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Assessment of Mechanical Characteristics in Polymer Composites Reinforced with Carbon Nanotubes, PALF Fibers, and Nano Silica Particles

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Abstract

The automotive industry is one of the fastest-growing areas where natural fibers are being used, largely because of their potential as renewable and biodegradable components. Natural fiber reinforced polymer composites are being used in the automotive industry for a variety of paneling components in wagons and a few interior components. Pineapple leaf fiber (PALF) and epoxy were used to examine the scattering of nano silica and multi-walled carbon nanotubes (MWCNT). The composite was fabricated with nano silica particles (2 wt.%) and MWCNTs (0%, 1.5%, 2.5%, and 5 wt.%). Using ASTM-standard testing protocols, mechanical parameters were established, and test composites were sized accordingly. The results showed that a 2 wt.% increase in nanotubes improved the nanotube composite's mechanical properties. When carbon nanotubes (CNT) were introduced at concentrations of 2% and 5%, tensile strength (TS) increased by 13.26% and 15.47%, respectively. The flexural strength (FS) was improved by 73.4% and 125.9%, respectively, when CNT was added at the prescribed weight percentages.

Keywords

Nano silica powder, Tensile properties, PALF fiber, Flexural properties

Introduction

The study of bio composites, or natural fiber composites, has seen a recent uptick in popularity. To make these products, natural fibers are encased in a resin matrix [1]. For prospective structural applications, the mechanical characteristics of polymer composites reinforced with coir fiber/aluminium oxide (Al_2O_3) microparticles were investigated. The mechanical strength of coconut bunch fibers was found to be improved upon after being exposed to nanoparticles. Another study looked at how adding fibers from behaviour diffuse roots and luffa to epoxy composites affected their durability and how the mechanical properties of epoxy composites changed when combined with PALF [2]. It was observed that the composites' responses to stress, strain, and displacement were influenced by the volume percentage of fibers used. Further research was conducted on the impact of nanoparticles on PALF fiber composites. It was noted that neither zinc oxide (ZnO) nanoparticles nor zirconium dioxide (ZrO_2) nanoparticles were added in amounts exceeding 0.5% to the activated PALF fiber composite plates [3, 4]. However, the composites with ZrO_2 nanoparticles showed better mechanical characteristics compared to those with ZnO nanoparticles and plain Sisal fiber composites. Additionally, the tensile, bending, and electrical insulation properties of Vakka natural fiber-reinforced polyester composites were studied, assessing their potential enhancements [5].

The fibers must be meticulously separated from the composites by hand for analysis. Each composite's TS, flexural toughness, and dielectric properties are rigorously tested and benchmarked against those of bamboo, PALF and various PALF-based composites [6]. Research indicated that epoxy resin composites with carbon fiber reinforcements exhibit improved tribological (friction and wear) properties [7]. Additionally, the mechanical characteristics of polymer composites reinforced with woven glass fibers were detailed, demonstrating significant performance outcomes. It was discovered that integrating CNT with a minimum aspect ratio into the composite material significantly enhanced its fatigue life, while also inhibiting the initiation and propagation of fatigue cracks. Researchers have also investigated how nanoscale cellulose fibers impact the structural networks of MWCNT, further contributing to our understanding of composite material behaviors at the nanoscale [8, 9].

Composite materials are finding widespread technical applications, especially in the transportation and aerospace industries, because of their exceptional qualities. Mechanical, thermal, electrical, and optical qualities can be combined in composites because they are made from a combination of two or more materials [10]. By merging the attributes of different materials, it is possible to create composites with unique and improved characteristics. The primary structure of most composites consists of a matrix reinforced with fibers. Additional fillers and other additives may be incorporated to enhance specific properties. The matrices can be made from polymers, metals, or ceramics, each lending unique strengths to the resulting composite [11]. The aerospace and automotive industries are particularly focused on developing materials that offer higher efficiency and lighter weight compared to current materials [12]. This pursuit has escalated the volume of research aimed at achieving such innovations. Fiber Reinforced Polymer (FRP) materials are pivotal in the manufacturing sector due to their favorable qualities, which include a low cost in relation to their high stiffness-to-weight and strength-to-weight ratios [13].

In the current climate of material science research, natural fibers are becoming increasingly prominent because of their minimal environmental impact, ease of fabrication, cost-effectiveness, and broad applicability [14]. In the context of this experimental study, a composite material was created utilizing CNT within a polymer matrix, which was further reinforced with PALF fiber. This innovative combination exploits the desirable properties of each constituent CNT contribute to electrical conductivity and mechanical strength, the polymer matrix provides shape and resilience, while the PALF fiber offers sustainability and additional reinforcement potentially yielding a composite material well-suited for advanced engineering applications. CNT allotrope molecules are spherical and arranged in a hexagonal lattice. Their dimensions are between 1 and 100 nm [15]. These nanoparticles have sparked interest from researchers who want to learn more about how they might be used in engineering and as composite fillers [16]. These nanoparticles have ultra-high strengths and exceptional mechanical and thermal characteristics.

The hybrid composites reinforced with PALF, and glass fiber were studied for their mechanical properties [17]. When comparing HFREC to GFREC, the TS of the former was found to be 1.36 % higher. The authors [18] studied the PALF fiber/glass fiber hybrid composites' mechanical characteristics. Several plates were made, each with a different combination of ingredients. The study by authors [19] found that a polymer reinforced exclusively with PALF exhibited a TS of 1000 N. However, when this polymer was reinforced with a combination of PALF fiber and hair, the TS increased to 1250 N, indicating that the hybrid reinforcement provided a 25% improvement in TS. Further research [20] explored what happens when additional PALF fiber is incorporated into an epoxy resin. The findings suggested that integrating more PALF fiber could enhance the material's tensile and FS by up to 60%, a substantial increase that highlights the effectiveness of PALF fibers in strengthening epoxy resin composites. Additionally, authors [21] compared the mechanical properties of composites reinforced with treated versus untreated PALF fibers. This comparison would have likely investigated the impact of surface treatments on the fibers, which can enhance the bonding between the fibers and the matrix, resulting in different mechanical outcomes. Surface treatments can include chemical treatments, coatings, or other modifications to improve the interaction of the fibers with the polymer matrix, ultimately affecting the composite's TS, durability, and other mechanical properties [22-24].

Fabrication and characterization of a hydroxyapatite-CNT composite [25]. Composites containing CNT were incorporated into a hydroxyapatite matrix in varying percentages. Although it was found that increasing the CNT-to-material ratio reduced bending strength at first, this effect was later proven to be reversed. Epoxy resin composites manufactured from carbon fiber were used in their experiments, with varying percentages of CNT added (0.3, 0.6, 0.9, 1.2, and 1.9% by weight) [26]. When they tested the material, they discovered that its tensile and FS improved as it hardened. Nanocomposites bonded with CNT and polypropylene were studied for their mechanical and physical properties. In their experiments, they tried out a range of quantities of CNT. The tensile and FS of the material were found to be significantly improved after CNTs were introduced.

The results demonstrated the multiwalled carbon nanotube-coated cellulose fiber superior sensing capabilities, indicating the fibers potential use as smart materials. The modification of nanocomposites' mechanical properties is due to the addition of MWCNT. The mechanical quality of the products improved dramatically. The research involved the usage of a CNT reinforcement. The nano tube dispersion was made using epoxy at varying concentrations. To finish preparing the composite, PALF fiber was incorporated.

Materials and Methods

CNT filler was used with three-layer PALF fiber in this research for superior reinforcing. Table 1 displays the results of testing five distinct composite samples made with epoxy as the matrix material. The sliced samples were put through a battery of ASTM-standard tensile and flexural testing.

Composite samples could be made by following these steps: (i) A mould can be constructed to contain the composite material without leaking by joining silicon strips to the limits of a standard-sized polyester sheet. (ii) Here are the directions for combining LY-556 epoxy and HY-951 hardener: At 300 rpm, hardener and epoxy are mixed at a ratio of 10:1. The final ingredient is a CNT, which (iii) is introduced to the pot. The PALF fiber is placed into the mould after the epoxy mixture has hardened. (iv) In this case, the top of the mould is covered with a polyester sheet. The mould is squeezed into the desired shape by applying considerable weight, as per the specifications. Five different composite sheets were used to create test specimens for flexural, tensile, and impact loading. In figure 1 we see the standard measurements as defined by the ASTM.

FS was performed according to ASTM D-790 standards. This instance was measured at 80 mm. The chosen test speed is 2 mm/min (Figure 2 and figure 3).

Within the elastic area, the relationship between stress and strain establishes the tangent modulus of elasticity. The methodology for calculating this modulus is graphically demonstrated as finding the slope of the tangent to the most steeply rising straight section of the load-deflection curve [27, 28].

$$E = \frac{L^3 m}{4 b d^3} \quad (1)$$

Where

d = Thickness;

m = Slope;

b = width; and

L = Length.

As required by ASTM D-638-02, we tested the material's TS. The assessment was carried out with the use of a UTM. The length of the gauge will remain at 50 mm, and the distance between the grips will remain at 115 mm. The velocity of the tests was 5 mm/min. That's the inclination at which the stress axis begins to rise in proportion to the strain axis. To calculate this young's modulus, use the following formula [29, 30]:

$$E = \frac{\sigma L}{\delta} \quad (2)$$

Whereas,

E = Young's modulus.

σ = Deflection.

L = Span of gage. and

δ = stress.

Table 1: Preparation of experimental composition of samples.

Designation of samples	Epoxy	PALF fiber	Nano silica powder	MWCNT
S1	70	28	2	0%
S2	70	27	2	1%
S3	70	26.5	2	1.5%
S4	70	26	2	2%
S5	70	25.5	2	2.5%

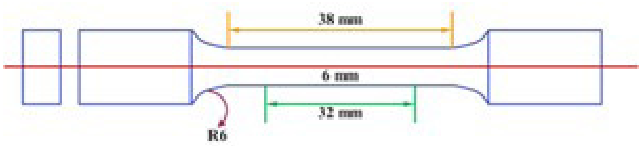

Figure 1: Sample of mechanical properties with ASTM standard.

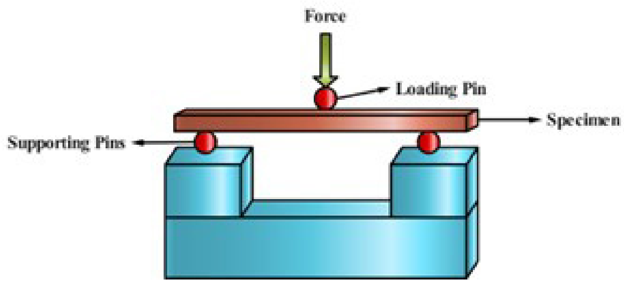

Figure 2: An outline of the experimental arrangement of flexural properties.

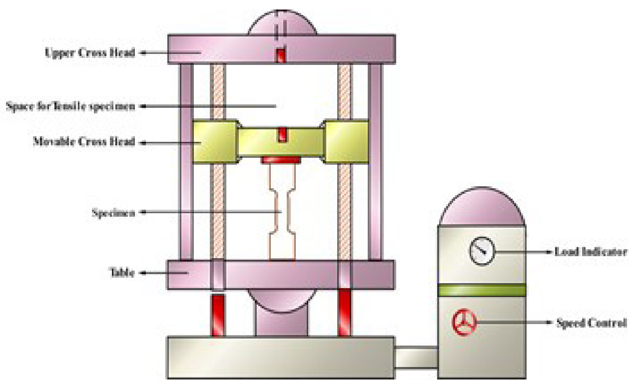

Figure 3: An outline of UTM experimental arrangement.

Results and Discussion

FS

Five test composites were subjected to flexural testing according to the ASTM standards. Five samples were evaluated using a variety of nanotube fillers to measure FS. FS was dramatically improved in the S4 sample that was loaded with 1.5% CNT. The flexural properties of a composite material are observed to improve with the addition of nano tube fillers, but only up to a concentration of approximately 1.5%. Beyond this threshold, the FS tends to decrease, a trend attributed to the agglomeration of the nano tubes, which can interfere with the material's uniformity and structural integrity. To evaluate the

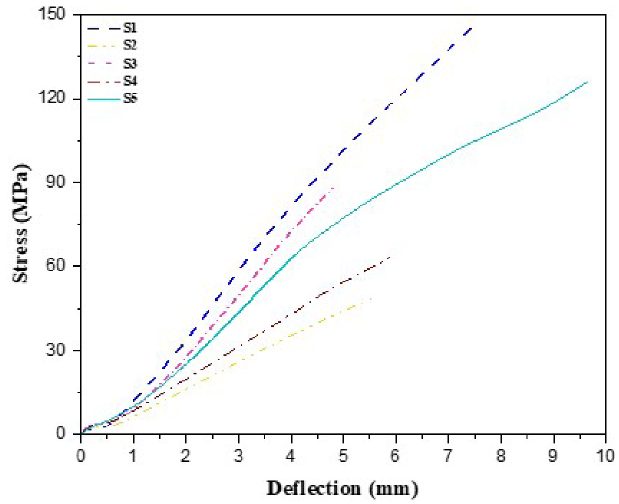

Figure 4: Evaluation of stress and deflection of flexural properties.

Table 2: Experimental outcome of flexural properties.

Specification of composites	FS (MPa)	Flexural modulus (GPa)	Flexural strain
1	130.36	14.26	7.35
2	65.23	10.58	6.9
3	82.56	12.42	7
4	70.68	11.68	7.5
5	125.12	13.74	11.4

material's performance under bending stresses, flexural tests were conducted to determine the maximum strain the material could endure, the modulus of elasticity in flexure, and the ultimate FS. The calculation of the flexural elastic modulus was performed using a specific equation, labeled as equation 2, with the results depicted in figure 4 and detailed in table 2.

Composite S5, which is composed of 13.5% PALF fiber and 2.5% CNT, was found to have the highest strength and flexural modulus of elasticity among all tested composites (Figure 5, figure 6 and figure 7).

TS

The impact of CNT filler on the tensile properties of composite materials was assessed by measuring the average TS across five different test composites. It was observed that the composite with a 1.5% volume of filler showcased the highest TS, attributing this increase to the enhancement of carbon-carbon bonding within a three-layer PALF laminated by the nano carbon filler. However, beyond this filler concentration, the TS decreased, likely due to the clumping of the filler within the polymer matrix. Key mechanical properties such as TS, maximum strain rate, and Young's modulus were determined, with the latter's results being shown in figure 8 and table 3.

The results show that among the PALF fiber composites, composite S5 is the strongest (Figure 9, figure 10 and figure 11). Young's modulus increased with the addition of CNT up to 27wt % fiber loading but decreased down to 26 wt. % fiber loading.

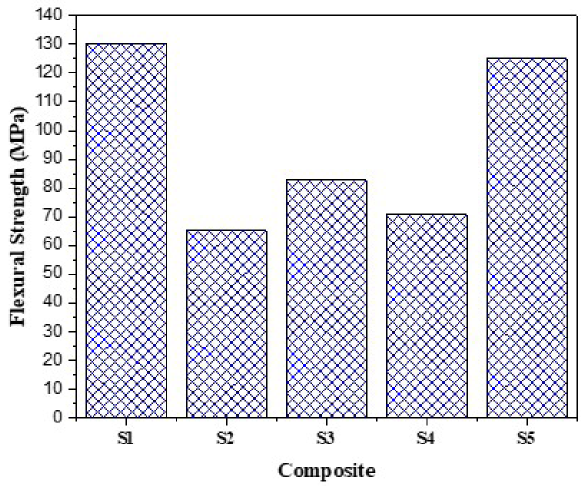

Figure 5: Evaluation of FS of various composites.

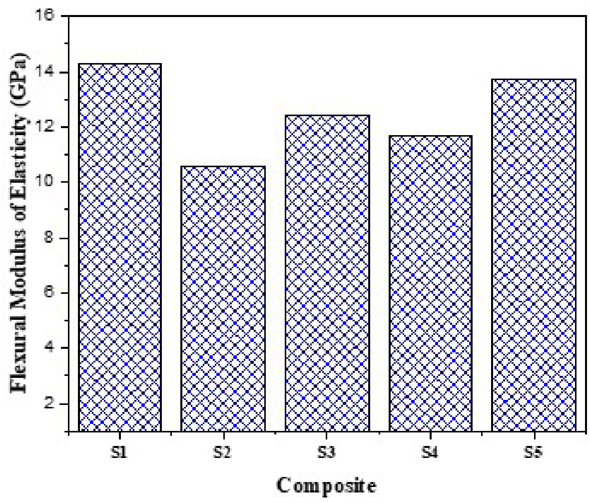

Figure 6: Evaluation of flexural modulus of elasticity.

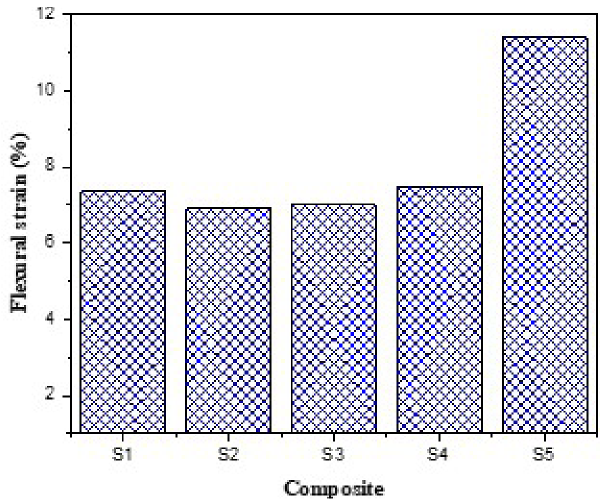

Figure 7: Comparison of flexural strain for various composites.

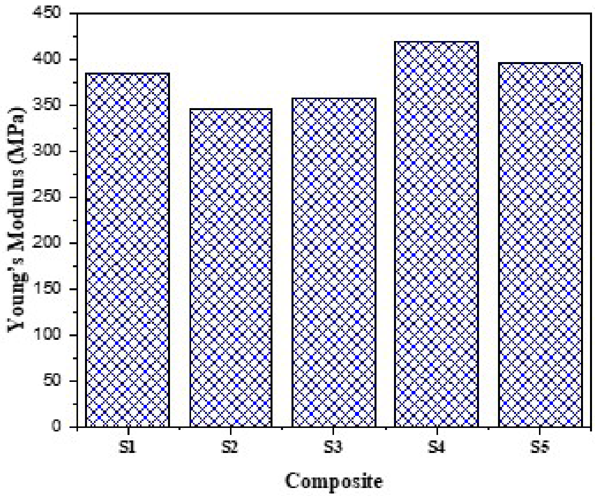

Figure 8: Evaluation of young modulus for various composites.

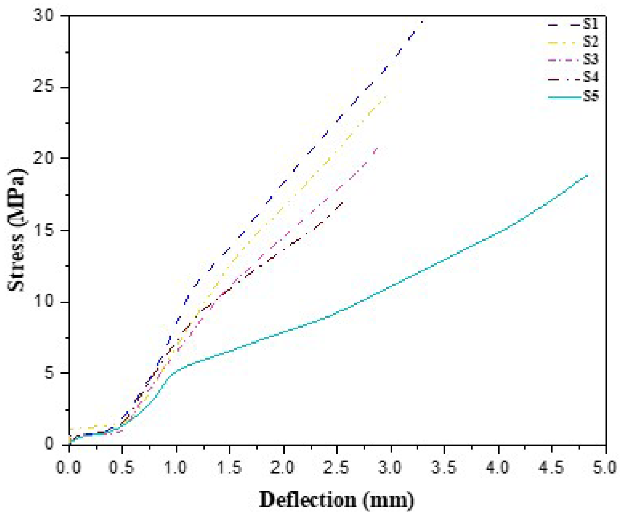

Figure 9: Evaluation of tensile stress and deflection curve.

Table 3: Experimental results of tensile properties.

Exp. trial	TS (MPa)	Tensile modulus (MPa)	Tensile strain
1	38	385	13.2
2	28	345	12.5
3	30	358	16.9
4	31	419	13.7
5	33	395	13.6

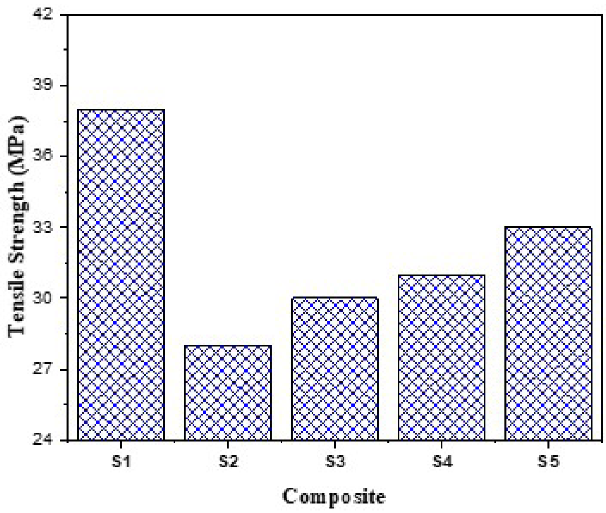

Figure 10: Evaluation of TS for various composites.

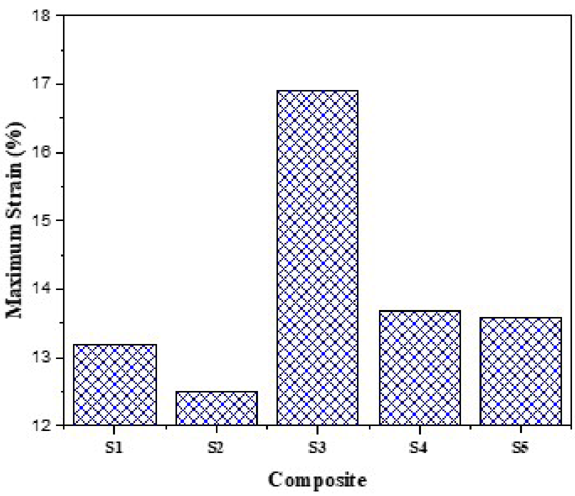

Figure 11: Evaluation of maximal tensile strain.

Conclusion

Epoxy composites with PALF fibers and nanotubes as filler were studied for their mechanical properties. There was an examination of mechanical qualities. Maximum flexural and TS are found to rise with increasing percentages of CNT, as shown by comparative tensile tests. Flexural testing reveals that the flexural modulus of elasticity increases as the amount of CNT in the material increases. This improves Young's modulus initially, but further addition of CNTs diminishes it. The composite with the highest performance without filler was determined to have a fiber loading of 26 wt.%. Sonicating or magnetically spinning the nanoparticles can help distribute the fillers uniformly throughout the matrix and fill the holes.

Adding nano tubes to PALF fiber at a volume fraction of 1.5 % enhanced its TS. The TS of a composite material can be improved by using CNT as a filler. The FS of the composite was greatly enhanced by the addition of CNT filler at a volume fraction of 1.5 %. After the CNT agglomeration, the composite material's FS decreases by more than about 2%. As with the other composites tested, increasing the volume percentage of carbon nano tube filler to 1.5% boosted the composite's impact strength. Incorporating nano fillers into natural fiber composites is the focus of this research.

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None.

Conflict of Interest

None.

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