand lay-up fabrication involved preparing the reinforcement materials (fiberglass and date palm fiber), matrix materials (epoxy and hardener), and mold material. A metal mold and mold release agent were used to facilitate the removal of the hybrid composite.

Five types of samples (A1, A2, A3, A4, and A5) were prepared with varying mixing ratios of epoxy, fiberglass, and date palm fiber, maintaining a constant 70% weight fraction of epoxy. Table 1 shows the weight fraction of the samples. In this study, the weight ratio was set at 70% epoxy and 30% combined natural (date palm fiber) and synthetic fiber (glass fiber). The example of the calculation of the weight ratio when a final composite piece weighing 100grams. The total fiber content is consistently 30%, the total mass of all fibers required would be 30 grams, with the remaining 70 grams allocated for the resin matrix. The specific weight ratios for the samples is the individual fiber weights are calculated from the total composite weight. Then, to obtain a 21% glass fiber ratio, it would need to measure out 21 grams of glass fiber. Similarly, to achieve the 9% date palm fiber ratio, 9 grams of that fiber is required. By combining these precisely measured amounts 21g of glass fiber, 9g of date palm fiber and 70g of resin and the final 100g sample will accurately reflect the desired material constitution. Lastly, a sandwich configuration was employed for the composite samples.

The epoxy and hardener were stirred using a flat stick to create a homogeneous mixture as shown in Figure 2. This process is important to prevent bubbles, which can affect tensile and flexural testing results. The metal mold was prepared by lining it with clear tape and applying a release mold agent with a brush. The epoxy and hardener mixture then applied and the fiberglass and date palm fiber were stacked according to the layers and weight ratios in Table 1. The hybrid composite was left to cure for 2 days at room temperature. Figure 3 shows sample A4 (70% Epoxy and 30% Fiber glass) after curing and A5 (100% pure epoxy) after mixing, while Figure 4 shows samples A1, A2, and A3 after curing.

FIGURE 2. Homogeneous mixture of epoxy and hardener

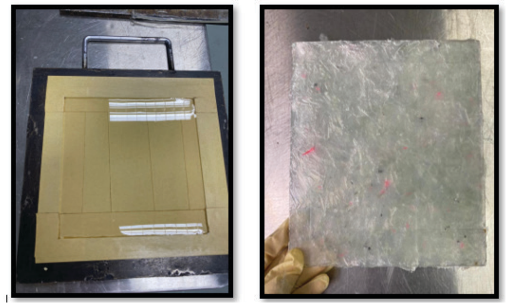

FIGURE 3. Sample A4 in right (after curing process) and A5 in left (after the mixing process)

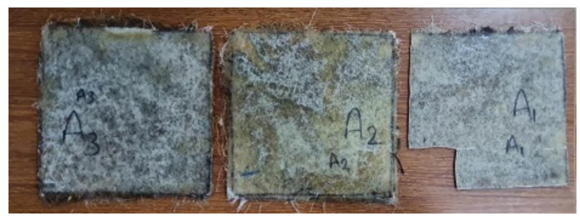

FIGURE 4. Sample A2, A3 and A4 after curing process

The cured samples were cut using a Proxxon table saw, shown in Figure 5, according to the standard dimensions required for mechanical testing. The drawing in Figure 6 shows the specimens with dimensions of 12.7 mm wide, 127 mm long, and 4 mm thickness.

FIGURE 5. Proxxon table saw

FIGURE 6. Drawing of the specimen

TESTING AND CHARACTERIZATION

The mechanical properties of the hybrid composites were evaluated using tensile, flexural, and impact tests, following the American Society for Testing & Material (ASTM) standards. Each test was repeated three times with new specimens. The morphological surface of the samples was examined using Scanning Electron Microscopy (SEM).

Tensile tests were conducted according to ASTM D3039 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials. The specimens with dimensions of 12.7 mm wide, 127 mm long, and 4 mm thickness were tested using the Instron Universal Testing Machine (UTM) as shown in Figure 7. The specimens were placed in the UTM grips, ensuring more than half of the grip length was in contact. Specimen measurements and test speed (2-5 mm/min) were entered before testing. Maximum load, tensile stress, and tensile strain were recorded.

FIGURE 7. The Instron Universal Testing Machine (UTM) used in the experiment.

Flexural tests, also known as 3-point bending tests, were performed according to ASTM D790-17 Standard Test Method for Unreinforced and Reinforced Plastics and Electrical Insulating Materials. The specimens with dimensions of 127 mm length, 12.7 mm width, and 4 mm thickness were used, with a support span to depth ratio of 80mm. The tests were conducted by using the Instron Universal Testing Machine (UTM) as shown in Figure 8. The specimen was placed on two supporting pins and the loading pin was positioned at the midpoint. Specimen measurements and test speed (2-5 mm/min) were input into the computer. The maximum load, flexural stress and flexural strain were recorded.

FIGURE 8. The flexural testing by pin Instron Universal Testing Machine (UTM)

Impact tests were performed using the pendulum impact Charpy tester as shown in Figure 9, following ASTM D7136 Standard Test Method for Measuring the Damage Resistance of a Fiber-Reinforced Polymer-Matrix Composite to a Drop-Weight Impact Event. Specimens were attached to an aluminum pendulum, and the impact strength was measured using a Digital Charpy Izod impact tester (Jinan Hensgrand Instrument Co., Ltd). Flexural strength and elastic modulus were also calculated using a universal testing machine with a crosshead speed of 5 mm/min and a load of 50 kilogram-force.

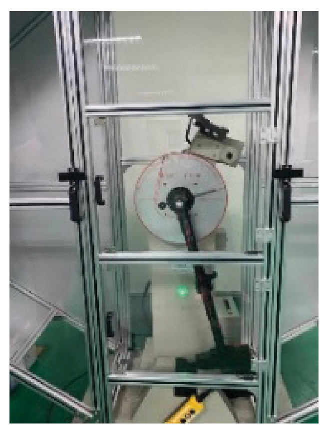

FIGURE 9. The Impact Testing by the pendulum impact Charpy tester.

The morphology of the composite surface was examined using Scanning Electron Microscopy (SEM) as shown in Figure 10 to assess the bonding adhesion between the matrix and fibers. Samples were coated with a thin conductive layer of carbon onto a non-conductive sample. to enhance conductivity and mounted on a sample holder, as shown in Figures 11. The SEM parameters were sets and the electron beam was used to visualize the sample surface at low magnification (50x to 80x) and higher magnification (500x to 700x).

FIGURE 10. The Scanning Electron Microscope (SEM)

FIGURE 11. The samples coated with a thin conductive layer of the carbon.

TABLE 1. The layers and weight for all samples

Sample name	Materials	Number of layers	Weight ratio (%)
A1	Glass fiber	4	26
	Date palm fiber	1	4
A2	Glass fiber	4	21
	Date palm fiber	2	9
A3	Glass fiber	4	17
	Date palm fiber	4	13
A4	Glass fiber	1	30
	Date palm fiber	0	0
A5	Glass fiber	0	0
	Date palm fiber	0	0

RESULT DAN DISCUSSION

TENSILE TESTING

Tensile tests measure a material's hardness, elastic modulus, and ultimate tensile strength (Oliver & Pharr, 1992; Setiyana et al. 2018; Xu et al. 2023). The test involves applying a uniaxial force to the material until it fractures (Xu et al. 2023). Tensile stress and strain are measured to assess the material's response to the applied force. Tensile stress and tensile strain (extension) at maximum load are obtained from the tensile test. The average tensile stress at maximum load with the standard deviation for all ratios are discussed.

The tensile strength of the composite samples, each with distinct epoxy, glass fiber, and date palm fiber ratios, demonstrates a clear performance hierarchy in bar graph as shown in Figure 12. Sample A1 (70% epoxy, 26% glass fiber, 4% date palm fiber) exhibits the highest tensile strength (87.70 MPa) due to a synergistic fiber-matrix interaction. A reduction to 74.60 MPa insample A2 (70% epoxy, 21% glass fiber, 9% date palm fiber) implies that increased date palm fiber content may diminish composite stiffness.

Sample A4 (70% epoxy, 30% glass fiber) yields a tensile strength of 40.11 MPa, lower than A1 and A2, indicating that the hybrid fiber composition is more effective for tensile strength. Pure epoxy (sample A5) shows a moderate tensile strength of 51.12 MPa, confirming the necessity of fiber reinforcement. The lowest tensile strength (14.20 MPa) is observed in sample A3 (70% epoxy, 17% glass fiber, 13% date palm fiber), potentially due to compromised fiber-matrix adhesion or inherent date palm fiber limitations.

Furthermore, surface irregularities in samples A1, A2, and A3, possibly from fiber migration during fabrication, might have affected clamping and stress distribution during testing. Overall, optimizing the glass fiber to date palm fiber ratio is crucial for maximizing tensile strength in these composites.

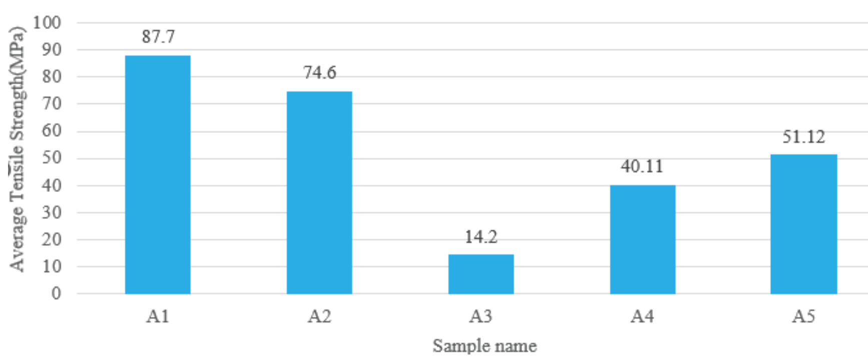

FIGURE 12. Comparison all samples for the Average Tensile Strength

FLEXURAL TEST

The aim of the flexural testing in this experiment is to evaluate the bending strength and flexibility of the composite materials. Specifically, the flexural test is used to understand how the composite materials behave under bending or flexural loads, which is important for applications where the material will experience bending forces.

Figure 13 presents bar graph of the average maximum flexural stress of five composite samples with varying compositions. Sample A5 (100% epoxy) exhibits the highest flexural stress (218.04 MPa), attributable to the inherent stiffness of the epoxy matrix. A1 (70% epoxy, 26% glass fiber, 4% date palm fiber) demonstrates the second-highest flexural stress (148.63 MPa), indicating that a high glass fiber content, combined with a small amount of date palm fiber, maintains substantial stiffness.

Sample A2 (70% epoxy, 21% glass fiber, 9% date palm fiber) shows a reduction in flexural stress to 98.87 MPa. This decrease suggests that increasing the date palm fiber content, which has lower stiffness than glass fiber, reduces the composite's resistance to bending. Sample A4 (70% epoxy, 30% glass fiber) has a flexural stress of 58.82 MPa. The absence of date palm fiber results in a higher flexural stress than A3, but lower than A1 and A5.

Sample A3 (70% epoxy, 17% glass fiber, 13% date palm fiber) exhibits the lowest flexural stress (48.15 MPa) among the fiber-reinforced samples. This indicates that a high proportion of date palm fiber significantly diminishes the composite's bending strength.

In summary, flexural stress is primarily influenced by glass fiber content. Higher glass fiber content enhances rigidity and bending resistance, while increased date palm fiber content reduces flexural stress. Pure epoxy demonstrates the highest flexural stress. The optimal balance of these components is crucial in achieving desired flexural properties in composite materials.

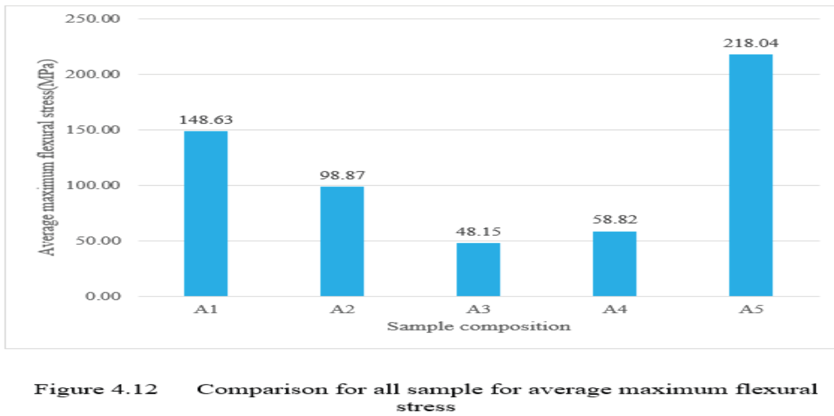

FIGURE 13. Comparison all sample for average maximum flexural stress

IMPACT TEST

The impact test results, detailed in Table 3 and illustrated in Figure 14, compare the average impact strength of various composite formulations. The samples, designated A1 through A5, comprise differing ratios of epoxy, glass fiber, and date palm fiber. The impact strength, measured in kilojoules per square meter (kJ/m²), indicates the material's ability to absorb energy during a sudden force or impact.

The samples are ranked in order of decreasing impact strength: A2 (101.4 kJ/m²), A1 (67.8 kJ/m²), A4 (55.2 kJ/m²), A5 (35.8 kJ/m²), and A3 (31.3 kJ/m²). This ranking highlights the significant effect of composite composition on impact performance. Notably, sample A2, with 70% epoxy, 21% glass fiber, and 9% date palm fiber, exhibits the highest impact strength. This suggests that a balanced combination of glass and date palm fibers within the epoxy matrix optimizes energy absorption.

The presence of date palm fiber appears to influence impact strength. Composites A1 and A2, both containing date palm fiber, demonstrate higher impact strengths than A4, which contains only glass fiber. This suggests that date palm fibers contribute

to energy dissipation during impact. However, an excessive date palm fiber content, as seen in A3 (70% epoxy, 17% glass fiber, 13% date palm fiber), leads to a reduction in impact strength. Furthermore, the pure epoxy composite, A5, exhibits the lowest impact strength, underscoring the importance of fiber reinforcement for enhancing this property.

These findings are consistent with existing research. Fitri & Mahzan (2020) established the influence of fiber content and length on impact strength, while Hernández-Díaz et al. (2020) demonstrated that coupling agents can enhance impact strength by improving fiber-matrix interaction.

The ratio of epoxy, glass fiber, and date palm fiber significantly affects a composite's ability to withstand impact. Using A4 (70% epoxy, 30% glass fiber) as a reference, the percentage differences in impact strength were calculated as shown in Table 3. Sample A2 shows the greatest improvement in impact strength (+83.70%), followed by A1 (+22.83%). In contrast, A3 and A5 exhibit lower impact strengths than A4 (-43.30% and -35.14%, respectively). This reinforces the conclusion that a specific proportion of date palm fiber can enhance impact strength, while excessive date palm fiber or the absence of fiber reinforcement reduces impact resistance.

TABLE 3. The differences of the other sample with Sample A4(references).

Sample name	Average impact of strength (KJ/m2)	Differences with Sample A4 (as references sample)
A1	67.85	+22.83%
A2	101.44	+83.70%
A3	31.27	-43.30%
A4	55.23	0.00% (reference point)
A5	35.83	-35.14%

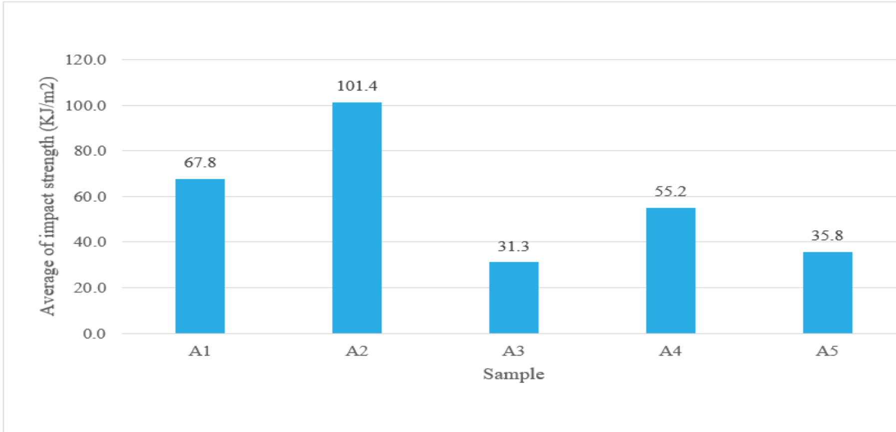

FIGURE 14. The average impact strength (KJ/m2) of the sample

RELATIONSHIP BETWEEN FLEXURAL STRESS, TENSILE STRESS AND IMPACT STRESS

The average tensile strength, flexural stress, and impact strength for five different composite samples with varying compositions of epoxy, glass fiber, and date palm fiber have been analyzed. The analysis of the relationship between these mechanical properties across the samples A1, A2, A3, A4, and A5 for the tensile strength is with A1 and A2 have the highest tensile strength, suggesting that a certain ratio of glass fiber to date palm fiber within an epoxy matrix yields a composite with good tensile properties. As the percentage of date palm fiber increases (A3) and glass fiber content decreases, there is a notable drop in tensile strength. Based on Alarifi (2020) presents the investigation into the morphological and mechanical properties of date palm fiber-reinforced epoxy structural composites. The study reports the maximum tensile strength of 3.45MPa for the composites, providing valuable information on the tensile strength of epoxy-based composites reinforced with date palm fibers. Next, the sample of A4, which has a higher percentage of glass fiber and no date palm fiber, does not perform as well as A1 and A2, indicating that a synergy between the glass and date palm fibers may contribute positively to tensile strength. Lastly, A5, which is 100% epoxy, has the lowest tensile strength, highlighting the critical role of fibers in reinforcing the matrix.

For the Flexural Stress, it started with A5 shows the highest flexural stress, indicating that the composite's ability to resist bending improves with zero amount of glass fiber dan date palm fiber content. Then, A1 has the second-highest flexural stress, again supporting the idea that a mix of glass and date palm fibers provides good reinforcement. After that, A2, A4, and A3 show progressively lower flexural stress, suggesting that increasing the glass fiber and date palm fiber content decreases the composite's rigidity and its ability to withstand bending forces. In this situation can related with Kazi et al. (2021) characterizes interwoven roselle/sisal fiber-reinforced epoxy composites and reports flexural strength values for different composite compositions. This study provides specific flexural strength values for different composite compositions, which are essential for understanding the flexural stress of the composite materials.

For the Impact Strength, the sample A2 has the highest impact strength, significantly more than the other samples, which implies that the specific ratio of glass to date palm fiber in A2 offers the best resistance to sudden impacts. Next, sample A1 also has good impact strength, although less than A2, reinforcing the benefit of a hybrid fiber composition. While the samples of A3, A4, and A5 show a decrease in impact strength, with A5 having the lowest. This suggests that either a high content of date palm fibers (A3) or a lack of reinforcement (A5) diminishes the material's ability to absorb energy during impact.

In this experiment the Tensile Strength and Fiber Content can be related when a mix of glass and date palm fibers in the right proportions seems to provide a composite with higher tensile strength than composites with high glass fiber content alone or no fiber reinforcement. In addition, the Flexural Stress and Glass Fiber Content also observed when the higher glass fiber content within the composite correlates with higher flexural stress, indicating that glass fibers contribute significantly to the composite's rigidity and bending resistance.

Lastly, the Impact Strength and Hybrid Fiber Synergy can be related due to the impact strength is highest for a composite with a balanced mix of glass and date palm fibers, suggesting that this hybrid mix is optimal for energy absorption during impacts. The data indicates that no single composition is superior in all aspects of mechanical performance. Instead, each composition offers a trade-off between tensile strength, flexural stress, and impact strength. The choice of composite would depend on the specific application and the mechanical properties that are most critical for performance in that context.

SCANNING ELECTRON MICROSCOPY (SEM) TEST

THE MAGNIFICATION OF 50X TO 80X

Scanning electron microscopy (SEM) is a pivotal technique for characterizing the microstructural morphology of composite materials. In this study, SEM was employed to investigate the surface topography, microstructure, and nanoscale features of the produced hybrid composites, providing insights into the interfacial bonding between the matrix and the reinforcing fibers. The analysis was conducted using a JEOL scanning electron microscope.

Figures 15 through 10 present SEM micrographs of the hybrid composite samples at relatively low magnification (50x to 80x). These images provide an overview of the surface texture and general fiber distribution within the composite materials.

Sample A1 (70% Epoxy, 26% Glass Fiber, 4% Date Palm Fiber) in Figure 6 reveals a relatively uniform and smooth surface texture, with the glass fibers appearing to be well-embedded within the epoxy matrix. Minimal porosity is observed and the fiber distribution is consistent prove that is effective interfacial bonding between the fibers and the matrix. This morphology implies a well-integrated composite structure which is often associated with enhanced mechanical properties.

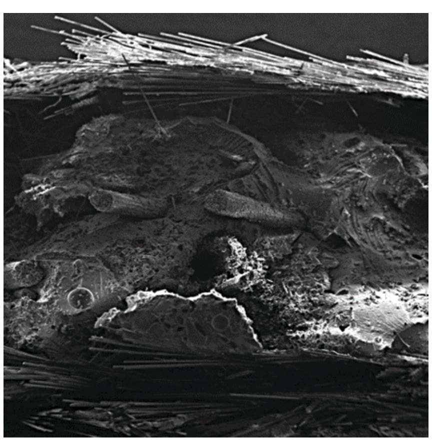

FIGURE 15. Captured by SEM in range of 50x to 80x for sample A1

Sample A2 (70% Epoxy, 21% Glass Fiber, 9% Date Palm Fiber) shows the surface texture in Figure 16 exhibits slightly increased roughness compared to Sample A1. This can be attributed to the higher content of date palm fiber, which possesses a naturally rougher surface. While the fiber distribution remains relatively uniform, a slight increase in porosity is observed. This increased porosity could potentially influence the mechanical performance of the composite particularly its resistance to crack propagation.

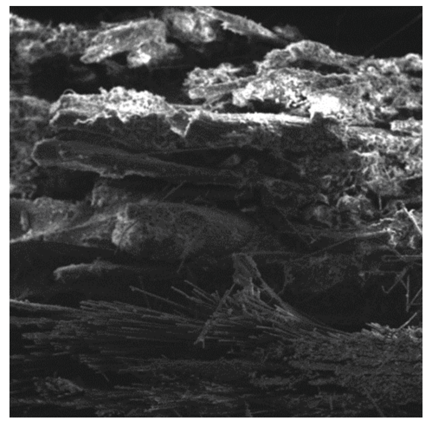

FIGURE 16. Captured by SEM in range of 50x to 80x for sample A2

Sample A3 with 70% Epoxy, 17% Glass Fiber, 13% Date Palm Fiber) in Figure 17 with the highest date palm fiber content, displays the roughest surface texture among the samples analyzed. The fibers appear to be less uniformly distributed with some regions exhibiting a higher concentration of fibers. This non-uniformity in fiber distribution may indicate some degree of fiber agglomeration or phase separation, which could lead to localized stress concentrations and potentially compromise the mechanical integrity of the composite. The increased roughness observed in this sample is consistent with the findings of previous research, which has documented the rougher surface characteristics of date palm fibers compared to synthetic fibers.

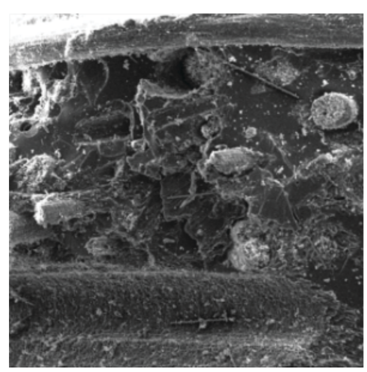

FIGURE 17. Captured by SEM in range of 50x to 80x for sample A3

Sample A4 (70% Epoxy, 30% Glass Fiber): in Figure 18 reveals a high degree of glass fiber reinforcement with numerous fibers protruding from the epoxy matrix. While the fibers appear to be well-embedded, some evidence of fiber pull-out is visible, prove that the interfacial bonding between the fibers and the matrix may not be optimal in all regions. The surface exhibits a degree of roughness due to the presence of the fibers, and some small voids and imperfections are observed.

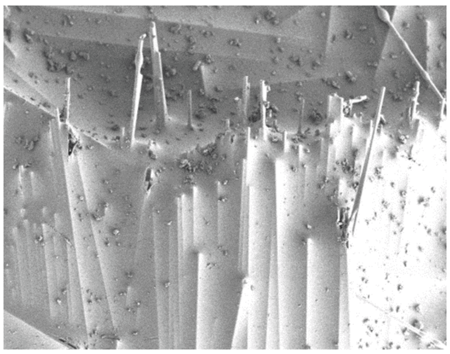

FIGURE 18. Captured by SEM in range of 50x to 80x for sample A4

Sample A5 is 100% Epoxy is contrast to the fiber-reinforced samples, Sample A5 in Figure 19, consisting of pure epoxy, exhibits a significantly smoother surface texture. However, flow lines and slight variations in material density or composition are visible, indicating that the matrix is not perfectly uniform. Minor surface imperfections are also present, but overall, the sample displays a good surface finish with minimal porosity at this magnification.

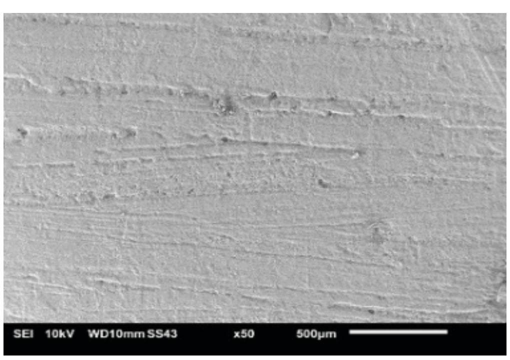

FIGURE 19. Captured by SEM in range of 50x to 80x for sample A

THE MAGNIFICATION OF 500X TO 700X

The SEM micrographs at higher magnification (500x to 700x), presented in Figures 20 through 25, provide a more detailed examination of the microstructural features of the composite samples. In Figure 11 illustrates the microstructure of Sample A1 at 500x-700x magnification. At this level, the glass fibers are clearly discernible as the primary reinforcing phase within the composite. The fibers exhibit smooth surfaces and are observed to be closely packed with a high degree of alignment. This arrangement shows a structured composite, which likely contributes to its enhanced tensile properties.

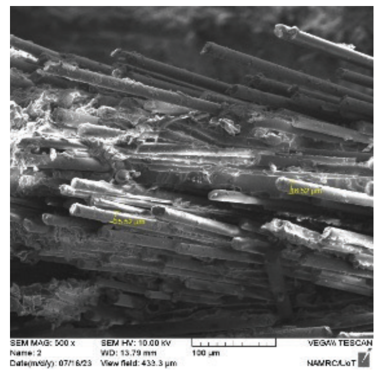

FIGURE 20. Captured by SEM in range of 500x to 700x for sample A1

The microstructure of Sample A2, as shown in Figure 19, differs from that of Sample A1. The increased date palm fiber content in A2 introduces a more varied and rougher texture. The date palm fibers, in contrast to the smooth glass fibers, exhibit a more irregular surface and shape. This difference in surface morphology can influence the mechanical interlocking between the fibers and the matrix. Compared to Sample A1, A2 exhibits noticeable porosity and potential voids. These voids may arise from the inherent variability in the natural date palm fibers or from challenges encountered in achieving uniform dispersion and adhesion within the epoxy matrix. The matrix itself appears less smooth and more disrupted, which may be attributed to the presence of the rougher date palm fibers. The presence of these voids and the less homogenous matrix structure may contribute to a reduction in mechanical performance, particularly in comparison to Sample A1.

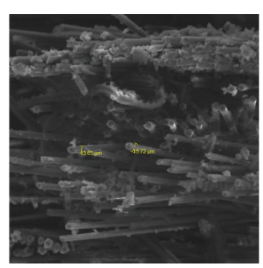

FIGURE 21. Captured by SEM in range of 500x to 700x for sample A2

Based on Figure 22, present the SEM image of Sample A3, which has the highest date palm fiber content among the samples. The matrix texture in this sample appears quite rough, likely due to the dominant presence of the date palm fibers. The micrograph reveals the presence of voids and gaps, which are more pronounced than in Samples A1 and A2. These voids may be attributed to fiber pull-out or the entrapment of air bubbles during the composite processing. Additionally, scattered debris and particulates are observed across the matrix, which could be remnants from the fracture process or other materials introduced during fabrication. These microstructural features suggest a less consolidated and potentially weaker composite structure.

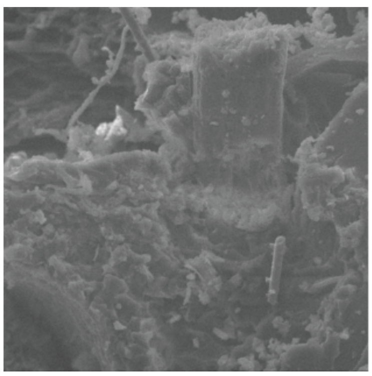

FIGURE 22. Captured by SEM in range of 500x to 700x for sample A3

The Figure 23 shows the microstructure of Sample A4, where glass fibers are the sole reinforcing component. The glass fibers are observed to be embedded within the epoxy matrix. However, the micrograph also reveals evidence of fiber pull-out indicating that while the glass fibers provide reinforcement, the interfacial bonding between the fibers and the matrix may not be optimal in all locations.

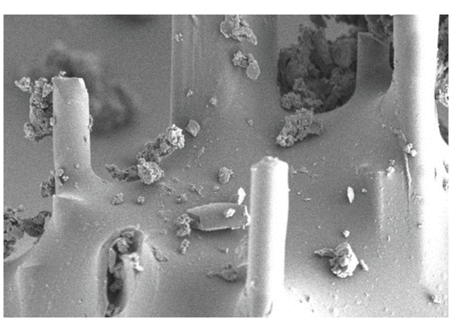

FIGURE 23. Captured by SEM in range of 500x to 700x for sample A4

In contrast to the fiber-reinforced samples, Sample A5, composed of pure epoxy, exhibits a significantly smoother texture at this magnification in Figure 24. The absence of reinforced fibers results in a less complex microstructure. However, the micrograph reveals the presence of flow lines, which may indicate slight variations in material density or composition during the curing process. The smoother texture of Sample A5, compared to the rougher textures of the fiber-reinforced samples, is consistent with the lower mechanical properties typically observed in unreinforced polymers.

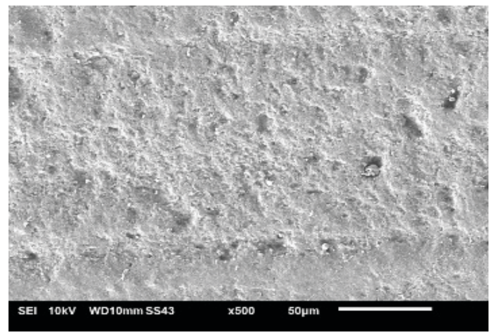

FIGURE 24. Captured by SEM in range of 500x to 700x for sample A5

In summary, the higher magnification SEM images provide valuable information about the microstructural differences among the composite samples. These differences, including variations in fiber distribution, porosity, fiber-matrix adhesion, and matrix texture, can be directly related to the observed variations in the mechanical properties of the composites.

CONCLUSION

In this study, the effect of partially replacing glass fiber with date palm fiber in hybrid epoxy composites was investigated. The mechanical properties of the resulting composites were evaluated through tensile, flexural, and impact tests, and the microstructure was characterized using scanning electron microscopy (SEM).

The results indicate that the incorporation of date palm fiber influences the mechanical behavior of the hybrid composites. Sample A1 (70% epoxy, 26% glass fiber, 4% date palm fiber) exhibited the highest tensile strength (87.7 MPa), proving that a specific combination of glass and date palm fibers enhances resistance to stretching forces. However, increasing the date palm fiber content generally reduced tensile strength as observed in Samples A2 and A3.

For flexural stress, pure epoxy (Sample A5) demonstrated the highest value (218.04 MPa), indicating its superior resistance to bending. The addition of fiber particularly glass fibers, also improved flexural performance compared to composites with higher date palm fiber content. Sample A1 also displayed good flexural stress.

In contrast, Sample A2 (70% epoxy, 21% glass fiber, 9% date palm fiber) showed the highest impact strength (101.4 kJ/m2), proving that a balanced amount of date palm fiber improves the composite's ability to absorb energy during sudden impact.

SEM analysis revealed that the microstructure of the composites varied with composition. Sample A1 exhibited a uniform and smooth texture with well-embedded fibers correlating with its high tensile strength. Higher date palm fiber content led to increased surface roughness and porosity.

In conclusion, while glass fibers are effective in enhancing tensile and flexural properties, the incorporation of date palm fibers can improve impact strength. An optimal balance between the two fiber types is crucial for achieving the desired mechanical properties in hybrid epoxy composites.

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DECLARATION OF COMPETING INTEREST

None.

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