Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 8, No.4, August : 2024

A COMPREHENSIVE REVIEW ON DESIGN AND ANALYSIS OF WIND TURBINE BLADE

J.BALA MANI VENKATA KUMAR, R.SYAM KUMAR, M.GAYATRI PRASAD, UG students, Department of Mechanical Engineering, NRI Institute of Technology, Vijayawada, A.P, India-521212.
Mrs.CH. SRI LATHA Associate Professor, Department of Mechanical Engineering, NRI Institute of Technology, Vijayawada, A.P, India-521212.

ABSTRACT
Wind power is one of the source of natural energy which is tapped by wind turbines in open areas of land. The biggest task involved in this, is achieving maximum efficiency with minimal cost. One way this can be achieved is by replacing the turbine blades with hybrid composite material blades. The main advantage of this is to increased strength and stiffness. Wind turbine blades area advancements in design and materials, including glass fiber reinforced thermoplastics, hybrid composites, jute fiber reinforced epoxy composites, Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) composites for wind turbine blades, finding material superior in mechanical properties and durability. It also explores lightweight materials, Nano composites, fatigue response models, and bamboo fiber and recycled plastics composites. The study aims to maximize energy production and minimize blade weight.
Keywords: GFRP, CFRP, Materials, Wind turbine, blade

I. Introduction
Wind energy is a key component of the global shift towards renewable energy sources, and the blades of wind turbines are central to their efficiency and performance. The design and materials used for these blades are crucial for their effectiveness and longevity. Composite materials, such as glass fiber epoxy, polymers, resign epoxy, and plastic, are used in wind turbine blades. Blade design is a complex process involving aerodynamic, structural, and material considerations. Fiber-reinforced polymers (FRPs) have become increasingly important in blade design due to their advantages over traditional metallic and non-composite materials. Carbon Fiber Reinforced Polymer (CFRP) is known for its exceptional strength-to-weight ratio, offering superior mechanical properties and reducing fatigue. Glass Fiber Reinforced Polymer (GFRP) is cost-effective, flexible, and suitable for many applications. Hybrid composites combine CFRP and GFRP to optimize performance while controlling costs, achieving a balance between strength, weight, and cost-efficiency.

II. Literature
Peter L. Bishay et al., [1] described the SCAMORSA-1 was a small-scale camber-morphing turbine blade designed for increased aerodynamic efficiency and load avoidance. It consists of three sections: a rigid section, a morphing section, and a fixed blade tip covered by composite skin. The blade incorporates advanced camber-morphing technology, hybrid ribs, hexagonal honeycomb infill, servo motors, and PCTPE nylon-based 3D-printing material. The blade features a composite skin structure, not relying on stretchable skin, and sliders to maintain a smooth cambered surface during operation. The blade's design aims to extract maximum energy without excessive stress levels.
Daniel Trento et al., [2] The study suggests a method to reduce the negative effects of coarse recycled aggregate in concrete mixes by incorporating raw-crushed wind-turbine blade waste. This method reduces plastic shrinkage and increases flexural and compressive strength while maintaining a constant compressive strength. The construction sector's aggregate consumption is increasing by 5.2% annually, resulting in 51.79 billion tons in 2019. Recycling aggregate from construction and demolition waste can reduce natural-aggregate consumption and recover landfilled materials. Strategies like mortar removal, supplementary materials, and fiber incorporation can improve RAC properties. The study

found that replacing coarse aggregate with recycled aggregate and adding RCWTB to concrete decreases workability due to higher interlocking forces and interference with other component movement. A higher water/cement ratio is required for CRA and RCWTB. The research suggests a sustainable method to enhance concrete properties with coarse recycled aggregate, incorporating RCWTB for improved performance in fresh density and air content.
Vanesa Ortega-Lopez et al., [3] described the Concrete mixes containing Raw-Crushed Wind-Turbine Blade (RCWTB) can improve compressive stress-strain performance by enhancing ductility and load-bearing capacity. The material, obtained through crushing wind-turbine blades, contains 66.8% GFRP-composite fibers, 6.3% balsa-wood particles, 8.3% polyurethane particles, and 18.6% composite micro-fibers. The study found that higher RCWTB content enhances elastic stiffness and plastic deformability, improving concrete ductility. Compressive strength initially increases with 1.5% RCWTB due to fiber crack-stitching, but decreases due to increased water/cement ratio and flexible waste particles. RCWTB consistently enhances failure strain and fracture strain, indicating improved deformability and energy absorption, comparable to commercial fibers.
Mishnaevsky Jr. Leon et al., [4] this article explores recycling technologies for wind turbine blades, focusing on the potential for new recyclable blade generation. It highlights the challenges of balancing blade durability and strength requirements with material separation costs and limited usability of recycled products. The article also discusses recent developments in pyrolysis and solvolysis technologies for glass fiber/epoxy blades and thermoplastic and recyclable polymers. The article highlights Siemens Gamesa's Recyclable Blade as the first wind turbine blade recyclable. The sustainability of wind turbines can be achieved by developing effective recycling technologies for current blades and new recyclable composites for large blades.
Zachariah Arwood et al., [5] he research on glass fiber reinforced thermoplastic composites has shown that infusible acrylic resins can replace epoxy-based systems in wind blade manufacturing. Comprehensive static test protocols were performed on unidirectional and biaxial E-glass reinforced thermoplastic and epoxy laminates. The results support infusible acrylic thermoplastic resins as a viable alternative. Traditional E-glass fiber reinforced thermoplastics are used due to their low cost and high specific properties. However, research is ongoing for a recyclable thermoplastic substitute due to poor recyclability. Potential applications include furniture, low-cost residential roofing, and interior walls. Low viscosity liquid thermoplastic resins offer thermoformability, weldability, and recyclability, making them cost-effective. The study examined the mechanical properties of E-glass fiber reinforced laminates made with acrylic resin, finding similar matrix adhesion to fiber in both acrylic and epoxy infused samples. The thermoplastic infusion process is still in its infancy, but further investigation can optimize it. Elium resin showed increased static moduli and superior biaxial loading properties, making it a promising alternative to epoxy in GF laminates for wind blade manufacturing.

R. Gukendran et al., [6] the study examines the performance of composite materials in wind turbines under various load conditions using the ANSYS Workbench. The research focuses on the need for increased energy efficiency and lifetime of wind turbines due to rapid advancements in the energy sector. Common composite materials used include epoxy, Aramid Fibres, and CFRP. The study analysed a wind turbine blade with a stress distribution of 600kw using the finite element method. The analysis revealed that E-Carbon, E-glass fiber, Kevlar fiber, and Carbon fiber Reinforced Polymer were the most suitable materials for pin wheel type blades. The study aimed to improve the design of a mall wind turbine blade using a computer program, revealing its superior performance.
Sri Sai P. Reddy et al., [7] he explores the use of hybrid composite materials in wind turbine blades, focusing on their potential for increased efficiency and cost-effectiveness. Common materials include fiber glass, which is used in spectacles, concrete, and bricks. Hybrid composite materials are being developed for nanoscale structure improvement. The paper also discusses the importance of transitioning from non-renewable to renewable sources and the use of aramid fibers in composite materials. Wind turbines consist of a tower, blades, generator, nacelle, and hub, with blades being the

primary component. The paper highlights the need for eco-friendly solutions and the energy crisis, emphasizing the importance of optimizing wind turbine materials. Glass fiber composites are effective, but carbon, aramid, and basalt fibers are more promising. Hybrid composites may be widely used in wind turbine blade production.
Abhishekh R. Gatlewar et al., [8] he research the use of a Savonius rotor Vertical wind turbine for household and domestic electricity generation. Using various blade materials and ANSYS software for design and analysis, the study finds structure steel suitable for this application due to electricity scarcity. Wind turbines are a clean energy solution, requiring only wind energy and maintenance. The study uses ANSYS Workbench platform for engineering simulation generation and uses Pro-E software for geometric modelling. The analysis reveals that structural steel is a robust material with minimal deformation and effective stress and strain withstand ability, making it suitable for turbine rotor blades. The study developed a CR-VAWT using CAD software, demonstrating its advantages over single-rotor turbines and adaptability for large-scale wind power generation.
V. Cognet et al., [9] described a new type of wind turbine with bio-inspired flexible blades has been developed, which improves efficiency by extending working range and varying pitch angle. The blades are designed using a universal scaling method, which maximizes efficiency using Cauchy and centrifugal numbers. This method results in 5%-20% lighter blades and saves weight and complexity in rotor design. The method involves calculating the optimal pitch angle, finding the optimal soft materials, and determining material parameters. This method increases the total efficiency of horizontal-axis turbines operating at constant wind velocity or rotation rate, ranging from 4% to 150% depending on the operating mode.
Tianyu LONG et al., [10] he examines the mechanical properties of composite blades with different carbon fiber and glass fiber ratios. It reveals that increasing carbon fiber content leads to increased blade mechanical properties and strengthened torsional vibration resistance. Hybrid fiber composites have longer service life, reducing material wastage and environmental protection. The energy crisis has increased demand for small wind turbines due to their high wind energy harvesting efficiency, wide application range, unlimited sites, and low cost. The study uses modular analysis to analyse the dynamic properties of the blade structure, considering vibration forms like flapping, shimmy, and torsion. The study concludes that the hybrid fiber composite wind turbine blade has superior mechanical properties compared to pure glass fiber.

Mohammad Kafashha et al., [11] the study comparing Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP) composites for wind turbine blades found that CFRP has superior mechanical properties, decreased fatigue slope, and prolonged lifespan, making it a viable renewable energy choice. The study used INVENTOR software to design and implement the wind turbine model, examining structural variables and wind force calculations. Results showed that CFRP significantly enhances wind turbine performance, reduces blade weight, increases energy exchange efficiency, reduces blade maintenance requirements, and enhances tensile strength, corrosion resistance, and wear resistance, contributing to increased turbine durability and reduced maintenance and repair costs.
Robson Luis et al., [12] the study demonstrates the use of jute fiber reinforced epoxy composite in small-scale wind turbine blade construction, demonstrating its potential for increasing energy generation in low wind speed regions. Jute fiber is a viable alternative to carbon and glass fibers, which require high energy for manufacturing. The study uses the S1210 aero foil geometry for low-intensity winds and developed a wind blade with seven layers of jute yarn reinforcement. The blade geometry was optimized for horizontal axis wind turbines, achieving a power coefficient greater than 40% at low wind speeds. The study shows efficient aerodynamic and structural modelling, accurate torsional and flexural stiffness estimation, and lower maximum stresses than allowable stresses.
N.Lakshminarayanan et al., [13] he discusses the use of polymer composite materials in wind turbine blades to improve energy generation efficiency and reduce vibration damage. The blade profile is

crucial in a wind turbine generator and is determined by blade element momentum. The optimal design of composite blades involves aerodynamically optimal cord lengths and twist angles of air foils for blade cross-sections along the blade span-wise direction and optimal material distribution. Blades are typically made from materials like structural steel, epoxy carbon, s-glass, e-glass, and aluminium alloy. The paper aims to design and analyse polymer composite wind blade materials for efficient conversion of wind to mechanical energy with low chances of blade breakage. Two models of wind turbine blades are designed using epoxy polymer composite material, with the first model having better rigidity and stability compared to the second. The entire length of the profile angle may be optimized for better blade life in the future.

Bassey Okon Samuel et al., [14] he explores the use of natural fibers in wind turbine blades, highlighting their potential for eco-friendliness and cost-effectiveness. Wind energy is a growing renewable energy source, with a capacity of 600GW in 2018 and a predicted 49% increase in renewable energy use by 2015-2050. The wind energy industry is exploring materials like thermoset composites, thermoplastic composites, natural fiber composites, and hybrid fiber composites to improve efficiency and reduce costs. Carbon nanotube fibers are a better choice due to their exceptional properties and low density. Recent studies have shown promising performance in various composites, suggesting the potential of natural fibers as reinforcement in wind turbine blade development.

Stephane Redonnet et al., [15] the study explores the use of morphing wind turbine blades to improve aero-structural performance and efficiency. It found that void size and fraction significantly impact mechanical properties, with non-fossil energy sources boosting wind energy production. The research suggests integrating non-fossil energy sources like natural gas and fuel cells to enhance turbine efficiency. Gorney flaps and morphing mechanisms are proposed to optimize blade function, but they add complexity to design and operation. The study validates the concept through small-scale experiments in the Small Wind Tunnel at HKUST.

Haseung lee et al., [16] the study examines the use of Acoustic Emission (AE) signals to monitor the structural health of wind turbine blades, focusing on detecting internal manufacturing flaws. The research found inconsistent properties in AE waves across different test phases, complicating the correlation between AE wave characteristics and damage location. This highlights the need for more reference test data to better understand and utilize AE data for wind turbine blade monitoring. The study found that AE signals correlated with defect locations and development, but future work will focus on spatial calibration, reference blades, and further AE-signal testing.

Adam Mielke et al., [17] the study investigates the use of Acoustic Emission (AE) signals to monitor the structural health of wind turbine blades, focusing on detecting internal manufacturing flaws. The research uses specialized software to analyse the blade and identify issues identified through AE signals. The study used a 14.3-meter blade with four wrinkle defects, and found correlations between AE signals and defect locations. Future improvements include spatial calibration, using reference blades, and further AE-signal testing to enhance monitoring accuracy. The study aims to reduce costs associated with costly wind turbine maintenance.

Pavana Koragappa et al., [18] the research focuses on a 20 MW offshore wind turbine blade design that significantly enhances power and thrust, achieving 80.84% and 88.67% improvements in efficiency at a rated wind speed of 12 m/s. The study emphasizes the importance of advanced aerodynamic design in optimizing wind turbine performance. The research uses Blade Element Momentum Theory (BEMT) for designing rotor blades, three-dimensional inviscid vortex methods, and computational fluid dynamics (CFD) for detailed simulations. The EU-supported 'Up Wind Research Project' investigates design challenges for larger turbines, such as those with rotors around 250 meters in diameter. The study found that cylindrical domains with single blades were more efficient, and simulations indicated satisfactory performance with inlet and outlet positions.

Peng Xue et al., [19] the study presents a structural optimization framework for Vertical Axis Wind Turbines (VAWTs), using a parametric Finite Element Analysis (FEA) model and a Genetic Algorithm

(GA) to minimize mass while meeting complex constraints. The research highlights the potential of CFRP blades, which are 47.1% lighter than GFRP blades, for optimizing scale and structural design. The study also uses a TCL script within Hyper Works to automate the process of FEA modelling for wind turbines, facilitating modelling, analysis, and post-processing tasks. The study also analyses cylinder structures, finding that optimal blade mass trends may exceed industry standards due to VAWT blades having uniform cross-sections along their length. The study recommends tailoring VAWT structure design to the structure size and material substitutions for optimal performance and cost efficiency.
Heloisa Guedes Mendonça et al., [20] the study explores the impact of out-of-plane wrinkles on wind turbine blade fatigue using Glass Fiber Reinforced Polymer (GFRP) laminated specimens. It found that these defects affect resistance to cyclic loading under tension-compression fatigue. The research also found that specimens with lower aspect ratios showed better resistance to reversed fatigue loading. The study also introduced a numerical fatigue framework for evaluating fatigue fracture in laminates, focusing on delamination as the primary failure mechanism. The findings suggest that decreasing Mode II parameters can increase resistance by 0.20 decades, while increasing them decreases it by 0.15 decades. This research contributes to the development of more durable wind turbine blades.

Aam Amaningsih Jumhur1 et al., [21] A study has optimized the blade thickness of Darrius wind turbines to balance weight and strength. The research used AutoCAD software for preliminary calculations and 3D manufacturing to determine the optimal blade thickness. The yield stress value was optimized to 3.0, with the most effective blade thickness identified as 0.2 mm. Indonesia is turning towards renewable energy sources like biomass, hydropower, wind, micro-hydro, and solar energy, particularly wind energy. The study found that vonmiss stress decreases as blade thickness increases, with the optimal variant identified as B-3, with a 0.2 mm blade thickness. This research provides valuable insights for designing more efficient Darrieus wind turbines.
Ahmed A. Geneid et al., [22] this paper explores the design and optimization of vertical-axis wind turbines (VAWTs) using biodegradable materials, beam element methods, genetic algorithms, and ANSYS software. The aim is to improve the performance and sustainability of VAWTs by reducing fatigue and reducing production costs. The study uses classical laminate theory to assess blade fatigue, and genetic algorithm operators for elite selection. The model is implemented in MATLAB and validated using ANSYS 16 ACP-Tool. The case study focuses on the H-Darrieus blade structure, aiming to balance mass, cost, life expectancy, and fundamental frequency for optimal blade design.
Roham Rafiee et al., [23] The study explores the failure of trailing edge (TE) in commercial wind turbine blades (WTBs) and the impact of adhesive thickness and band width on TE failure. It uses static load cases, sub-part modelling, and cohesive zone modelling to identify critical regions of TE failure and determine optimal dimensions for WTB production. The study highlights the importance of adhesive joint design in enhancing the durability and reliability of wind turbines, as approximately 19.5% of component failures occur in the blades. The research emphasizes the need for precise adjustments during production to ensure optimal blade performance and longevity.
Nguyen Ngoc Hoang Quan et al., [24] Researchers have developed an optimal aerodynamic model using computational fluid dynamics (CFD) and genetic algorithms to enhance wind turbine energy efficiency. This research aims to improve the lift-to-drag ratio and lift coefficient of wind turbine air foils, such as the S809, using a multi-objective genetic algorithm (MOGA) and commercial software like FLUENT. The study uses a CFD-based optimization framework to refine the shape of the S809 airfoil, aiming to increase either the lift or lift-to-drag ratio. However, the methodology is primarily focused on 2D profiles, which may not fully address the aerodynamic characteristics of wind turbines due to the complex effects of wingtip vortices in 3D models.
K. P.M.Y.V. Dathu et al., [25] Windmill blades, traditionally made from materials like glass fiber, polyester, and carbon fiber, have been limited by their weight and speed. New lightweight materials like Nickel-Titanium, Copper-Aluminium-Nickel, and Copper-Zinc-Aluminium offer increased

efficiency, improved properties, reduced noise and heat, and enhanced durability. This transition represents a significant advancement in wind turbine technology, enhancing blade performance, power generation efficiency, and supporting the optimization of wind energy as a sustainable and effective power source.
K. Ansal Muhammed et al., [26] the study investigates the use of nanocomposites in wind turbine blades to enhance efficiency and durability. The research uses montmorillonite nano clay in AW 106 Epoxy/E-Glass fiber composites, focusing on wind energy. The composites show significant improvements in efficiency, tensile strength, and hardness compared to traditional materials. Scanning Electron Microscopy (SEM) images and ANSYS simulations confirm the structural benefits of the nanocomposite. This research can contribute to more efficient and reliable wind turbines, supporting renewable energy goals.
Clarence Rubiella et al., [27]This paper reviews various models used to assess the fatigue response of composite wind turbine blades, categorizing them into life-based failure criterion models, residual property calculation models, and progressive damage models. These models offer different insights into blade fatigue but have their own advantages and limitations. The paper highlights three main types: life-based failure criterion models, residual property calculation models, and progressive damage models. These models focus on predicting the lifespan of materials based on fatigue loading and failure criteria, incorporating degradation of material properties. Progressive damage models are highlighted as the most promising, offering a detailed view of how damage evolves over time. Challenges associated with fatigue modelling for composites include the complex behaviour of composites, the difficulty of predicting fatigue behaviour using experimental data and S-N curves, the limitations of material-specific models, and subjectivity and discrepancies. Further research is needed to develop more robust fatigue models for composite wind turbine blades.
Hicham Boudounit et al., [28] this study investigates the mechanical performance and structural integrity of a large offshore wind turbine blade under critical loads using blade element momentum. The majority of wind turbine components are made of GFRP (glass fiber-reinforced polymer) due to its ease of use, low technology requirements, reasonable cost, and elastic qualities. The model studied is a 48-m-long industrial WTB with shell elements, deformable, and box-side spars. Carbon fiber is used to reduce the blade mass by 2.64 tons, resulting in a lighter rotor for a three-blade wind turbine. The blade laminated with glass fibers shows significant displacement values at its tip, unlike the carbon fiber blade, which has high resistance to damage and displacement. The simulations help identify and predict sensitive zones to damage and failure, as well as evaluate the potential of composite materials (carbon fiber and glass fiber) in reducing the rotor's weight and increasing resistance to wear and stiffness.

Temesgen Batu et al., [29] this paper evaluates the potential of natural fiber reinforced composite (FRC) materials for small wind turbine blade applications. Eleven natural fibers reinforced composites in epoxy resin were studied using Qblade software for airfoil analysis. The Halpin-Tsai equation was modified for randomly oriented fiber reinforced composites. The maximum von Mises stress was 405.77 MPa, and the tip deflected was 0.758 m along the x direction and 0.894 m along the z direction for Banana/epoxy properties. The stress distribution, deformation, and weight of different natural fiber reinforced with epoxy were analysed under dynamic loads. The use natural frequency of each material was numerically computed by QFEM and discussed. The study found that replacing glass/epoxy composite-based wind turbine blades with natural fiber reinforced composites leads to a weight reduction per blade by 27.9% to 38%, which aligns with experimental results.
Sang-Lae Lee et al., [30] the study proposes an improved optimization framework for wind turbine blades, involving initial blade configuration and cross-sectional design optimization. The genetic algorithm ensures structural integrity evaluation, resulting in safe configurations. The lighter blade reduces applied load on the turbine, reducing overall system weight. Wind turbines are complex engineering objects subjected to fluctuating loads, making optimal design crucial. Researchers use

blade element momentum theory (BEMT) for blade design and performance estimation. Studies have shown improvements in aerodynamic performance through cavity shape optimization, aerodynamic shape optimization, and multi-objective genetic algorithms. The spar cap, a crucial blade structural member, is often used to counteract bending load. Two optimization schemes for blade structural design focus on optimizing spar cap design using normalized spar cap thickness distribution. Variables like spar cap plies, skin, shear web, root/shear web location, and shear web foam thickness are used to ensure safety and maximize turbine capacity. The article introduces a method for optimizing blade sectional design, involving baseline configuration and final configuration with optimal cross-sectional design for blade span wise direction.

Christian Pavese et al., [31] this study investigates the use of backward swept blades for passive load alleviation on wind turbines. The load alleviation can be achieved by changing the blade geometry according to three parameters: starting point for the change along the blade span, blade tip sweep, and blade forward sweep. The efficacy of the design procedure is proven through its application on a 5 MW wind turbine design. According to "The Economics of Wind Energy," the rotor blades of a 5 MW onshore wind turbine contribute to the overall turbine cost between 20 and 25%. Blade manufacturers have taken up the challenge to scale down the increase in total mass of the blades. The study involves 25 blade geometries, divided according to the span wise location where the first control point for the polynomial is placed. Numerical results from load analysis depending on the swept geometries are reported and discussed. The paper also studies extensive load analyses to investigate backward swept blade designs for passive load alleviation on multi megawatt wind turbines.

Jin Chen et al., [32] this paper designs a 2 MW composite wind turbine blade using new airfoils families and a procedure combining finite element analysis and particle swarm algorithm. The blade's maximum thickness is 96.8 mm, with a gradual reduction along the blade. The blade's strain analysis reveals the main bending strain, posing a challenge for structural strength. New composite materials must be selected to replace original materials. The optimized blades show significant weight savings, especially for scheme II, which exhibits more mass-saving properties.

Kadhim Fadhil Nasir et al., [33] A study in Al-Mussaib, Iraq, examined the performance of H vertical wind turbines at different wind speeds. The experimental test rig had six plastic blades, each 50 cm in diameter. The turbines produced varying power outputs based on wind speed, rotational speed, and turbine elevation. The research emphasizes the importance of understanding fluid dynamics and heat transfer in various fields, promoting wind energy as a renewable energy source.

D. Todd Griffith et al., [34] Wind energy is a significant producer of composite structures, requiring high reliability, low cost, and reuse. This paper explores the challenges of composite materials for wind energy applications, particularly in wind turbine blades. It examines the flexural properties of 3D-printed beams, in-plane shear properties, DIC images, and failure modes of 3D-printed core sandwich composites. The study identifies a suitable resin uptake regime for four core sandwich composites, potentially aiding in wind turbine blade design.

P. Y. Andoh et al., [35] the study investigates the use of bamboo fibre and recycled plastics composites for wind turbine blade fabrication. Bamboo fibre was extracted from raw bamboo and combined with recycled HDPE. Mechanical tests showed that increasing the bamboo fibre percentage increased tensile strength and impact energy. However, water absorption and sun radiation tests showed no significant impact on the composite's mechanical properties. The specimen with 25% bamboo fibre and 75% HDPE matrix is suitable for wind turbine blade fabrication. Natural fibers are more suitable for wind turbine blade fabrication due to their economic and environmental friendliness.

J.H. Lee et al., [36] the increasing global warming is causing natural disasters, and eco-friendly technologies are being developed to reduce CO2 emissions. Wind power deployment is expected to increase to 180 GW annually, with a net zero by 2050 scenario aiming for 160 GW by 2025 and 280 GW by 2030. Natural fibers like flax, hemp, and jute offer advantages over synthetic fibers in reinforcing polymer composites. A study aims to investigate substituting glass-fiber reinforced plastic

(GFRP) for flax-fiber reinforced plastic (FFRP) for small wind power generators. Natural fibers can reduce environmental load, with a 30 kW blade designed using natural flax fiber.

Xiao Chen et al., [37] Wind turbine rotor blades, the largest fiber composite components globally, are subject to damage and failure due to various factors. These blades, made from fiber fabrics, resin, core material, and adhesives, are manufactured using a vacuum-assisted resin infusion process. Non-destructive testing is conducted to detect major defects, and factors such as operational loads, environmental effects, structural design, material properties, and manufacturing processes contribute to blade damage. Recent research has made significant progress in understanding the damage and failure of composite rotor blades in multi-megawatt wind turbines, particularly in ultimate loading situations.
D. Moroney et al., [38] the increasing size of wind turbine blades necessitates improved design and maintenance procedures, particularly for the trailing edge. DADTA approaches are used to predict the service life of trailing edge blades, which can lead to component failures and decreased reliability. The growing use of wind energy in offshore locations is driving technological advancements, but these systems introduce complexity in design, manufacturing, and installation. Trailing edge failures can occur due to structural overload from extreme or fatigue loads. Certification agencies require full-scale ultimate load and fatigue load testing to demonstrate compliance with design requirements. The paper suggests that two-dimensional cross-sectional modelling may be sufficient for trailing edge DADTA life prediction, as it accurately represents trailing edge constituents and examines cyclic loading and peel stresses.
Haneen M. Jaber et al., [39] Wind turbines are essential for generating and converting wind energy into electrical energy, and to address fatigue issues due to changes in air pressure, composite materials are used. An air turbine model was designed to simulate the pressure generated from the air, and the optimal configuration (0, 0, and 0) is preferred for optimal performance. A stochastic technique was used to simulate wind flow on the blade using a Weibull wind speed distribution. Accumulated fatigue damage modelling was used as a damage estimate rule. Experimentally, structural deterioration in composite wind turbine blades was observed under fatigue stress, affecting bending stiffness, natural frequencies, and damping ratios. Progressive damage models are the most effective tool for assessing the fatigue response of composite wind turbine blades. A computational model of a turbine blade was developed using two different manufacturing materials and their resulting stresses were compared. The research found that the pressure value on a turbine blade at 5 m/s was 15 Pa, while at 10 m/s it was 60 Pa. The optimal configuration for composite materials was achieved by arranging angles, with the stress value being 358650 Pa. This research underscores the importance of balancing air pressure and material arrangement effectively.
Temesgen Abriham Miliket et al., [40] the study explores the performance of hybrid Natural Fiber-Reinforced Composites (NFRCs) made from E-glass, Nacha, and Sisal fibers for wind turbine blade applications. The composite manufacturing process involves harvesting and extracting fibers, treating them with NaOH, and removing remnants. The composites undergo tensile, compressive, and flexural tests using a universal testing machine. The study found that Nacha fiber significantly contributes to the strengths of the composites. Wind turbine blades face various load conditions and are manufactured using synthetic or natural fiber composites. Proper choice of material and manufacturing methods is essential for stiffer blade surface quality and reducing external weight. The study focuses on the use of nano-renewable fuel cells (NRFCs) for wind turbine structural applications.

III. Conclusion

Wind turbine blade design aims to extract maximum energy without stress. We study different composite materials like glass fiber reinforced thermoplastics, hybrid composites, jute fiber reinforced epoxy composites, Carbon Fiber Reinforced Polymer (CFRP) and Glass Fiber Reinforced Polymer (GFRP). This materials can be achieved through existing composites and new composites. These composite materials are helped to get the better power and high efficiency and more durability. A hybrid fiber composite blade made of glass fiber and carbon fiber enhances blade stiffness and torsional vibration resistance, prolonging blade service life and environmental sustainability. Jute fibers show potential as renewable reinforcement material. Most of the blades are made up of glass fiber and carbon fiber because they gave the better performance and improve long lasting of the blade. Some of the papers discuss about the change in the blade design, this design helps to get the better rotation and get better performance.

References

1. Peter L. Bishay, Toby McKinney, Garrett Kline, Maria Manzo, Arthur Persian, Derenik Bakhshi , Andrew Langwald , Abraham Ortega , Matthew Gagnon "Scamorsa-1:A Camber-Morphing Wind Turbine Blade With Sliding Composite Skin", Journal of Engineering Research, Department of Mechanical Engineering, California State University, Northridge , USA,PP NO: 2307-1877, 2024
2. Daniel Trento, Flora Faleschini, Víctor Revilla-Cuesta, Vanesa Ortega-Lopez "Improving The Early-Age Behavior Of Concrete Containing Coarse Recycled Aggregate With Raw-Crushed Wind-Turbine Blade", Journal of Building Engineering, PP NO:2352-7102, 2024
3. Vanesa Ortega-Lopez , Flora Faleschini , Nerea Hurtado-Alonso , Javier Manso-Morato , Victor Revilla-Cuesta "Analysis Of Raw-Crushed Wind-Turbine Blade As An Overall Concrete Addition: Stress-Strain And Deflection Performance Effects", Journal of Composite structures, 0263-8223, May 2024
4. Mishnaevsky Jr. Leon developed "Recycling of Wind Turbine Blades: Recent Developments", Science Direct, 2452-2236, January 2023
5. Zachariah Arwood, Dylan S. Cousins Dayakar Penumadu, Aaron P. Stebner, "Infusible Thermoplastic Composites For Wind Turbine Blade Manufacturing: Static Characterization Of Thermoplastic Laminates Under Ambient Conditions", science direct, volume: 2666-6820, PP NO:-68-71, MAY 2023
6. R. Gukander, m. Sambath kumar, c. Sabari, "Structural Analysis Of Composite Wind Turbine Blade Using Ansys", science direct, volume: - 2214-7853, PG NO: -76-81, JULY 2021
7. Sri Sai D. Reddy, rohan suresh,b.p. shiva kumar, "Use Of Composite Materials And Hybrid Composite In Wind Turbine Blades", Science Direct Volume:- 2214-7853, PG NO:-96-99, FEBRUARY 2021
8. Abhishekth r, gahewar, nithi k. Mandavgade,vijayn, "Material Selection For Rotor Blade Of Vertical Axis Wind Turbine" , science direct, volume:- 2214-7853, PG NO:-81-86, MARCH 2021
9. V. Cogent, s.coorrech du point,b. Thirla , "Material Optomisization Of Flexibleblades For Wind Turbines", science direct, volume:- 2020,09601481, PP NO:- 88-93, MAY 2020
10. Tinny Long, Xiaodong Chen, Li Qiu, Jia Han, and Qi Jing Dong, "Wind Turbine Blades with Hybrid Fiber Composite Tensile Properties and Numerical Verification", Thermal Science, PP No: -546-62, 2024
11. Mohammad Kafashha, Elham Banitalebi, Shahram Mahboubizadeh, Omid Ashkani, "Optimizing Wind Turbine Blade Performance: A Comparative Analysis Of Mechanical Properties In Cfrp And Gfrp Composites", ISSN, PP No:- 656-72, 2023
12. Robson Luis. Cardoso, Roberto Paulo. Ramosb, Elza. Leao Filha, Mauricio M. Ribeirod, Veronica S. Candido, Jean da S. Rodrigues, Douglas S. Silva, Rai Felipe P. Junioe, Sergio N. Monteiro, Roberto T. Fujiyama, "Modelling and analysis of jute fiber reinforced epoxy composite in the development of wind blade for low intensity winds", Elsevier, PP No:- 3619-3630, 2023
13. N.Lakshminarayanan, J.Senthil, A.Alvin raja, N.Jesudawson Silvanus and Satish, "Design and static analysis of polymer composite wind turbine blade", Material science and engineering, 2020
14. Bassey Okon Samuel, Malachy Sumaila & Bashar Dan-Asabe, "Physical and Mechanical Properties of Natural Fiber Reinforced Polymer Composites with Potentials for Wind Turbine Blade Applications: A Review", Material science and engineering, PP No:-1-14, 2022

15. Haseung Leea, Hyunbum Parka "Damage Modelling And Analysis Of Composite Blade For Wind Turbine", science direct, Elsevier, volume: -52, ISSN: -252-258, December-2023
16. Stephane Redonnet, Antoine Bach, Sahil Kunder, Thomas Schmidt, Nazmus Rahman "Computational And Experimental Exploration Of A Morphable Blade Concept For Wind Turbines", science Direct, Elsevier, volume:-12,PP NO: -277-293, February 2024
17. AdamMielkea, Hans-Henrik Benzonb, Malcolm McGuganb, Xiao Chenb, Henrik Madsena, Kim Brannerb, Tobias K.S. Ritschela "Analysis Of Damage Localization Based On Acoustic Emission Data From Test Of Wind Turbine Blades", science Direct, Elsevier, volume:-231, PP NO:-0263-2241, April 2024
18. Pavana Koragappa, Patrick G. Verdin, "Design And Analysis Of A 20mw Offshore Wind Turbine Blade", Science direct, Elsevier, volume:- 8018, April 2024
19. Peng Xue , Yi Wan, Jun Takahashi, Hiromichi Akimoto, "Structural Optimization Using A Genetic Algorithm Aiming For The Minimum Mass Of Vertical Axis Wind Turbines", Science direct, Heligon, June 2024, PP NO:- 2405 – 8440
20. Aam Amaningsih Jumhur, Sirojuddin , Haryo Suharjo, Dyah Arum Wulandari, Nur Najmi ,Jaafar, "Wind Turbine Plate Thickness Design Optimization", university Malaysia PAHAG, volume:- 8, December 2023
21. Ahmed A. Geneid, Mostafa R. A. Atia, Adel Elsabbagh, Mohammed Hedaya, "Structural Design Optimization of Laminated Composites For Vertical Axis Wind Turbine Blades: A Single Objective Approach", February 2024
22. Heloisa Guedes Mendoncaa, Lars Pilgaard Mikkelsena, Bing Sheng, Giuliano Allegric, Stephen R. Hallettc, "Fatigue Delaminations In Composites For Wind Turbine Blades With Artificial Wrinkle Defects", ,Elsevier, International Journal Of Fatigue, Science Direct, June 2023
23. S Roham Rafiee , Mohammad Reza Hashemi-Taheri, "Failure Analysis Of A Composite Wind Turbine Blade At The Adhesive Joint Of The Trailing Edge", Engineering Failure Analysis, ISSN 1350-6307,Volume:-121,PP No:-1-16, 2021.
24. Nguyen Ngoc Hoang Quana, Pham Van Lamb, Le Van Longc, "Wind Turbine Blade Design Optimization Using Open Foam And Dakota Software", Science Direct, ISSN 10.1016, Volume:- 56, PP No:-1-6,2021.
25. K. P.M.Y.V.Dathu, R. Hariharan, "Design of Wind Turbine Blade Material for Higher Efficiency", Materials Today: Proceedings, ISSN 214-7853, PP No:-1-5, 2020.
26. K. Ansal Muhammed, C. Ramesh Kannan, B. Stalin, M. Ravichandran, "Experimental Investigation On Aw 106 Epoxy/E-Glass Fiber/Nano Clay Composite for Wind Turbine Blade", Materials Today: Proceedings, PP No:- 1-4,2019.
27. Clemence Rubiella, Cyrus. Hessabi, Arash Soleiman Fallah, "State Of The Art In Fatigue Modelling Of Composite Wind Turbine Blades", International Journal Of Fatigue, ISSN 0142-1123, Volume:-117, PP No:-230-245, 2018.
28. Haneen m. Jaber1, ouf a. Shams, hasan s. Majdi, atheer raheem Abdullah, laith j. Habeeb, victor revilla "Numerical Analysis Of Wind Turbine Blades Manufactured From Composite Materials At Different Velocities And Arrangements Strain And Deflection Performance Effects", Journal of Engineering Science and Technology, volume:09, PP NO: 3715-3720, March 2023
29. Patrick D. Moroney and Amrit Shankar Verma "Durability And Damage Tolerance Analysis Approaches For Wind Turbine Blade Trailing Edge Life Prediction: A Technical Review", ENERGIES MDPI, volume:06, ISSN: 1624-7934, December 2023
30. Temesgen Abriham Miliket , Mesfin Belayneh Ageze , MulukenTemesgen Tigabu "Experimental Characterizations Of Hybrid Natural Fiber-Reinforced Composite For Wind Turbine Blades", Heliyon , ELSEVIER, volume: 07, ISSN 2405-8440, March 2022
31. Sang-Lae Lee & Sang Joon Shin, "Structural Design Optimization Of A Wind Turbine Blade Using The Genetic Algorithm", science direct, Elsevier, volume:-54:12:2053-2070, PP NO:-10/1080,03052, September 2021

32. Temesgen Batu1, Hirpa G. Lemu, Belete Sirhabizuh, “Study Of The Performance Of Natural Fiber Reinforced Composites For Wind Turbine Blade Applications”, Science Direct, Elsevier, Volume:-14, PP NO: - 67-75, June 2020.
33. Hicham Boudounit, Mustapha Tarfaoui, Dennoun Saifaoui and Mora Nachtane. “Structural Analysis of Offshore Wind Turbine Blades Using Finite Element Method”, Science Direct, Volume:- CNRS6027, F- 29200, PP NO: - 95- 97, 2019
34. Christian Pavese, Taeseong Kim, Juan Pablo Murcia, “Design Of A Wind Turbine Swept Blade Through Extensive Load Analysis”, Science Direct, Volume:-0960-1481, PP No: - 55-59, October 2016
35. Jin Chena, Quan Wanga, Wen Zhong Shenb, Xiaoping Panga, Songlin Lia, Xiaofeng Guo, “Structural Optimization Study Of Composite Wind Turbine Blade Blade Applications”, Science Direct, Volume:- 0261-3069/S:206-401, PP No:- 476-71, October 2012
36. Kadhim Fadhil Nasir1, Hassan Ali Jurmut1, Mahir Faris Abdullah, Rozli Zulkifli, “Experimental Analysis Of A Vertical Wind Turbine Using Plastic Blades”, Journal Of Advanced Research In Fluid Mechanics And Thermal Sciences 118, ISSN2289-7879, PP NO:-196-206, 2024.
37. D. Todd Griffith1, Dongguan Cao, Honking Lu1, Dong Qian, “Composite Materials In Wind Energy: Design, Manufacturing, Operation, And End-Of-Life”, Materials Science And Engineering, ISSN 1293 012002, PP No:-1-16, 2023.
38. P. Y. Andoh, A. Agyei-Agyemang, P. O. Tawiah, C. K. K. Sekyere, C. M. Asante. “Development of Composite Material for Wind Turbine Blades”, Journal of Applied Engineering and Technological Science, Volume:-2, PP No:-139-150.
39. J.H. Lee, C. Collier, J. Ainsworth, K.N. Cho, Y.S. Lee, “Development Of Natural Fiber Wind Turbine Blades Using Design Optimization Technology”, PP No:-1-7,2021
40. Xiao Chen and Martin Eder, “A Critical Review of Damage and Failure of Composite Wind Turbine Blade Structures”, PP No:-1-21, 2020