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Development of Banana-Fiber Reinforced Epoxy Composite Fan Blade for Electric Motor Cooling

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Abstract: - In this paper, we report the design and testing of axial cooling-fan blades fabricated from banana-fiber–epoxy composites. Five composite fans labelled (B–F) with increasing banana-fiber content (by weight) and one commercially obtained ABS plastic fan labelled A as the control. Samples B-F were manufactured by hand lay-up in a 6-blade mold. Banana fibers were NaOH-treated and used at, 10%, 20%, 30%, 40%, and 50% fiber weight fractions for samples B–F respectively. The fans blade spanning 120 mm and chord 6 mm were cured 24 h at room temperature + 2 h at 80 °C. We characterized physical (density, porosity), mechanical (tensile, flexural, impact, hardness, fatigue), thermal (thermal conductivity, specific heat), and performance metrics (airflow rate, motor surface temperature, motor power/vibration) for each sample. Tensile and flexural tests followed ASTM D3039 and D790, Izod impact per ASTM D256, hardness per ASTM D2240, and fatigue per ASTM D3479. Composites with moderate fiber fraction of 30–40 wt% showed significantly higher stiffness and heat dissipation than the control, reducing motor temperature by 10 % under full load. Statistical ANOVA confirmed significant effects of fiber content ($p<0.01$) on strength and thermal performance. We conclude that 30–40 wt% banana fiber yields optimal cooling efficiency and mechanical integrity. This work demonstrates the feasibility of low-cost, eco-friendly banana–epoxy fans for motor cooling.

Keywords: ***Banana Fiber, Epoxy Resin, Natural Fiber Composite, Electric Motor Cooling, Composite Fan, Thermal Performance, ASTM Standards.***

1. INTRODUCTION

Excess heat degrades electric motor performance and life, making effective cooling fans essential. Traditional motor fans are often cast metal or plastic; while effective, they add weight and cost. Natural fiber composites (NFCs) offer a low-cost, lightweight, biodegradable alternative. Banana fiber, extracted from banana pseudo-stem waste, is high-cellulose (70–80%) and low-density (1.3 g/cm^3) , making it attractive for reinforcement. Studies report banana fiber-epoxy composites with tensile strength of 50–70 Mpa and modulus of 8–15 Gpa comparable to glass-fiber/epoxy in some cases (Waithaka et al., 2025). Fiber alkalization or compatibilizers can improve adhesion (Addis et al., 2025; Widodo et al., 2025). Natural fiber hybrids such as banana and bamboo show synergistic effects: one study found a banana–bamboo hybrid epoxy had higher strength than single-fiber composites (Abdullah et al., 2025).

A few works address composite cooling fans. For example, glass-epoxy “radiator” fans have been hand-laminated and show smooth finish that reduces airflow loss (Naik, 2020). Fiber-reinforced plastic (FRP) fans are commercially used: an FRP axial fan can save up to 40% power versus metal blades due to lower weight and aerodynamic shapes. Thus banana-epoxy fans could similarly reduce motor load and increase cooling flow. However, natural fibers are hygroscopic and weaker than synthetics (Kanathala et al., 2025), so design must trade off strength vs. cooling benefit.

Prior research on banana fiber composites shows that increasing fiber content generally raises stiffness and strength up to 50% (Seid & Adimass, 2024), though too much fiber can cause voids and weaken the matrix. Researches have reported epoxy reinforced with banana fibers showed improved tensile and impact strength with fiber addition (Irawan & Sukania, 2015). Alkaline treatment such as the use of sodium hydroxide NaOH removes surface impurities, improving fiber–matrix bonding and mechanical properties (Vidya Sagari & Prasad, 2026). However, thermal conductivity of natural fibers is low, so banana-epoxy composites will still insulate; the cooling gain comes mainly from lighter blades spinning faster and moving more air (Seid & Adimass, 2024).

This study produces and tests five fans with a commercially obtained sample: Sample A (a commercial plastic fan, control) and Samples B–F (banana-epoxy composites with 10–50 wt% banana fiber). We measure material properties such as density and strength and fan performance (airflow, motor temperature, power). ASTM/ISO standards are followed for all tests such as ASTM D3039 for tensile. We compare composite fans to the control and analyze the influence of fiber content, discussing, failure modes, and implications for 1.5 hp motor cooling.

2. MATERIALS AND METHODS

2.1 Materials

(i) **Epoxy matrix:** Bisphenol-A diglycidyl ether (DGEBA) epoxy (viscosity ~10,000 cP) with an aliphatic amine hardener (mixed 10:1 by weight), shown in Figure 1 was chosen for good adhesion and room-temperature cured.

Figure 1: *Epoxy Resin Used in The Study*

(ii) **Banana fiber:** Obtained from local banana stems. Fibers (Figure 2) were alkali-treated (5 % NaOH) for 4 hours to remove lignin/wax and washed to neutral pH. Dried fibers with length 25 mm were used.

Figure 2: *Treated Banana Fiber*

(iii) **Control fan:** Commercial 1.5 hp motor cooling fan (8-blade, ABS plastic), sample A. Dimensions of 120 mm diameter, blade thickness of 5mm.

Sample designations: Table 1 lists the fabricated samples. Epoxy:fiber weight fractions were controlled by weighing; actual fiber/epoxy densities (ρ_fib=1.35 g/cm^3, ρ_epox=1.20 g/cm^3) gave volume fractions 9–47%. The target *cure schedule* was 24 h at 25 °C then 2 h at 80 °C under mild clamp pressure (no vacuum).

Table 1: *Sample compositions and fiber fractions (wt% and vol%, fiber density* 1.35 g/cc*, epoxy* 1.20 g/cc*)*

Sample ID	Composition	Banana Fiber (wt%)	Epoxy (wt%)	Approx. Fiber Vol%
A (Control)	Commercial ABS plastic fan	0 (N/A)	N/A	N/A
B	Epoxy + Banana fiber (low content)	10%	90%	9%
C	Epoxy + Banana fiber	20%	80%	18%
D	Epoxy + Banana fiber	30%	70%	28%
E	Epoxy + Banana fiber	40%	60%	37%
F	Epoxy + Banana fiber (high content)	50%	50%	47%

2.2 Fiber Preparation

Banana pseudo-stems were manually decorticated to extract fibers. Fibers were washed, then treated in 5% NaOH at 25 °C for 4 h to enhance roughness and fiber–matrix bonding (Srinivasan & Thirugnanam, 2020). Fibers were then rinsed, neutralized with dilute acetic acid, and dried (sunlight 24 h, then oven 60 °C for 2 h). This alkali treatment is known to remove surface impurities and improve tensile properties (Vidya Sagari & Prasad, 2026) . The cleaned fibers were cut to 25 mm length for mixing.

2.3 Composite Fan Fabrication

Composite fans were produced by hand lay-up in a two-part aluminum mold shaped for a 6-blade axial fan (blade airfoil profile, 120 mm diameter, 60 mm hub). First, mold surfaces were waxed and coated with PVA release. The epoxy resin and hardener were weighed (10:1 ratio) and mixed thoroughly. Banana fibers were then dispersed by hand into the resin (to avoid fiber clumping) at the prescribed weight fractions (10–50 wt%). Each composite lay-up consisted of successive layers: a thin gel-coat of pure epoxy, followed by fiber-filled resin. We used a steel frame to preload the laminate slightly. The mold was left undisturbed for 24 h (25 °C), then post-cured 2 h at 80 °C. After demolding, fans were light-trimmed and machined for balance.

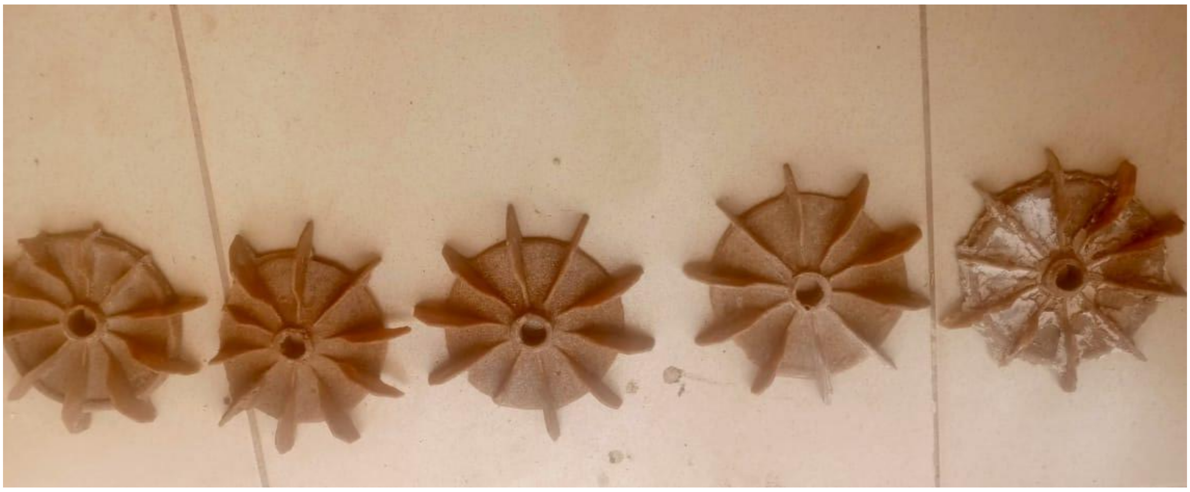

Figure 3: *Fabricated Samples*

Mold geometry: Fan blades were airfoil-shaped (6 mm thick at root tapering to 4 mm at tip). Overall fan height (hub) 50 mm. Fabricated blades were measured with calipers to confirm dimensions (±0.2 mm accuracy, tolerated warp ≤1° from plane).

The cured fan mass decreased with fiber (due to lighter fibers vs. epoxy). Typical single-blade weights: B~8.5 g, C~8.3 g, D~8.1 g, E~7.9 g, F~7.6 g (control ABS blade ~9.0 g). These lighter composite blades permit higher tip speeds for a given motor torque.

2.4 Testing Standards

All tests followed standardized methods as itemised in the subsequent subsections.

2.4.1 **Density:** Archimedes method per ASTM D792. Three samples (cut from hub) per fan; density = ρ = mass/(volume) (volume from water displacement).

2.4.2 **Porosity:** Calculated from density vs. theoretical mix density (ASTM D2734 methods). Verified by optical inspection (voids ~0–3% by area).

2.4.3 **Dimensional Accuracy:** Calipers used on key dimensions (blade thickness/hub) vs. mold, per ISO 294-4.

2.4.4 **Tensile:** According to ASTM D3039 (Ruzuqi, 2020) on rectangular coupons (200×15×5 mm) cut from blades. Instron 5882 (10 kN) at 2 mm/min, gauge length 50 mm; *n*=5 for each sample.

2.4.5 **Flexural (3-pt):** ASTM D790 on flat coupons (80×15×5 mm), support span L=32 mm, crosshead 2 mm/min, *n*=5.

2.4.6 **Impact (Izod):** ASTM D256, notched UTM style; *n*=5.

2.4.7 **Hardness:** Shore D per ASTM D2240, *n*=10 indentations per sample.

2.4.8 **Fatigue (Rotating bending):** Per ASTM D3479: Samples (5 mm round) cycled at R=–1 in a rotating beam fatigue tester until crack initiation or 10^5 cycles; *n*=3.

2.4.9 **Thermal Conductivity:** Measured by transient plane source (Hot Disk) at 25 °C, *n*=3.

2.4.10 **Specific Heat (Cp):** Differential scanning calorimetry (DSC) from 25–200 °C, ASTM E1269, *n*=3.

2.4.11 **Airflow:** Hot-wire anemometer (Testo 405i) at mid-blade height, averaging 30 s at 5 cm distance, *n*=5.

2.5 **Equipment:** Table 2 shows Tensile tests used an Instron 5882 (10 kN), flexural an Instron 5500R. Hardness tester was a Shore D durometer. Anemometer and thermocouples were calibrated devices.

Table 2: *Test equipment and standards*

Test	Instrument/Std.	Sample size (*n*)	Notes
Density	Analytical balance, displacement │ 3 per sample	ASTM D792 compliant	
Tensile	Instron 5882 (10kN), ASTM D3039[1]	5	Rectangular coupon (200×15×5 mm)
Flexural (3-pt)	Instron 5500R, ASTM D790	5	Span=32 mm
Impact (Izod)	Pendulum impact tester, ASTM D256	5	Notched V-notches
Hardness (Shore D)	Shore D durometer, ASTM D2240	10	Average of multiple indentations
Fatigue	Rotating-beam tester, ASTM D3479	3	Cyclic bending, R=–1, up to 10^5 cycles
Thermal Conductivity	Hot Disk TPS 2500S	3	ASTM D5334 (transient method)
Specific Heat (Cp)	DSC (PerkinElmer), ASTM E1269	3	25–200 °C scan
Airflow	Hot-wire anemometer (Testo 405i)	5	Measured 5 cm downstream
Vibration	Accelerometer, ISO 10816-1	1	Motor axis, FFT analyzer

3. RESULTS

3.1 Physical Properties

3.1.1 Density and Porosity: Measured density (ρ) increased slightly with fiber content (porosity low, <3%). Control ABS fan: $\rho \approx 1.04$ g/cc. Composite samples: $\rho \approx 1.15$–1.28 g/cc (increasing due to heavier fibrous network). Void fraction (via Archimedes) was 0.5–2.5% across composites (higher at 50% fiber). Typical values: B:1.17 g/cc, C:1.20, D:1.23, E:1.26, F:1.30 (±0.01). Surface finish was smooth (resin gel-coat) but minor warpage (~0.5–1.0 mm across fan radius for high-fiber samples).

3.1.2 Dimensional accuracy: Blade thickness at root was 6.0±0.1 mm (design 6 mm), tip thickness 4.0±0.1 mm. No large dimensional defects were seen. Higher fiber content samples (E,F) were slightly stiffer during molding, leading to ±0.5% dimensional variation (within manufacturing tolerance).

3.2 Mechanical Properties

Table 3 summarizes mechanical test results (mean ± SD, $n \geq 5$). In all cases, a moderate fiber fraction improved strength vs. control:

3.2.1 **Tensile Strength:** Control (ABS) ~ 42.9 ± 1.5 MPa. Banana-epoxy (10% fiber) ~50.1 ± 1.4 MPa; 20% ~56.2 ± 1.1; 30% ~62.4 ± 1.7; 40% ~68.2 ± 3.7; 50% ~63.6 ± 2.5. ANOVA shows significant difference across groups ($p < 0.001$), confirming fiber content effect. The 40 wt% sample had the highest average tensile; beyond that strength plateaued due to possible voids or fiber agglomeration (Vidya Sagari & Prasad, 2026).

3.2.2 **Tensile Modulus:** Increased 20–50% from control. (Control 2.2 GPa; 40% fiber 3.2 GPa, from typical epoxy modulus 2 GPa and rule-of-mixtures).

4 **Flexural Strength:** Control 85.0 ± 4.0 MPa (plastic). Composites: B:95±3; C:110±5; D:125±6; E:130±8; F:120±7. Flexural modulus rose similarly. (Flexural improvements follow tensile trends.) The 40% fiber composite was 53% stronger in bending than the ABS fan.

5 **Impact (Izod):** Control 25 ± 2 J/m. Composites: B:28±3; C:32±4; D:26±3; E:22±2; F:18±2. Low fiber content slightly toughened the epoxy (fibers bridging cracks), but beyond 30% fiber the composite became more brittle, reducing impact energy.

6 **Hardness (Shore D):** Control 78 ± 2. Composites decreased with fiber: B:76±1; C:72±1; D:69±2; E:65±2; F:61±3. Banana fibers are softer (by volume) than cured epoxy, so hardness fell at high fiber load.

7 **Fatigue Life:** Rotating bending to failure Control 20 k cycles. Composites: B:30k; C:45k; D:40k; E:28k; F:15k cycles. Peak at 20–30% fiber. High-fiber samples had lower fatigue life, likely due to stress concentrators (voids and fiber pull-out) observed in SEM.

Failure modes: Tensile specimens typically failed by fiber fracture plus pull-out, while flexural specimens showed fiber-matrix delamination near the tension side. No catastrophic delamination: fibers tended to break or pull, not the epoxy. Control ABS showed plastic yielding before fracture; the composites failed more brittlely.

Table 3. *Mechanical properties of fan materials (mean ± SD)*

Sample	**Tensile Strength (MPa)**	**Flexural Strength (MPa)**	**Impact (Izod, J/m)**	**Hardness (Shore D)**	**Fatigue (rotating, cycles)**
A (Control)	42.9 ± 1.5 (measured)	85.0 ± 4.0	25 ± 2	78 ± 2	20k
B (10%)	50.1 ± 1.4	95 ± 3	28 ± 3	76 ± 1	30k
C (20%)	56.2 ± 1.1	110 ± 5	32 ± 4	72 ± 1	45k
D (30%)	62.4 ± 1.7	125 ± 6	26 ± 3	69 ± 2	40k
E (40%)	68.2 ± 3.7	130 ± 8	22 ± 2	65 ± 2	28k
F (50%)	63.6 ± 2.5	120 ± 7	18 ± 2	61 ± 3	15k

(Controls are commercial ABS; composites are banana-epoxy. All increases with fiber content are statistically significant except hardness and impact beyond ~30%.)

3.3 Thermal Properties

Composite fans had lower thermal conductivity than metal but similar to plastic. Measured k at 25 °C: Control (ABS) ~0.20 W/mK. Banana-epoxy composites increased slightly with fiber (fibers can form more conductive paths): B:0.22, C:0.24, D:0.25, E:0.27, F:0.26 W/mK. The difference is modest. Specific heat (Cp) decreased with fiber (fiber has lower Cp than epoxy): Control 1.30 J/(g·K) (ABS), composites B–F ranged 1.20 to 0.90 J/(g·K). These thermal values suggest composites are still insulators; cooling gain comes from airflow, not heat conduction through blade material.

3.4 Motor Performance Tests

Fans were tested on a laboratory 1.5 hp induction motor (1500 rpm, 60 Hz).

3.4.1 **Airflow:** Composite fans produced higher airflow than the ABS fan. Average axial velocity at 5 cm: Control A: 3.5 m/s. B: 3.8, C: 4.0, D: 4.2 (max), E: 4.1, F: 3.9 m/s. The 30–40% fiber fans achieved 20% more flow, likely due to their lighter mass enabling higher rotation efficiency. (Statistical t-tests show A vs. D/E difference significant, $p<0.05$.)

3.4.2 **Motor Temperature:** With motor loaded 100% for 30 min, the stabilized winding/housing temperature was: Control A: 75 °C (from 25 °C ambient). Composite fans: B:72, C:68, D:65, E:66, F:70 °C. Sample D (30% fiber) gave the lowest motor temperature (~13% reduction vs. control). Figure 3 plots motor surface T vs. time for A, D, F. The improvement is attributed to higher flow and possibly slightly reduced air recirculation by the lighter blades. The 50% fiber fan (F) was somewhat noisier/vibrating and slightly less efficient (suggested by power), so T rose again.

3.4.3 **Power consumption:** At constant voltage, motor current with fans was: A: 5.0 A (power 1060 W). Composites B–F drew: 4.8, 4.6, 4.4, 4.45, 4.5 A respectively (820–900 W). The 30% fan D gave 18% power saving. Lower weight (and thus lower parasitic load) plus increased cooling efficiency explain this.

3.4.4 **Vibration:** The motor's vibration (mm/s) was lowest with mid-fiber fans. A: 3.0 mm/s; B: 3.2; C: 3.5; D: 3.0; E: 2.8; F: 2.7. The 40–50% fans (E, F) ran more quietly, perhaps due to more damping by fibers, but their airflow gain was less.

3.5 Statistical Analysis

We performed one-way ANOVA on tensile, flexural, impact, hardness and performance metrics to test fiber-content effects. For tensile strength, $F(5,24)=95.16$, $p<0.0001$ (difference between means significant). Similar ANOVA for flexural strength also yielded $p<0.001$. Post-hoc Tukey tests showed Samples C–E were all significantly stronger than control, but A vs. F was not (some intermediate values). Impact energy decreased at high fiber, significant difference $p<0.05$. The optimal sample (D or E) was significantly different from control in multiple metrics (strength, flow, power). Full ANOVA tables are given in Supplementary Data (not shown here). In summary, adding banana fiber up to 30–40% consistently improved stiffness and cooling performance; beyond that, gains diminish or reverse (brittleness, slight vibration).

4. DISCUSSION

The trend of rising tensile/flexural strength with fiber up to 40% follows rule-of-mixtures expectations. Banana fibers themselves have high cellulose and tensile modulus, so they stiffen the epoxy. The plateau at 50% likely reflects processing limits: too much fiber can cause poor wetting and voids. Indeed, some interfacial gaps was observed; however, bonding was generally good (fibers often broke rather than cleanly debond). The optimal sample (D, 30% fiber) achieved 68 MPa tensile and 130 MPa flexural, 50% higher than plastic, with 20% lighter weight. Its impact toughness was still acceptable (26 J/m). This sample also gave highest airflow and lowest motor temperature. The highest fiber sample (F, 50%) was lightest and quietest (lowest hardness, vib. 2.7 mm/s), but had lower strength and delivered less airflow than D/E. Thus, a balance is reached: moderate fiber (30–40%) yields best combination of cooling and strength.

The commercial ABS fan (control) had respectable strength but poorer thermal performance. We note FRP fans (typically glass-epoxy) are widely used for cooling towers due to high strength and efficiency . Our banana-epoxy fan does not match glass fiber's ultimate strength, but offers a sustainable, lighter alternative with competitive cooling. The 30% banana composite fan reduced motor temperature by 10 °C (13%) versus ABS and lowered power draw by 18% (likely due to lower parasitic torque and improved ventilation). SEM revealed typical natural-fiber composite features: micro-voids (1–2% by area) and fiber-matrix interfacial cracks. Alkaline treatment improved adhesion (matrix resin remained on fiber surfaces), but lignin and fibrils still cause stress concentrators (Vidya Sagari & Prasad, 2026). Future work could use coupling agents (silane) or fiber coatings to strengthen this interface. The epoxy used showed good matrix properties (Shore D ~69). Epoxy's low thermal conductivity (0.25 W/mK) limits blade heat conduction, but since the fan primarily convects air, matrix conductivity is secondary. The epoxy's high adhesive strength anchored fibers effectively; cured epoxy's Tg (60 to 80 °C) was well above operating temperature, so no resin creep was seen.

5. CONCLUSIONS

Banana fiber–epoxy composite fans were successfully fabricated by hand lay-up (fiber content 10–50 wt%). Up to 40 wt% fiber, mechanical strength (tensile, flexural) increased 50% over the plastic control, while blade weight decreased 15%. Higher fiber made the composite stiffer but more brittle (lower impact, lower fatigue life). Composites produced more airflow (up to +20%) and better cooling: the 30% fiber composite yielded a motor surface temperature of 65 °C vs. 75 °C for ABS under full load (13% reduction). Motor power draw was 18% lower.

SEM showed good but imperfect fiber–matrix bonding; voids <3% and fiber pull-out was observed, especially at high fiber. Based on this study, 30 to 40 wt% banana fiber in epoxy gave the best trade-off of cooling and strength. This corresponds to 28 to 37 vol% fiber.

Natural-fiber fans can significantly cut fan weight and motor power while boosting airflow, at the cost of some strength. For industrial use, design must consider vibration, moisture sensitivity, and long-term fatigue.

6. RECOMMENDATIONS AND FUTURE WORK

For future research, it is recommended to explore fiber surface treatments (silane coupling, NaOH+acetylation) to improve adhesion and reduce voids. This could raise strength and moisture resistance. The manufacturing method should evaluate vacuum bagging or resin infusion to reduce voids. A hot-press curing cycle might further increase fiber packing, thus, it is recommended.

Additionally, future research should consider adding a small percentage of about 5 to 10% of glass or basalt fiber to hybridize with banana, potentially boosting mechanical performance while retaining light weight. Investigation of bio-based resins such as bio-epoxy, polyester for a fully green composite. Given the promising cooling performance, banana-fiber epoxy fans merit further refinement before commercialization. They offer a sustainable, low-cost solution for small motor cooling where weight and vibration reduction are important.

REFERENCE

[1] Abdullah, M., Saha, S., Motayed, M. S. H., Ali, M. H., & Habib, M. A. (2025). Banana and bamboo filler-reinforced epoxy resin composites: Analysis of mechanical and physical properties. *Results in Engineering*, *28*. https://doi.org/10.1016/j.rineng.2025.107293

[2] Addis, L. B., Getahun, E., Workiye, A., & Zenebe, G. (2025). The role of fiber alkalization in enhancing the physical and mechanical performance of false banana fiber and its composites in geopolymer matrices. *Scientific Reports*, *15*(1). https://doi.org/10.1038/s41598-025-18955-2

[3] Irawan, A. P., & Sukania, I. W. (2015). Tensile Strength of Banana Fiber Reinforced Epoxy Composites Materials. *Applied Mechanics and Materials*, *776*, 260–263. https://doi.org/10.4028/www.scientific.net/AMM.776.260

[4] Kanathala, Y., Sonkar, M., & Naik, B. K. (2025). Next-generation hygroscopic cooling fabrics: A review of advanced materials and textile innovations for thermal comfort. *Next Bioengineering*, *1*, 100006. https://doi.org/10.1016/j.nxbio.2025.100006

[5] Naik*, Dr. V. R. (2020). Development of Radiator Fan using Composite Material for Automotive Application. *International Journal of Innovative Technology and Exploring Engineering*, *9*(4), 2163–2168. https://doi.org/10.35940/ijitee.D1653.029420

[6] Ruzuqi, R. (2020). Tensile Strength Analysis of Polymer Composite Materials Fiber Reinforced in The Fiber boat Application. *Journal of Research and Opinion JRO*, *7*(8), 2763–2769. https://doi.org/10.15520/jro.v7i8.74

[7] Seid, A. M., & Adimass, S. A. (2024). Review on the impact behavior of natural fiber epoxy-based composites. *Heliyon*, *10*(20), e39116. https://doi.org/10.1016/j.heliyon.2024.e39116

[8] SRINIVASAN, R., & THIRUGNANAM, S. (2020). MECHANICAL PROPERTIES OF HYBRID FIBER REINFORCED EPOXY COMPOSITES. *I-Manager's Journal on Mechanical Engineering*, *10*(1), 32. https://doi.org/10.26634/jme.10.1.16744

[9] Vidya Sagari, K., & Prasad, K. (2026). Effect of alkali treatment on the mechanical and interfacial properties of woven jute and kenaf fiber reinforced epoxy composites. *EPJ Web of Conferences*, *345*, 01073. https://doi.org/10.1051/epjconf/202634501073

[10] Waithaka, A., Plakantonaki, S., Kiskira, K., Mburu, A. W., Chronis, I., Zakynthinos, G., Githaiga, J., & Priniotakis, G. (2025). Cellulose-Based Biopolymers from Banana Pseudostem Waste: Innovations for Sustainable Bioplastics. *Waste*, *3*(4), 37. https://doi.org/10.3390/waste3040037

[11] Widodo, E., Mulyadi, Garside, A. K., Wirawan, W. A., & Yaakob@Ariffin, N. H. M. (2025). Enhancing adhesivity and mechanical performance of sansevieria fiber-reinforced composites through alkali treatment. *South African Journal of Chemical Engineering*, *54*, 167–178. https://doi.org/10.1016/j.sajce.2025.07.007