

Effect of Palm Flour Addition on Carbon Fiber/Epoxy Twill Composites Fabricated by Vacuum Bagging

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Abstract

Carbon fiber/epoxy composites are widely used in structural applications due to their high strength, good stiffness, and low weight. Along with the increasing demand for more economical and sustainable materials, arenga palm (*Arenga pinnata*) flour has the potential to be utilized as a natural filler in composite materials. However, the effect of arenga palm flour addition on the tensile properties of 2x2 twill carbon fiber composites produced using the vacuum bagging method has not been widely reported. This study aims to analyze the effect of arenga palm flour content on the tensile strength of carbon fiber/epoxy composites. The filler contents used were 0%, 5%, 10%, and 15% by resin mass, while tensile testing was carried out according to ASTM D3039 to determine the ultimate tensile strength (UTS) and young's modulus. The results showed that the average UTS values for the 0%, 5%, 10%, and 15% variations were 499.95 MPa, 484.29 MPa, 488.42 MPa, and 538.33 MPa, respectively. The highest young's modulus was obtained in the 0% variation at 25.11 GPa, whereas all specimens containing arenga palm flour showed values in the range of 21–22 GPa. These findings indicate that the addition of arenga palm flour tends to reduce composite stiffness. However, at certain compositions, it has the potential to improve the maximum tensile strength.

Keywords: arenga palm flour; carbon fiber composite; filler; tensile strength; vacuum bagging.

Abstrak

Komposit serat karbon/epoksi banyak digunakan pada aplikasi struktural karena memiliki kekuatan tinggi, kekakuan baik, dan bobot yang ringan. Seiring meningkatnya tuntutan terhadap material yang ekonomis dan berkelanjutan, tepung aren berpotensi dimanfaatkan sebagai filler alami pada komposit. Namun, pengaruh penambahan tepung aren terhadap sifat tarik komposit serat karbon twill pola 2x2 yang diproduksi dengan metode vacuum bagging masih belum banyak dilaporkan. Penelitian ini bertujuan untuk menganalisis pengaruh variasi penambahan tepung aren terhadap kekuatan tarik komposit serat karbon/epoksi. Variasi filler yang digunakan adalah 0%, 5%, 10%, dan 15% terhadap massa resin, sedangkan pengujian tarik dilakukan mengacu pada ASTM D3039 untuk memperoleh nilai ultimate tensile strength (UTS) dan modulus young. Hasil pengujian menunjukkan bahwa UTS rata-rata pada variasi 0%, 5%, 10%, dan 15% berturut-turut sebesar 499,95 MPa, 484,29 MPa, 488,42 MPa, dan 538,33 MPa. Adapun modulus young tertinggi diperoleh pada variasi 0% sebesar 25,11 GPa, sedangkan seluruh variasi dengan tepung aren berada pada kisaran 21–22 GPa. Dengan demikian, penambahan tepung aren cenderung menurunkan kekakuan komposit, tetapi pada komposisi tertentu berpotensi meningkatkan kekuatan tarik maksimum.

Kata kunci: kekuatan tarik; komposit serat karbon; pengisi; tepung aren; vacuum bagging.

1. Introduction

Carbon fiber/epoxy composites are widely used in structural applications due to their high specific strength, good stiffness, low density, and resistance to corrosion and aggressive operating environments. These characteristics make the material widely used in the aerospace, automotive, and modern manufacturing industries, which require a combination of light weight and strength [1]. In addition to material composition, fabrication methods also play a crucial role in the

quality of the resulting laminate. The vacuum bagging method is known to improve resin impregnation, reduce void content, and produce a more uniform pressure distribution compared to conventional hand lay-up methods [2,3].

In addition to the fabrication process, the fiber weave pattern also influences the mechanical performance of the composite. The 2×2 twill weave pattern has good drapability, making it easier to conform to the mold shape and resulting in a more uniform stress distribution compared to a plain weave pattern [4,5]. The 2×2 twill weave architecture is reported to exhibit superior drapability and a more uniform stress distribution compared with plain-weave fabrics, making it attractive for composite manufacturing. In addition, vacuum bagging is commonly employed to improve laminate consolidation and reduce void content, both of which are important factors affecting the mechanical performance of fiber-reinforced composites. Consequently, the combination of 2x2 twill carbon fiber, epoxy matrix, and vacuum bagging provides a practical approach for producing high-quality composite laminates.

As the demand for more economical and sustainable materials grows, the use of natural fillers has been increasingly explored as alternative secondary reinforcing agents in polymer composite systems [6,7]. Lu [6] emphasized that the tensile strength, modulus, and overall mechanical response of epoxy composites are substantially influenced by filler type, loading concentration, particle size, and the quality of interfacial adhesion between filler and matrix, all of which must be carefully optimized to achieve consistent performance improvements. Suriani et al. [7] further established that natural fiber-based fillers offer key advantages including low density, biodegradability, and cost efficiency, making them viable alternatives to synthetic fillers in hybrid composite configurations.

Recent studies have extended the concept of natural filler addition to high-performance carbon fiber systems. Joseph Jebaraj et al. [8] investigated the incorporation of natural rubber powder as a bio-filler into woven carbon fiber/epoxy composites fabricated via the vacuum bagging process at weight proportions of 5%, 10%, 15%, and 20%, and demonstrated that 10% filler addition yielded the best tensile and flexural improvement, while higher loadings led to diminishing performance due to poor filler dispersion within the matrix. In a closely related study, Abdelsalam et al. [9] investigated the incorporation of date seed powder as a cellulosic natural filler in carbon fiber reinforced epoxy composites fabricated using a hand lay-up and vacuum process. The addition of 15% filler resulted in increases of 28% in tensile strength and 23% in bending strength relative to the unfilled composite, indicating that bio based particulate fillers can contribute positively to the mechanical performance of CFRP laminates. These findings collectively support the feasibility of using natural particulate fillers to modify the mechanical response of carbon fiber composites.

One natural material with significant potential for this application is palm flour derived from the sugar palm tree (*Arenga pinnata*), which is abundantly available in tropical regions including Indonesia. Sahari et al. [10] investigated the physicochemical and thermal properties of *Arenga pinnata* starch, contributing to the understanding of sugar palm-derived materials and their potential utilization. Asyraf et al. [11] demonstrated that chemical surface treatment of sugar palm fibers significantly improved their compatibility with hydrophobic epoxy matrices, yielding measurable enhancements in tensile and flexural properties. These findings indicate that palm-derived materials carry favorable inherent characteristics for composite filler applications, though filler fraction, particle morphology, and interfacial bond quality must be carefully controlled to achieve reliable mechanical outcomes

However, research on the use of palm flour as a secondary particulate filler in carbon fiber/epoxy composites remains notably limited, particularly for 2x2 twill laminates manufactured via the vacuum bagging method. Prior investigations have predominantly positioned palm-derived materials as the dominant reinforcing phase rather than as supplementary fillers within high-performance hybrid composite systems. Mukhtar et al. [12] conducted a comprehensive review of sugar palm (*Arenga pinnata*) fiber composites and documented the fiber's promising mechanical profile and its widespread

use as a primary structural reinforcement in polymer matrices. Nevertheless, the potential of palm-derived flour as a low-fraction secondary filler in carbon fiber-reinforced composite systems remains largely unexplored. Sastra et al. [13] investigated the tensile properties of Arenga pinnata fiber reinforced epoxy composites and demonstrated that fiber arrangement and volume fraction significantly affect mechanical performance. Nevertheless, the study was limited to the use of palm fiber as the main reinforcement, leaving the potential application of palm derived flour as a secondary filler in carbon fiber reinforced composites largely unexplored.

While palm flour itself remains unexplored in CFRP applications, recent studies on analogous bio-filler systems provide a relevant scientific foundation. Abdelsalam et al. [9] showed that natural seed powder at 0–15 wt% fractions enhanced the tensile and bending strength of carbon fiber/epoxy composites by up to 28% and 23%, respectively, using a hand lay-up and vacuum process, while Joseph Jebaraj et al. [8] demonstrated that an optimal natural filler content of 10 wt% yielded the best tensile and flexural performance in woven carbon fiber/epoxy composites without compromising matrix integrity.

Together, these studies confirm the viability of bio-derived powder fillers as mechanical modifiers in CFRP, yet the use of Arenga pinnata palm flour specifically remains unaddressed. This gap motivates the present study, which aims to systematically analyze the effect of palm flour addition at filler weight fractions of 0%, 5%, 10%, and 15% on the ultimate tensile strength and Young's modulus of 2x2 twill carbon fiber/epoxy composites fabricated via the vacuum bagging method, tested in accordance with ASTM D3039 [14].

2. Material and Method

2.1 Materials

The materials used in this study consisted of 2×2 twill carbon fiber as the reinforcing material, Chempoxy A+B epoxy resin as the matrix and hardener, and palm flour as a natural filler. The palm flour was first dried in an oven at 80°C for 3 hours, then sieved to obtain a more uniform particle size before being mixed into the resin. The variations in filler content used were 0%, 5%, 10%, and 15% by weight of the resin.



Figure 1. Material Used: (a) Carbon Fiber Twill 2x2, (b) Epoxy and Hardener, (c) Palm Flour

The physical and mechanical properties of the constituent materials are presented in Tables 1–3. These properties provide a basis for understanding the role of each material and its contribution to the overall performance of the fabricated composites.

A. Carbon Fiber

The carbon fiber served as the primary reinforcement material in the composite. The mechanical properties of the carbon fiber twill 2x2 used in this study are summarized in Table 1 [15].

Table 1. Mechanical Properties of 2x2 Twill Carbon Fiber

No	Property	Value
1	Density	1.8 g/cm ³
2	Filament Diameter	7 μ m
3	Tensile Strength	3450 MPa
4	Tensile Modulus	230 GPa
5	Elongation	1.5

B. Epoxy Resin

Chempoxy A+B epoxy resin system was employed as the matrix material to bind the carbon fibers and facilitate load transfer within the composite structure. The mechanical properties of the epoxy resin are presented in Table 2 [16].

Table 2. Mechanical Properties of Epoxy Resin

No	Property	Value
1	Density Epoxy	1.14 - 1.18 g/cm ³
2	Density Hardener	1.20 g/cm ³
3	Tensile Strength	68-80 MPa
4	Tensile Modulus	2.9-3.2 GPa
5	Deformation	5-7 %

C. Palm Flour

Palm flour was utilized as a natural filler to investigate its effect on the composite properties. The Physico-chemical properties of the palm flour used in this study are summarized in Table 3 [10].

Table 3. Physico-Chemical Properties of Palm Flour

No	Parameter	Value
1	Amylose	37,60 %
2	Amylopectin	62,40 %
3	Ash content	0,2 %
4	Moisture content	10-20 %
5	Average particle size	36,308 μ m
6	Granule size	10-100 μ m

2.2 Fabrication Process

The composites in this study were fabricated using the vacuum bagging method, as this method enhances laminate consolidation and helps achieve better composite quality compared to the conventional hand lay-up process. The literature also indicates that vacuum bagging can produce laminates with lower void content and better mechanical properties when the impregnation and sealing processes are performed correctly [17].

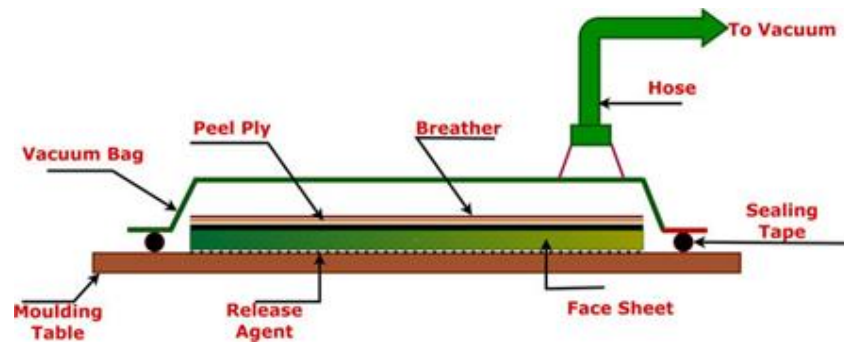


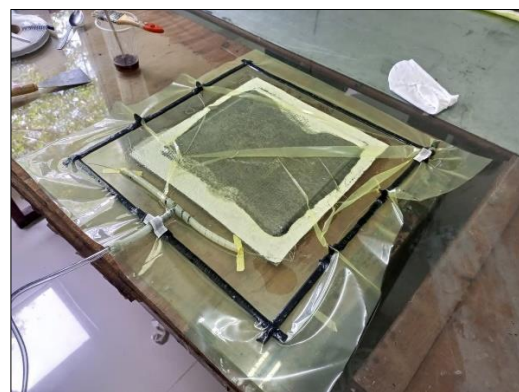
Figure 2. Components and vacuum bagging scheme (source: [18])

During the fabrication process, twill carbon fiber in a 2×2 weave was cut to the mold's dimensions and layered in eight layers. Before lamination, the mold was cleaned and coated with release wax to facilitate easy removal of the specimen after curing. Epoxy resin is then weighed as needed and mixed with palm flour at concentrations of 0%, 5%, 10%, and 15% by weight of the resin, then stirred until homogeneous. After that, hardener is added in a 100:30 epoxy-to-hardener ratio by weight, and the mixture is stirred again until homogeneous.

The mixture of resin, hardener, and filler is then applied evenly to the carbon fiber stack until all layers are fully impregnated by the matrix. The laminate is then covered with peel ply and a breather, wrapped in a vacuum bag, and sealed with sealant tape to ensure an airtight system. The vacuum pump is activated to remove air trapped inside the laminate so that the resin can penetrate the fibers optimally during the curing process. After the curing process is complete, the laminate is removed from the mold and cut into test specimens measuring 250 × 25 × 2.5 mm in according to ASTM D3039.



(a)



(b)

Figure 3. Fabrication Process: (a) Mixing, (b) Vacuum Bagging

2.3 Tensile Testing

Tensile testing was performed using a Tensilon RTF-2410 Universal Testing Machine in accordance with ASTM D3039 to evaluate the tensile properties of carbon fiber/epoxy composite specimens with four variations of palm flour content (0%, 5%, 10%, and 15% by weight). Prior to testing, the length, width, and thickness of each specimen were measured using a vernier caliper to determine the exact cross-sectional area. The specimen geometry followed the standard dimensions prescribed by ASTM D3039, with a total length of 250 mm, a width of 25 mm, and a thickness of 2.5 mm [14].



Figure 4. (a) Tensile Test process, (b) Example of tensile test specimen

A minimum of five specimens per variation were prepared and tested to ensure statistical validity, yielding a total of 20 specimens across all variations. The specimens were mounted and clamped parallel to each other within the machine's grips to ensure uniform axial tensile loading and to minimize eccentric stress during the test. Testing was conducted at a constant crosshead speed of 2 mm/min at room temperature ($23 \pm 3^\circ\text{C}$) with a relative humidity of $50 \pm 10\%$ RH. Each specimen was loaded monotonically until complete fracture occurred.

The maximum force recorded at failure (F_{max}) was used to calculate the mechanical properties of each specimen. The Ultimate Tensile Strength (UTS) and Young's Modulus were calculated using the following equations as defined in ASTM D3039.

A. Ultimate Tensile Strength

$$F^{tu} = \frac{F_{max}}{A} \quad (1)$$

where $A = w \times t$ is the cross-sectional area (mm^2), with w = width and t = thickness of the specimen.

B. Young's Modulus

$$E = \frac{\Delta\sigma}{\Delta\varepsilon} \quad (2)$$

where $\Delta\sigma$ is the change in tensile stress and $\Delta\varepsilon$ is the corresponding change in strain within the linear elastic region of the stress-strain curve.

The resulting stress-strain curves were plotted for each variation, and the mechanical properties obtained were statistically analyzed using mean and standard deviation values. The test results were subsequently compared across all four palm flour content variations (0%, 5%, 10%, and 15%) to evaluate the influence of palm flour addition on the tensile behavior of the carbon fiber/epoxy composite.

3. Results and Discussion

This section presents the results of tensile tests on 2x2 twill carbon fiber/epoxy composites with 0%, 5%, 10%, and 15% additions of palm flour, fabricated using the vacuum bagging method. The data presented includes a table of tensile

test results, stress-strain curves for each variation, and comparison graphs of the ultimate tensile strength (UTS) and Young's modulus. These test results were then analyzed to determine the effect of adding palm flour as a filler on the mechanical properties of the composite.

Table 4. Composite with palm flour filler tensile test results

Palm flour (%)	Max Load (N)	UTS (MPa)	Young's Modulus (GPa)	Strain (%)
0	29835.80 ± 1837.56	499.95 ± 30.58	25.11 ± 1.22	5.33 ± 1.29
5	35658.60 ± 1815.05	484.29 ± 29.54	21.12 ± 1.45	4.13 ± 0.33
10	32686.20 ± 3039.86	488.42 ± 57.93	22.34 ± 1.76	3.82 ± 0.26
15	38655.60 ± 3541.55	538.33 ± 62.04	22.23 ± 1.13	4.04 ± 0.35

Table 4 presents the results of tensile testing, showing the maximum force, ultimate tensile strength (UTS) and young's modulus for each variation of palm flour addition. The table indicates that each variation exhibits a different mechanical response to tensile loading. This table serves as the primary basis for comparing the quantitative performance of each filler composition, as the average data indicate that the addition of palm flour affects the mechanical properties of the composite in the form of specific increases or decreases in these values.

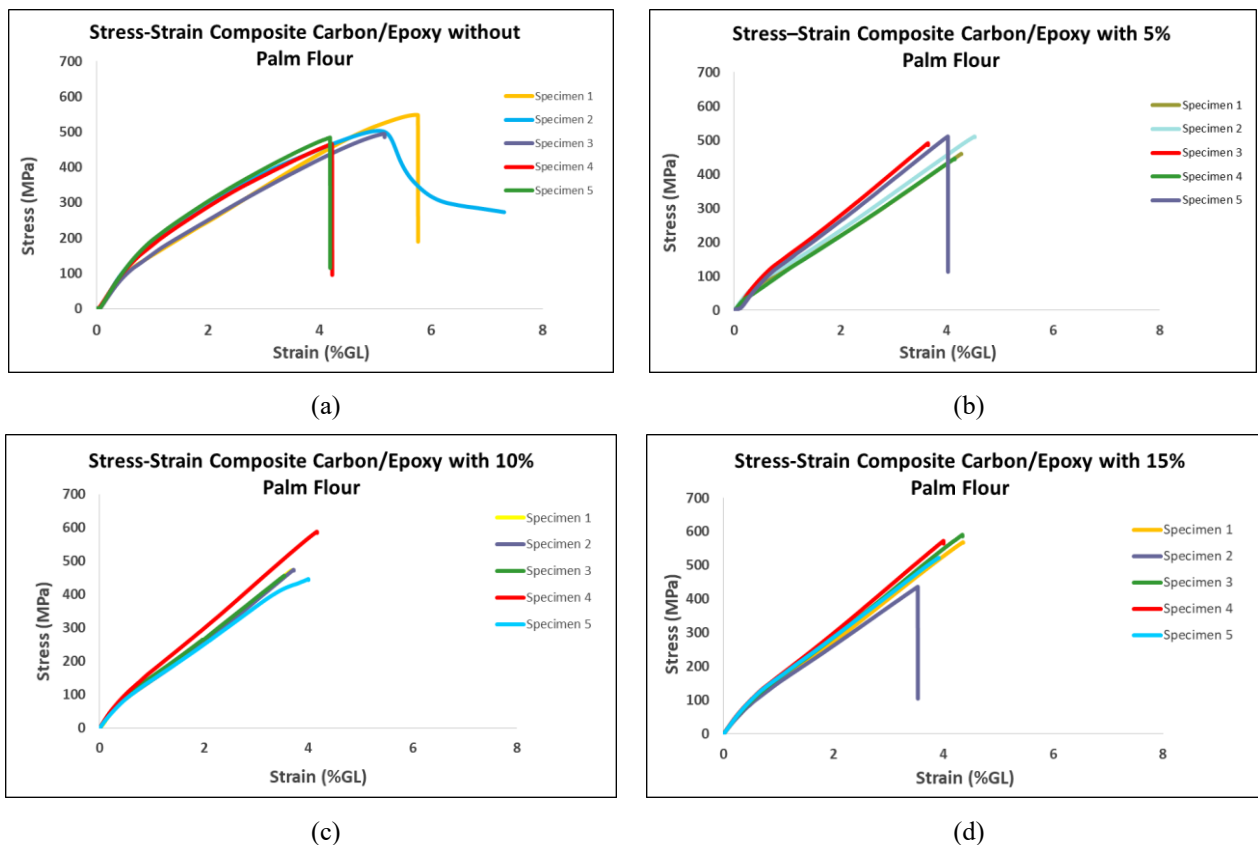


Figure 5. Stress-strain curve: (a) 0%, (b) 5%, (c) 10%, (d) 15%.

The stress-strain curves for each variation are shown in Figure 5, and from these curves, differences in the mechanical response of the composites during the loading process up to failure can be observed. The unfilled specimen exhibits a steeper curve slope in the young's region, indicating higher material stiffness compared to the other variations. Meanwhile, the variation with palm flour shows a change in the curve shape leading to a decrease in slope, which means

the young's modulus tends to decrease. This indicates that the natural filler added to the epoxy resin affects the composite's ability to maintain its young's deformation. On the other hand, in the 15% variation, the curve reaches a higher peak stress compared to other variations, indicating that at a certain concentration, palm flour can contribute to increasing the material's capacity to withstand maximum tensile load. Thus, the stress-strain graph shows that the addition of filler not only alters the final values of mechanical properties but also influences the composite's deformation behavior from the initial loading stage through to near failure.

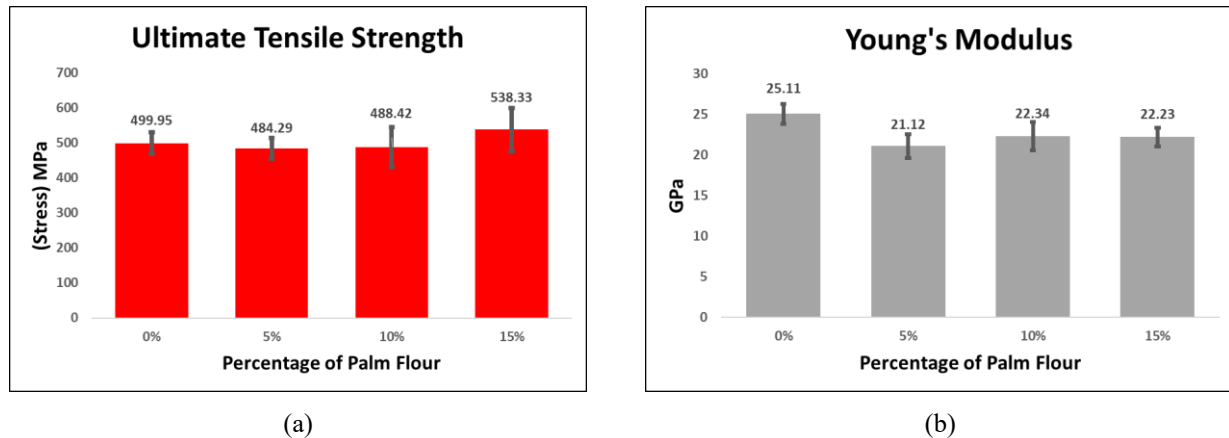


Figure 6 (a) Ultimate Tensile strength and (b) Young's modulus comparison

A comparison of the average values of ultimate tensile strength (UTS) and Young's modulus among the various palm flour formulations is presented in Figure 6a and Figure 6b, respectively, which clearly illustrate the effect of filler addition on the mechanical properties of the composite.

In the UTS graph, the 0% specimen yielded a baseline value of 499.95 MPa. Upon the addition of 5% and 10% palm flour, the UTS declined to 484.29 MPa and 488.42 MPa, respectively, before increasing significantly to 538.33 MPa at the 15% variation, representing a 7.68% improvement over the unfilled baseline. This non-monotonic trend is consistent with findings reported in analogous bio-filler studies. Joseph Jebaraj et al. [8] observed a similar pattern in carbon fiber/epoxy composites filled with natural rubber powder at weight proportions of 5% to 20%, where lower filler fractions initially reduced tensile performance before an optimal loading point was identified at 10%. Likewise, Abdelsalam et al. [9] incorporated date seed powder as a natural filler into carbon fiber/epoxy composites at 0%, 5%, 10%, and 15% weight fractions and reported that the 15% specimen achieved the highest tensile improvement of up to 28% relative to the unfilled composite, suggesting that higher filler fractions can promote more effective load redistribution when particle dispersion is sufficiently achieved.

In the context of the present study, the initial decline at 5% and 10% palm flour is likely attributable to incomplete homogenization of the filler within the resin, leading to localized stress concentrations and suboptimal fiber impregnation during the vacuum bagging process. At 15%, the filler appears to reach a more effective distribution threshold, facilitating stress redistribution and delaying initial crack propagation, mechanisms that were previously identified by Lu [6] as critical factors in achieving mechanical improvement in particulate-filled epoxy systems. The UTS values obtained in this study, ranging from 484 MPa to 538 MPa, are also consistent with the range reported for woven carbon fiber/epoxy composites fabricated via the hand layup and vacuum bagging process in recent literature, where Varghese et al. [19] recorded tensile strengths of 337.5 MPa to 475 MPa for similar fabrication configurations with nanofiller additions, confirming the mechanical competitiveness of the composite system evaluated in the present study.

In the Young's modulus graph, a consistent decreasing trend is observed across all palm flour addition variations compared to the unfilled specimen, with values of 21.12 GPa at 5%, 22.34 GPa at 10%, and 22.23 GPa at 15%, relative to the baseline value of 25.11 GPa. This result indicates that the incorporation of palm flour reduces the stiffness of the composite regardless of the filler fraction applied. This behavior is consistent with findings reported for other bio-derived fillers incorporated into carbon fiber reinforced epoxy systems, where studies on biochar-filled composites demonstrated that tensile modulus values were consistently lower in all filler-modified specimens compared to the unmodified baseline, a trend attributed to the lower intrinsic stiffness of the organic filler particles relative to the carbon fiber and epoxy matrix [20]. The modulus reduction observed in the present study is therefore physically consistent and mechanistically expected, as palm flour is a lignocellulosic material with significantly lower stiffness than carbon fiber, and its presence within the matrix effectively reduces the load-bearing contribution of the fiber-matrix system. These findings confirm that palm flour functions more effectively as a tensile strength modifier than as a stiffness-enhancing agent. Accordingly, this filler is most suitable for composite applications where the primary design objective prioritizes ultimate load-bearing capacity over structural stiffness. The results collectively demonstrate a strength-stiffness trade-off that must be carefully considered when selecting an appropriate palm flour content for specific engineering applications.

4. Conclusion

Based on the research results, the addition of palm flour as a filler in twill carbon fiber composites with a 2×2 weave pattern, fabricated using the vacuum bagging method, affects the material's mechanical properties. Adding 5% and 10% palm flour tended to lower the ultimate tensile strength (UTS) compared to specimens without filler, whereas at 15% the UTS increased to the highest value, which was 538.33 MPa. However, the young's modulus values showed a decreasing trend across all variations of palm flour addition compared to the 0% specimens, indicating that the material's stiffness decreased. Thus, palm flour can influence the tensile characteristics of the composite, but its use must be optimized to ensure that an increase in tensile strength is not accompanied by an excessive decrease in stiffness.

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