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Development and Characterization of Natural Fibre Reinforced Polymer Composite for Helicopter Tail Rotor Blade

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***Abstract* - The helicopter tail rotor blade is used to counteract the torque of the main rotor and maintain directional control. It generates lateral thrust to prevent yaw motion and ensure stability. These blades operate at high rotational speeds and are subjected to aerodynamic, centrifugal, bending, and torsional loads. The blade root experiences maximum stress and must withstand cyclic loading. Composite materials are commonly used for tail rotor blades due to their high strength-to-weight ratio, corrosion resistance, and ability to tailor stiffness. Dynamic behaviour is also important, as the blade must operate away from natural frequencies to avoid resonance and vibration. Proper material selection and structural design help improve stability, reduce vibration, and ensure safe and efficient helicopter operation.**

The present work investigates the fabrication and evaluation of a sustainable natural fibre reinforced polymer composite using sisal and sunn hemp fibres with epoxy resin and rice husk filler. The laminate was prepared by hand lay-up with controlled curing. The composite exhibited a maximum tensile strength of 55.89 N/mm², flexural strength of 66.96 N/mm², hardness of 78–79 Shore D, and low moisture absorption of 2.1–2.6%. ANSYS-based structural analysis showed deformation increasing from 2.42 mm to 21.79 mm and stress from 10.64 MPa to 95.58 MPa with rising angular velocity (50–150 rad/s). Modal analysis indicated stable dynamic behavior with key frequencies at 15.33 Hz, 106.65 Hz, and 652.99 Hz. The results demonstrate that the developed composite is suitable for lightweight aerospace applications such as secondary structures and low-RPM rotor components, offering sustainability and cost benefits.

Keywords - NFRP Composite, Sisal Fibre, Sunn Hemp Fibre, Rice Husk Powder, Aerospace.

I. INTRODUCTION

A. Composite Material

A composite material is created by joining two or more different materials to form a new material with better properties. This approach helps take advantage of the strengths of every individual material while reducing individual weaknesses.

- Matrix:- It is base material in a composite that holds everything together. It surrounds and supports the reinforcement (like fibres) and helps transfer load between them. The matrix also protects the reinforcement from damage and gives the composite its overall shape.
- Reinforcement:- It is the strong material added to a composite to improve its strength and stiffness. It is usually in form of fibres, particles, or layers. The main job of reinforcement is to carry most of the load and make the composite stronger than the matrix alone.

Composite material is classified based on materials used and how they are combined. The main types are:

- Based on Matrix:-
  a. Polymer Matrix Composites (PMCs)
  b. Metal Matrix Composites (MMCs)
  c. Ceramic Matrix Composites (CMCs)
- Based on Reinforcement Type:-
  a. Fiber-Reinforced Composites
  b. Particle-Reinforced Composites
  c. Structural Composites
- Based on Nature of Materials:-
  a. Natural Fiber Composites
  b. Synthetic Fiber Composites
  c. Hybrid Composites

Fabrication Techniques:- The manufacturing method of composite material will depend on type of fibres, matrix material, and required shape. Some common fabrication methods are:

- Hand Lay-Up Method
- Compression Moulding
- Vacuum Bag Moulding
- Pultrusion
- Resin Transfer Moulding (RTM)

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Applications:- Composite materials are widely used due to their high strength-to-weight ratio, lightweight nature, and corrosion resistance. In aerospace, they reduce weight and improve fuel efficiency. In automotive applications, composites help produce lightweight and strong components for better performance. They are also used in construction for durability, in sports equipment for high performance, and in medical applications due to their biocompatibility and strength.

Limitations:- Composite materials offer high strength-to-weight performance but have several limitations. Fabrication is costly due to expensive materials and processing methods. Recycling is difficult, especially for thermoset composites. Repair and maintenance are complex, and damage detection often requires advanced inspection. Their properties are direction-dependent, and environmental factors such as moisture can reduce performance.

B. Natural Fibre/Material used for the project

Raw materials are essential for composite fabrication and directly influence strength, weight, durability, and cost. Composites mainly consist of a matrix material (resin) that binds the structure and reinforcement materials (fibres/fillers) that improve mechanical properties.

- Sisal fibre:- It is obtained from the leaves of the sisal plant grown in hot climates. It offers good strength, durability, and moderate moisture resistance. Being natural and renewable, sisal fibre is suitable for eco-friendly composite applications.
- Sunn hemp:- It is a fast-growing plant that provides strong, lightweight, and biodegradable fibres. These fibres are suitable for sustainable composite fabrication and are increasingly used in environmentally friendly applications.
- Rice husk:- It is an agricultural waste converted into fine powder. It contains silica, which improves heat resistance, surface strength, and moisture resistance. It is a low-cost and eco-friendly filler material.
- Epoxy resin:- It acts as the matrix material, while the hardener initiates curing. Together, they form a strong bond that holds fibres and provides shape and strength to the composite.

C. NACA 0012 Airfoil

The NACA 0012 is a symmetrical airfoil with zero camber and 12% thickness, widely used in aerospace applications. Its simple geometry and well-documented characteristics make it suitable for rotor blades and control surfaces. Due to symmetry, it provides similar aerodynamic behaviour for positive and negative angles of attack, producing balanced forces and improved stability, which is useful for helicopter tail rotor blades.

The airfoil also offers structural and dynamic advantages such as uniform stress distribution, predictable vibration behaviour, and reduced pitching moment. Its 12% thickness provides sufficient space for structural reinforcement while maintaining a good stiffness-to-weight ratio. These features make the NACA 0012 airfoil suitable for rotor blade applications requiring stability, control, and vibration reduction.

II. FABRICATION PROCESS

A. Material Selection

Figure 1. Types of Fibers and Powder

Sisal fibers, sunn hemp, and rice husk powder are commonly used as natural reinforcements in composite materials due to their availability, low cost, and biodegradability. These fibers improve the mechanical strength, impact resistance, and thermal stability of composites while reducing environmental impact. Their use supports sustainable material development and reduces reliance on synthetic fibers.

Figure 2. Epoxy Resin & Hardner

Epoxy Resin and Hardener:- L-12 & K-6 are used.
Resin L12 is a commonly used epoxy with high strength, good bonding, and chemical resistance, making it suitable for composite fabrication. It acts as the matrix material that holds the reinforcing fibres and provides structural integrity. Hardener K6 is used as the curing agent with L12 resin. When mixed in the recommended ratio, it initiates cross-linking and converts the resin into a solid structure, improving strength, thermal stability, and durability. The L12–K6 system is widely used in aerospace and engineering applications for reliable composite manufacturing.

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B. Formulation

Volume Fraction method:-

$$V_{composite} = V_{fibre} + V_{matrix}$$
$$V_{c(100\%)} = V_{f(30\%)} + V_{m(70\%)}$$
$$V_{c(100\%)} = V_{sisal(15\%)} + V_{sunn\ hemp(15\%)} + V_{m(70\%)}$$

The volume fraction method defines the composite as a combination of fibre and matrix volumes. For example, the composite may consist of 30% fibre and 70% matrix. The fibre portion can be divided into 15% sisal fibre and 15% sunn hemp fibre, with 70% matrix forming the remaining volume. This method helps in accurately determining the proportion of each constituent in the composite.

$V_{composite}$:-

$V_c = 0.3m \times 0.3m \times 0.0032m = 2.88 \times 10^{-4}\ m^3$
Length = 0.3m
Breadth = 0.3m
Thickness = 0.0032m

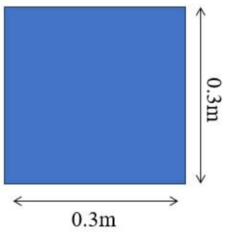


Figure 3. Mold Dimension

The volume of the composite (Vc) is calculated by multiplying its length, breadth, and thickness. Given the dimensions as 0.3 meters in length, 0.3 meters in breadth, and 0.0032 meters in thickness, the resulting volume is 2.88×10^{-4} cubic meters. This method of determining composite volume aligns with procedures as in ASTM standards.

Fibres Weight & Density:-

Table 1. Weight and Density of Fibres & Powder

Fibre	Weight(per layer)	Density
Sisal	25g	1580 kg/m³
Sunn Hemp	35g	1400 kg/m³
Rice Husk Powder	20g	350 kg/m³

Calculations for Reinforcements(Fibres):-

The fibre content in a composite can be calculated by multiplying the fibre percentage by the total composite volume (Vc). This estimation is useful for determining the amount of reinforcement present in composite, which directly influence the mechanical behaviour and overall performance.

Amount of Fibre In Composite = % of Fibre × V_c :-
Amount of Sisal In Composite = $15\% \times 2.88 \times 10^{-4} = 4.32 \times 10^{-5}\ m^3$
Amount of Jute In Composite = $15\% \times 2.88 \times 10^{-4} = 4.32 \times 10^{-5}\ m^3$

The volume of a single fiber layer can be theoretically calculated by dividing weight of the fiber by its density. This relationship allows for determining physical space occupied by the fiber layer within a composite, which is essential for analyzing the material's structure and optimizing its mechanical properties.

Volume of 1 layer of Fibre = Weight of fibre/Density of fibre:-
Volume of 1 layer of Sisal = $0.0255/1580 = 1.61 \times 10^{-5}\ m^3$
Volume of 1 layer of Sunn Hemp = $0.0350/1400 = 2.50 \times 10^{-5}\ m^3$

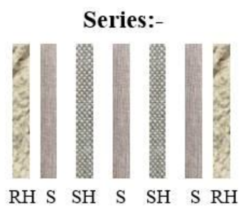
The number of fiber layers in a composite can be theoretically calculated by dividing total amount of fiber by the volume of a single fiber layer. This help in determining how many layer is needed to achieve the desired fiber content and composite thickness for specific mechanical performance.
Number of Layers of Fibre = Amount of Fibre / Volume of 1 layer of Fibre :-
Number of Layers of Sisal = $4.32 \times 10^{-5} / 1.61 \times 10^{-5} = 2.68 \approx 3$ Layers
Number of Layers of Sunn Hemp = $4.32 \times 10^{-5} / 2.50 \times 10^{-5} = 1.72 \approx 2$ Layers

Calculation for Matrix (Epoxy Resin):-

$V_{matrix} = 70\% \times V_{composite} = 70\% \times 2.88 \times 10^{-4} = 2.016 \times 10^{-4}\ m^3$
Density = Mass / Volume
Mass = Density × Volume
= $1.2 \times 10^3 \times 2.016 \times 10^{-4}$
= 0.24192 kg
1 Lt = 916 gm
Quantity of Matrix = 241 gm
Quantity of Matrix = (1000 ml × 241 gm) / 916 gm
= 263.1 ml
Overall Quantity of Matrix = 263.1 ml + 26.3 (10% error)
= 289.4 ≈ 290 ml

The volume of the matrix (Vmatrix) is calculated as 70% of the total composite volume. For a composite volume of $2.88 \times 10^{-4}\ m^3$, the matrix volume is $2.016 \times 10^{-4}\ m^3$. Using the density formula (Density = Mass / Volume), the mass of the matrix is got from multiplying the density of the resin ($1.2 \times 10^3\ kg/m^3$) with the matrix volume, resulting in a mass of 0.24192 kg. Since 1 liter of the matrix material weighs approximately 916 grams, this mass converts to 241 grams. The volume required is then calculated using the proportion: (1000 ml × 241 g) / 916 g, yielding 263.1 ml. To account for possible processing losses or measurement errors, a 10% margin is added, resulting in a final matrix quantity of approximately 290 ml. This theoretical approach ensures accurate estimation of the resin required for composite fabrication.

Series Selection of Fibres:-



RH-Rice Husk ; S-Sisal ; SH-Sunn Hemp
Figure 4. Series of Fibres for Composite

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To achieve optimal quality and improved mechanical performance in the composite, a specific layup sequence is adopted by using hand lay-up method. The layering is done in the order of sisal, sunn hemp, sisal, sunn hemp, and finally sisal, forming a five-layered reinforcement structure. This alternating arrangement is selected to balance the properties of both fibers—sisal for its excellent tensile strength and durability, and sunn hemp for its good flexibility and biodegradability. The repetition of sisal layers ensures structural integrity and load-bearing capacity, while the inclusion of sunn hemp enhances overall toughness and fiber bonding. To improve the surface finish and add an extra layer of protection, rice husk powder is used as a surface coating.

C. Prototype Development

Figure 5. Fabrication of Composite Material

To begin fabrication, sisal and sunn hemp fibres were cut into 30 × 30 cm square pieces using suitable tools, ensuring clean and uniform edges for proper stacking and bonding. The hand lay-up technique, a simple open-mould process for producing fibre-reinforced composites, was used. It requires minimal equipment and allows good control over fibre orientation and resin application. A clean aluminium mould plate was used as the base, coated with mould release wax and aluminium foil to prevent adhesion. Rice husk powder was mixed with epoxy resin in a 1:2 ratio and applied to one side of the first sisal layer. Then, epoxy mixed with hardener was applied for proper bonding. A sunn hemp layer was placed over it and coated with resin. This sequence continued with layers arranged as sisal–sunn hemp–sisal, each thoroughly impregnated. The top layer was coated with the rice husk–epoxy mixture. X`After stacking five layers, the laminate was compressed using an aluminium plate with an applied load of about 150 kg and cured at room temperature for 48 hours. The laminate was then removed easily using the aluminium foil. Finally, it was visually inspected for defects like air voids or uneven resin distribution, and prepared for cutting, shaping, and testing.

D. Test Specimen Preparation

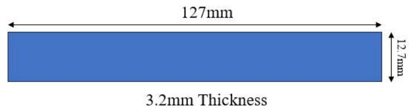
Figure 6. Test Specimen Preparation

After removing the aluminium foil, the composite surface was smooth and defect-free, indicating good resin penetration and effective hand lay-up with proper curing. The laminate was then trimmed to remove excess material, producing clean edges and ensuring dimensional accuracy. Test specimens were prepared according to ASTM standards for tensile, flexural, and hardness testing, with appropriate shapes and surface finish to ensure reliable results.

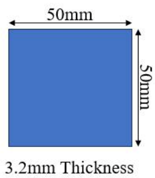
<u>Dimensions for the specimen preparation as per ASTM Standards:-</u>

Tensile Test Specimen :-

Flexural Test Specimen :-



Hardness Test Specimen :-



Moisture Absorption Test Specimen:-

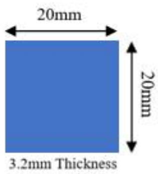


Figure 7. Test Specimen Dimensions

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III. CHARACTERIZATION & SOFTWARE TOOLS

Mechanical testing is used to evaluate the strength, durability, and performance of composite materials under different loading conditions. For natural fibre composites, these tests help determine suitability for structural applications. ASTM standards ensure reliable and comparable results. Properties such as strength, stiffness, hardness, and moisture resistance are evaluated to predict material behaviour in service conditions.

- Tensile Test (ASTM D3039):- The tensile test measures tensile strength, modulus, and elongation under axial loading. It evaluates the ability of the composite to withstand pulling forces.
- Flexural Test (ASTM D790):- Flexural testing determines bending strength and stiffness of the composite. It indicates resistance to deformation under transverse loading.
- Hardness Test (ASTM D2240):- Hardness testing evaluates resistance to surface indentation and wear, indicating surface durability of the composite.
- Moisture Absorption Test (ASTM D570):- This test measures water absorption of the composite. It helps assess environmental durability and the effect of moisture on material properties.

In this study, CATIA is used to create the three-dimensional model, while ANSYS is used to analyse structural response under applied loading conditions. Finite element analysis predicts stress, deformation, and overall performance, supporting experimental results. A helicopter tail rotor blade based on the NACA 0012 airfoil was modelled and analysed using static structural, thermal, and modal analysis to evaluate suitability of the developed composite for aerospace applications.

IV. RESULTS AND DISCUSSION

The experimentation and analysis phase carried out systematically assess the performance characteristics of developed natural fibre composite. Mechanical evaluation was conducted through tensile, flexural, hardness, and moisture absorption tests to examine strength, stiffness, surface durability, and environmental behaviour of material. In addition to experimental investigations, analysis performed using ANSYS to support and validate the test results. Static structural analysis, static thermal analysis, and modal analysis were executed to study stress distribution, temperature influence, and vibration response of the composite. The combined use of experimental testing and computational simulation enables a comprehensive understanding of the composite's behaviour and its suitability for engineering applications.

A. Mechanical Testing

Table 2. Mechanical Testing Results

SL No.	Experimental Test Name	Sample No.	Results
1	Tensile Test	1	TS:- 49.665 N/mm^2
		2	TS:- 55.893 N/mm^2
2	Flexural or Bend Test	1	FS:- 66.961 N/mm^2
		2	FS:- 61.293 N/mm^2
3	Hardness Test	1	78 Shore D
		2	79 Shore D
4	Water Absorption Test	1	2.1%
		2	2.6%

The developed composite tensile strength values in the range of 49.665 N/mm^2 to 55.892 N/mm^2, indicating its ability to withstand considerable tensile loading before failure. This behaviour confirms that the material possesses sufficient resistance to axial stretching forces. The measured flexural strength varied between 61.293 N/mm^2 and 66.961 N/mm^2, reflecting strong resistance to bending loads. Such flexural performance is particularly important for tail rotor blades, which are continuously subjected to bending stresses due to aerodynamic forces, as it helps maintain structural stability and integrity. The hardness of composite was found to be approximately 78–79 Shore D, signifying a hard and wear-resistant surface. This level of hardness enhances resistance to surface damage, abrasion, and minor impacts, thereby supporting smoother operation and extended service life of rotor components. Moisture absorption values ranged from 2.1% to 2.6%, which is considered acceptable for natural fibre–reinforced composites. These results indicate satisfactory moisture resistance, enabling the material to retain its mechanical properties under humid or wet environmental conditions, an essential requirement for aerospace components such as tail rotor blades.

Figure 8. Mechanical Test Specimens

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B. CAD Model of NACA 0012 Tail Rotor Blade

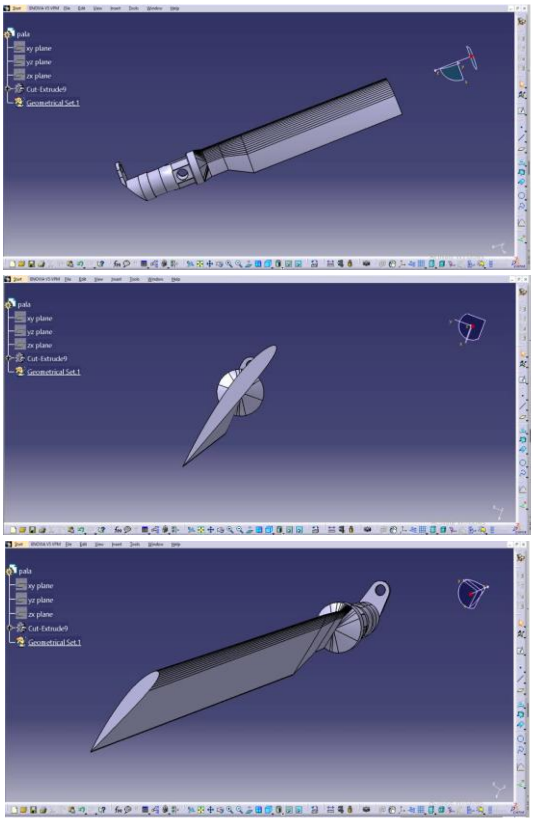

Figure 9. Model of NACA 0012 Tail Rotor Blade

The NACA 0012 airfoil is a symmetrical design with a thickness equal to 12% of its chord length, located halfway along the chord. It's commonly used in tail rotor blades because its symmetrical shape means it produces no lift at zero angle of attack, allowing it to perform equally well in both directions — which is crucial since a tail rotor must push air both ways to control a helicopter's yaw. This airfoil offers a good balance between strength and aerodynamic efficiency, providing stable performance, low pitching moments, and smooth stall behavior. Altogether, these features make the NACA 0012 an excellent and reliable choice for anti-torque systems in helicopters.

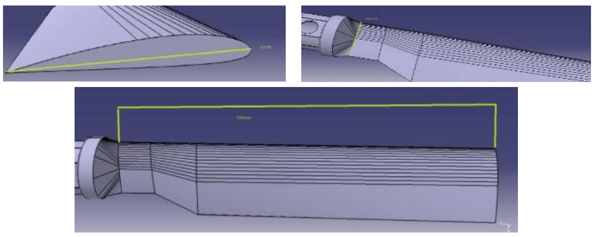

Figure 10. Tail Rotor Blade With Dimensions

Tip Chord :- 160mm

Root Chord :- 60mm

Span :-700mm

C. ANSYS Simulation & Analysis

At the initial stage, a new composite material designated as S/SH/R was defined in the Engineering Data module of ANSYS by specifying the required material properties. The NACA 0012 tail rotor blade geometry is imported to Model workspace for numerical analysis. An appropriate meshing strategy was applied by selecting a suitable element size and refinement level to achieve good results while balancing computational efficiency. Following the meshing process, a fixed support was assigned at blade root to represent actual constraint at tail rotor blade attachment. To simulate actual operating conditions, different values of rotational velocity were applied in the appropriate direction. The analysis was then performed to study the structural response of blade under rotational loading. The evaluated results included total deformation, equivalent elastic strain, and equivalent (von Mises) stress at various rotational speeds.

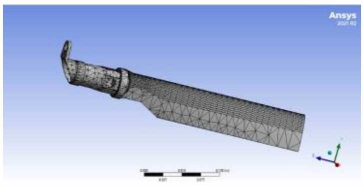

Figure 11. Mesh Generation of Blade

Static structural:- This analysis is performed to evaluate behaviour of a structure under loads and boundary condition that do not vary with time. This analysis used to determine key responses such as deformation, stress distribution, and strain developed within a component. It is widely applied to check whether a structure can safely sustain the expected service loads without experiencing failure. In engineering design, static structural analysis plays important role in material selection, design verification, and safety evaluation. Static structural analysis is performed for multiple rotational speed values to examine influence of speed on the structural response of the component. Variations in deformation, stress, and strain were analysed as the rotational velocity was changed. This method provides the behaviour of the structure under different operating conditions and helps in identifying safe operating ranges as well possible critical loading scenarios.

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At 50 rad/s:-

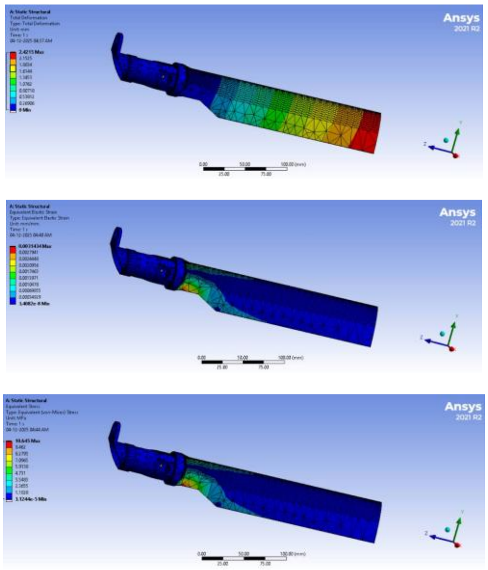

Figure 12. Static Structural Analysis at 50 rad/s

At 50 rad/s, the blade shows very low deformation (2.42 mm), indicating stable structural behavior. Stress and strain remain minimal, concentrated mainly near the root. The composite material safely withstands this loading without any risk of failure.

At 100 rad/s:-

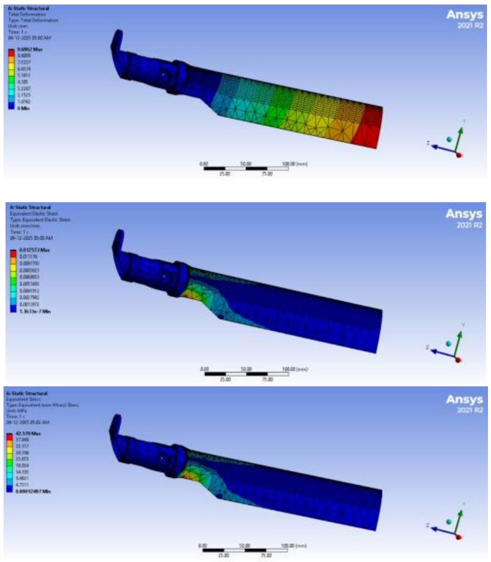

Figure 13. Static Structural Analysis at 100 rad/s

At 100 rad/s, deformation increases to 9.68 mm as centrifugal forces rise. Stress climbs to 42.57 MPa, approaching moderate loading but still within safe limits. The blade remains structurally stable, though higher speeds begin to challenge material strength.

At 150 rad/s:-

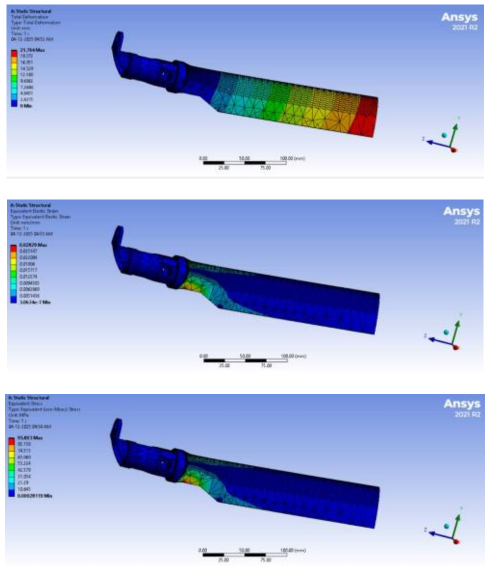

Figure 14. Static Structural Analysis at 150 rad/s

At 150 rad/s, deformation reaches 21.79 mm, showing significant deflection. Stress peaks at 95.58 MPa, which exceeds the composite's experimental strength. This indicates the material is not suitable for operating at this high speed and may fail at the root region.

Steady-State Thermal:- This analysis is used for determining/finding temperature distribution within component when thermal conditions remain constant over time. It helps in how heat flows through a material and how temperature gradients are formed. This analysis is important for evaluating thermal stability and heat resistance of materials. It ensures that the component can operate safely under continuous thermal exposure.

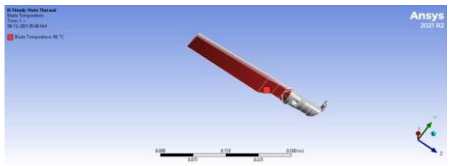

Figure 15. Blade Temperature

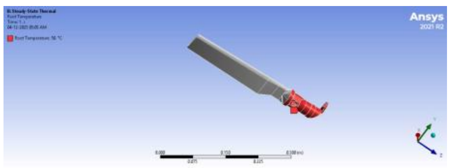

Figure 16. Root Temperature

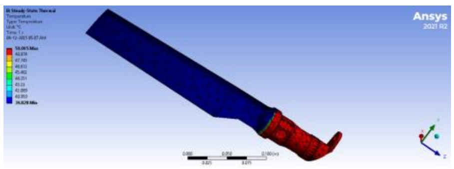

Figure 17. Steady-State Thermal Analysis

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The steady-state thermal analysis, performed by applying 50 °C at the root and 40 °C at the blade, shows a smooth heat distribution where the root remains the hottest region due to its structural thickness and load transfer role, while the blade gradually cools toward the tip, reaching about 39.8 °C. This uniform gradient indicates good thermal conductivity and no formation of critical hotspots, demonstrating that the composite material can withstand moderate operating temperatures without thermal instability.

Modal:-

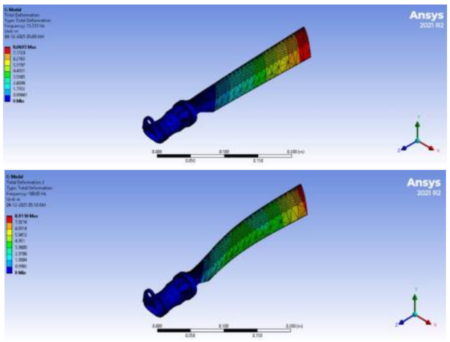

Figure 18. Modal Analysis - 1st Flap wise Bending and 1st Lead Lag Bending

The 1st flap-wise bending mode represents the primary bending of the blade in the direction perpendicular to the plane of rotation, mainly caused by aerodynamic and centrifugal forces. The 1st lead–lag bending mode corresponds to bending within the plane of rotation due to inertial and Coriolis effects. These fundamental modes are critical for assessing vibration behaviour and avoiding resonance during operation.

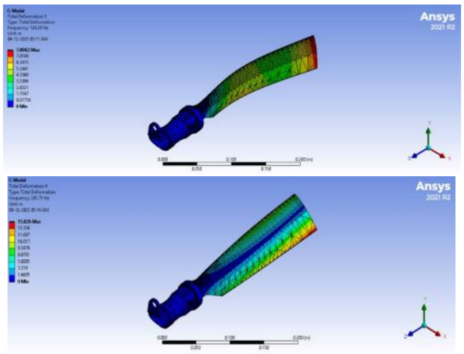

Figure 19. Modal Analysis - 2nd Flap wise Bending and 1st Torsional Mode

The second flap-wise bending mode describes a higher-order bending deformation of the blade occurring perpendicular to the plane of rotation, with greater curvature along the blade span. The first torsional mode involves twisting of blade to its longitudinal axis, which directly affects aerodynamic stability and control behaviour. Analysis of these modes is essential to understanding dynamic response of the blade and ensuring safe vibration performance.

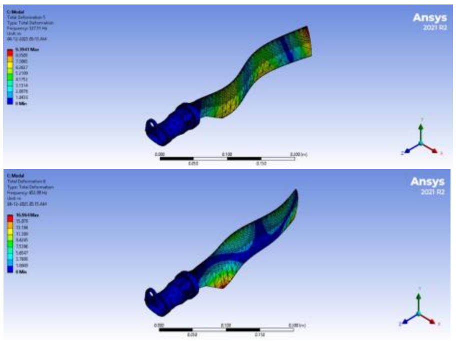

Figure 20. Modal Analysis - 2nd Lead Lag Bending and Coupled Flap Torsion Mode

The 2nd lead–lag bending mode represents higher-order in-plane bending of the blade with increased curvature along the span. The coupled flap–torsion mode involves simultaneous bending and twisting of the blade, showing interaction between flap-wise and torsional motions. Analysis of these modes is essential for understanding complex vibration behaviour and ensuring dynamic stability.

D. Overall Analysis

Static Structural Analysis:-

Table 3. Comparison Table of Static Structural Analysis

Parameter	50 rad/s	100 rad/s	150 rad/s
Max Deformation(mm)	2.42	9.68	21.79
Max Strain	0.001314	0.010257	0.022529
Max Stress(MPa)	10.64	42.57	95.58

Deformation, strain, and stress increase with rotational speed due to centrifugal loading, with safe performance at 50 and 100 rad/s but exceeding material limits at 150 rad/s. The blade root is the most critical region, experiencing maximum stress. This indicates suitability for low- to moderate-speed applications unless reinforced. Performance can be improved through root reinforcement, optimized fibre stacking, hybridisation with synthetic fibres, and advanced fibre treatments, along with further fatigue and dynamic analysis.

Modal Analysis:-

Table 4. Comparison Table of Modal Analysis

Modal Type	Frequency
1st Flap wise Bending	15.33 Hz
1st Lead–Lag Bending	100.65 Hz
2nd Flap wise Bending	124.29 Hz
1st Torsional Mode	201.71 Hz
2nd Lead–Lag Bending	327.51 Hz
Coupled Flap-Torsion mode	652.99 Hz

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Modal analysis identified six vibration modes, with frequencies ranging from 15.33 Hz to 652.99 Hz and deformation becoming more complex at higher modes. Lower modes show simple bending, while higher modes exhibit coupled bending–torsion behavior. The low first bending frequency is critical for avoiding resonance, whereas higher modes are less likely during normal operation but may occur under transient conditions. The results indicate a need for improved root stiffness, optimized fibre orientation, and damping, along with further harmonic and frequency analysis to ensure safe operation and durability.

Steady-State Thermal Analysis:-

Revealed a controlled temperature distribution, with higher temperatures near the root and lower values along the blade span, indicating good thermal stability of the composite. Modal analysis identified stable vibration behaviour, confirming suitability for lightweight rotor blade applications.

E. Comparison with Existing NFRP Material

Table 5. Comparison of S/SH/R NFRP with Existing NFRP Composite

Parameter	S/SH/R Hybrid	Flax Blade	Jute/Epoxy Blade
Density(Kg/m³)	1212	1280	1220
Peak Load(kN)	3.3	3.9	2.46
Moisture Absorption(%)	2.1-2.6	4-6	8-12
Static Structural Deformation(mm)	2.47	-	10-12mm

The S/SH/R hybrid composite demonstrates good overall performance compared with flax and jute/epoxy rotor blade materials. It exhibits lower moisture absorption in the range of 2.1–2.6%, which enhances environmental durability, and achieves a higher peak load capacity of 3.3 kN than jute/epoxy composites. At a rotational speed of 50 rad/s, the S/SH/R blade shows significantly reduced static structural deformation of 2.47 mm, whereas jute-based blades experience deformation in the range of 10–12 mm, indicating improved stiffness under rotational loading. Although flax-based blades display marginally higher peak load values, their increased moisture absorption and higher density make the S/SH/R hybrid composite a more balanced, lightweight, and suitable choice for rotor blade applications.

F. Applications and Limitations

Based on the mechanical test results and ANSYS evaluations, the developed natural-fibre composite (sisal + sunn hemp + rice husk with epoxy) can be effectively used in low-to-moderate load applications where sustainability and lightweight material is more critical than extreme strength:
Small UAV and Drone Rotor Blades:- Since the material shows moderate stiffness and low deformation at lower rotational speeds (2.47 mm at 50 rad/s), it is suitable for low-speed UAV rotors where loads are smaller than full-scale helicopter tail rotors.
Industrial Fan Blades & Ventilation Systems:- Moderate strength (TS ≈ 49–55 MPa, FS ≈ 61–66 MPa) and acceptable thermal behavior (40–50 °C temperature gradient) make the material feasible for medium-speed fan or blower blades.

LIMITATIONS:-

- Not Suitable for High-Speed Helicopter Tail Rotor Blades
- High Stress Concentration Near Root Region
- Modal Analysis Shows High Vibration Sensitivity
- Moisture Absorption Ruins Long-Term Stability

V.CONCLUSION

This work focused on fabrication and assessment of hybrid natural fibre composite composed of sisal and sunn hemp fibres with rice husk powder incorporated into an epoxy matrix, with the objective of investigating its potential as a sustainable material for aerospace applications. Experimental testing showed moderate tensile, flexural, and hardness values, confirming that the material possesses good stiffness-to-weight characteristics but falls short of the strength typically required for high-performance rotor components. ANSYS simulation further highlighted significant deformation, rising stresses, and strong vibration responses at increasing rotational speeds, indicating that the composite cannot safely withstand the demanding dynamic and thermal conditions of a helicopter tail rotor blade. Overall, while the material does not meet the requirements for full-scale rotor blade integration, it demonstrates promising potential for low-load aerospace components, UAV rotor blades, and other lightweight engineering applications. With improved fibre treatment, optimized stacking, higher fibre volume fractions, and advanced manufacturing methods, the performance of natural-fibre composites can be enhanced, supporting future progress toward greener and more sustainable aerospace materials.

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