Design Optimization of Wind Turbine Blades Using Composite and Natural Fiber Materials- A Survey

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Abstract- **In this research work, an attempt is made for the analytical analysis of the Wind Turbine Blades using Finite Element Methods. An investigation to be done for the performance of Wind Turbine Blade by using various natural fiber materials. Wind Turbine plays an integral part in the renewable energy generation and lighting the world by giving a big amount of energy to the world. In this analysis, we aim to use HAWT for design purpose. Natural fibers like Carbon fiber, E-Glass fiber, Hemp fiber and Jute Fiber materials were used for the performance evaluation and a then their performance evaluation was done.In the aftermath of the energy crisis that has gripped the rural sector, it has become increasingly important to investigate potential new sources of energy as well as technologies that may one day make it possible to extract energy from previously unused resources. There are still 80,000 villages in India that still need access to power. Therefore, these communities are in perpetual darkness. There are many different techniques for energy generation. Still, the only of them or hybrid system that rural communities can adopt at a cheap investment is only one of those methods. The efficiency of energy capture for the creation of electricity may be improved by utilizing turbines that rotate in opposite directions. i.e. electricity can be produced even with wind speeds as low as 3 metres per second. An attempt has been made to build a low-cost wind turbine with a power output of 0.80 kilowatts for use in residential settings, as well as 3 kilowatts for use in the management of agricultural operations and the pumping of water for irrigation. This study describes the methods used to make cost-effective turbine blades utilizing materials such as wood, natural fibres, and glass fibres, as well as inexpensive labour in distant locations.**

Keywords: Natural Fiber, Composite materials, FEM, Wind Turbine, Power Generation

1. INTRODUCTION

In recent years, there has been a sharp increase in consumer awareness of new renewable-energy products. Green marketing, new recycling directives, social influence, and a shift in cognitive values have influenced consumers to seek out environmentally friendly products. Composite materials, in particular, are being developed and redesigned with the goal of improving and adapting traditional products while also introducing new products sustainably and responsibly. This paper examines and discusses recent trends in fibre-reinforced bio-composite materials and provides information on natural fibres for bio-composites, focusing on properties and applications. Natural fibres are mostly derived from plants or animals. The first is mostly made of cellulose, while the latter is made of protein. Natural fibres are often referred to as vegetable fibres in the composites business. One of the problems with natural fibres is the need for more consistent information and claimed variances in mechanical characteristics. Furthermore, the selection process complicates the need for more standards for producers and users of these materials in terms of collecting, treating, processing, and post-processing natural fibres. These concerns are, in fact, major deterrents to the widespread use of natural fibres in a variety of applications. This study reviews various mechanical characteristics of natural fibres and their applications to fill this need. Natural fibres are divided into three categories depending on their origin: animal, mineral, and Plant. Plant fibres are the most widely recognized fibres in the industry and the most studied by researchers.

1.1 COMPONENTS

Table 1 Components of wind turbine

Blades	These are the most important parts of the windmill since they are the ones that regulate how fast the rotors spin.
Rotor	A rotor is sometimes referred to as a propeller
Anemometer	This component is utilized for determining the velocity of the wind
Towel	This is the support mechanism that keeps the blades and the propeller from coming apart

1.2 MATERIALS USED FOR WIND TURBINE BLADE

1.CARBON FIBRE- Carbon fibres, also known as CF, graphite fibre, or graphite fibre, are carbon-based fibres with a diameter ranging from 5 to 10 micrometres (0.00020–0.00039 in). [needs a reference] Carbon fibres have several advantages, including high stiffness, strong tensile strength, low weight-to-strength ratio, great chemical resistance, high-temperature tolerance, and little thermal expansion. Due to its unique properties, carbon fibre is extensively employed in aviation, civil engineering, military, racing, and other competitive sports. However, they are relatively expensive compared to equivalent fibres such as glass, basalt, or plastic fibres.

Table2.Properties of carbon fibre

Phase at STP	Solid
Density	2000 kg/m3
Ultimate Tensile Strength	4000 MPa
Yield Strength	2500 MPa
Young's Modulus of Elasticity	500 GPA
Brinell Hardness	N/A
Melting Point	3657 °C
Thermal Conductivity	100 W/mK
Heat Capacity	800 J/g K
Price	22 $/kg

DISADVANTAGES

Conductivity-This can be used both as an advantage in carbon fibre composites and as a drawback in practical applications. Carbon fibres are extremely conductive, while glass fibres are insulated. Many products use fibreglass instead of carbon fibre or metal because they require strict insulation. In the production of utilities, many products require the use of fibreglass. For example, the production of ladders uses fibreglass as a ladder because the possibility of electric shock is much reduced when the fibreglass ladder is in contact with the power line.

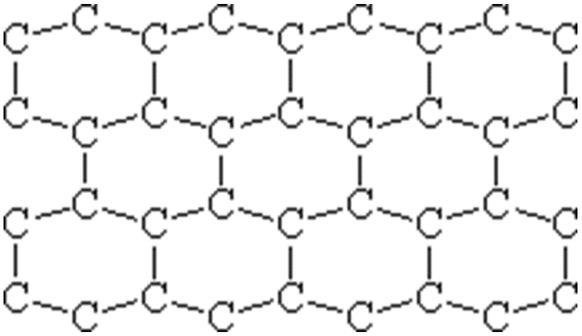

Figure 1-Structure of carbon fibre

ARAMID FIBRE - High-performance fibres created from artificial molecules with moderately rigid polymer chains are known as aramid fibres. Strong hydrogen bonds connect these molecules, effectively transmitting mechanical stress and permitting the use of chains with low molecular weight. These are the most important parts of the windmill since they are the ones that regulate how fast the rotors spin.

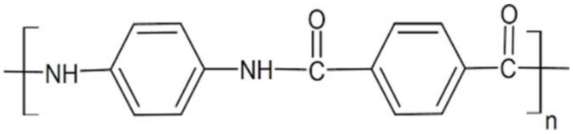

Figure 2- Aramid fibre structure

E-GLASS- E-glass fibres, the first major synthetic composite reinforcement, were originally developed for electrical insulation applications (that is the origin of the "E"). E-glass fibres are, by many orders of magnitude, the most widely used of all fibrous reinforcements. The primary reasons for this are their low cost and early development compared to other fibres. Glass fibres are produced as multifilament bundles.

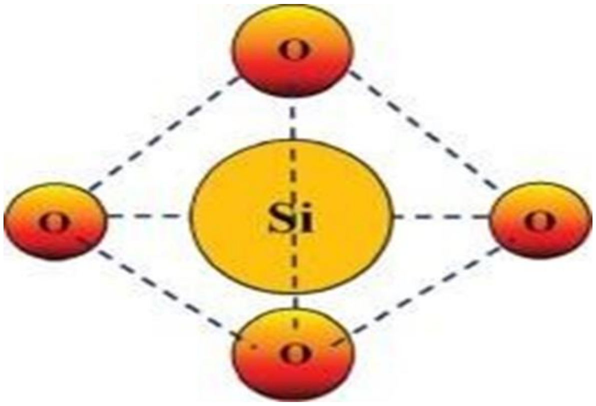

Figure 3- Structure of glass fibre

Table3. Properties of E-glass fibre

MECHANICAL PROPERTY	GLASS FIBRE
Youngs modulus	73
Tensile strength	3400
Weight	350
Density	2.6
Thickness	0.067
Ultimate strain	4.5
Colour	White

DISADVANTAGES

Moisture Issues-Fiberglass insulation is particularly prone to moisture. Unlike other materials, such as sprayed foam insulation or foam board, wet fibreglass insulation loses all R-value and has almost no insulating properties until it dries out. Moisture can harm insulation in attics as the primary location for fibreglass batts due to roof leaks or simple condensation. Mould Issues- Mould growth will occur when moisture is present in fibreglass insulation. It is more common in fibreglass as compared to other insulation materials, such as loose-filled cellulose, as cellulose does not permit free air movement that carries mould pores and delivers moisture. Air Exchange Issues- In addition to conduction directly through walls and ceilings, heat energy also moves through direct air exchange, such as air leaks through a ceiling into an attic. Other insulation materials, such as spray foam or loose-fill cellulose, are denser and give more effective protection against air leaks than glass fibre.

1.3 NATURAL FIBER USED FOR WIND TURBINE BLADE

Natural fibers are biodegradable substances over time and are derived from plants, animals, minerals, or geological processes. They may be woven, knitted, matted, or tied after being spun into filaments, threads, or ropes. Natural fibres do not need any formation or reformation since they are derived from natural sources. Cellulosic fibres derived from plant seed hairs, stems, and leaves; protein fibres derived from animal hair, fur, or cocoons; and crystalline mineral asbestos are the most economically significant natural fibres.

HEMP FIBRE

Hemp fibres are a strong member of the best natural fibres family, obtained from the hemp plant, which belongs to the Cannabis species. Because of their biodegradability and low density compared to artificial fibres, these fibres are now widely used as reinforcements in composite materials. Mechanical, thermal, and acoustic qualities are also inherent in these materials. Hemp fibre, like many other natural fibres, is seeing a resurgence in the building industry. This is due to its intrinsic qualities as well as the environmental advantages of energy conservation during building stages. The following are some of the main reasons that will make this possible:

cost-effective effective replacement for glass fibre

high tensile strength and stiffness

Figure 4 Hemp Plant

Table 4. Properties of Hemp fibre

Density (g/cm^3)	1.4–1.6
Tensile Strength (MPa)	200–1040
Stiffness (GPA)	17.6-66
Tensile modulus (GPa)	23.5–90
Specific tensile strength (MPa)	210–510
Young’s modulus (GPa)	30–60
Specific Young’s modulus (GPa × cm^3/g)	20–41
Diameter(μm)	270–900

JUTE FIBRE

Plants of the genus Corchorus, family Malvaceae, generate jute fibre. Jute is a lignocellulosic fibre that is both a textile and wood fiber. It's classified as a bast fibre (fibre collected from the bast or skin of the Plant). Cellulose (64.4 per cent), hemicellulose (12 per cent), pectin (0.2 per cent), lignin (11.8 per cent), water-soluble (1.1 per cent), wax (0.5 per cent), and water make up the chemical makeup of jute fibre (10 per cent). Jute fibre is made up of many cells. These cells are composed of cellulose-based crystalline microfibrils joined to a full layer by amorphous lignin and hemicelluloses.

Table5 Properties of Jute fibre

Density	1.35 gm/cc
Youngs modulus	20GPa
Tensile strength	393MPa
Poisson’s ratio	.38
Shear Modulus	7.24GPa

AMPLITEX FIBRE

AmpliTex powers are high-performing grid textiles manufactured from flax yarn based on proprietary power Ribs technology. The flax yarn location is adjusted throughout the manufacture to provide an application-specific mesh structure.To get the best mechanical qualities in the final composite material, flax fibre quality, yarn thickness, and twist are all tuned. This material increases the flexural stiffness of flat and curved surfaces by more than three times and the buckling resistance of hollow structures.

Figure 5- Amplitex fibre

Table 6. Properties of Amplitex fibre

Young’s Modules	32.1 GPA
Strength Parallel	394 MPA
Strength perpendicular	20.9MPA
Strain failure pillar	1.72
Strain failure perpendicular	0.54
Density	1515kg/m3

2. LITERATURE REVIEW

2.1 NOTEWORTHY CONTRIBUTIONS

MEM Microtabs were used by D. T. Yen Nakafuji, C. P. Van Dam, R. L. Smith, and S. D. Collins to improve aerodynamic characteristics, increasing section lift coefficient with minimal drag penalty. The results of computational and experimental wind tunnel tests using fixed and remotely actuated tab for a representative airfoil are compared. The findings show that Microtabs have muchpotential in active load control. Chalothorn Thumthae and Tawit Chitsomboon investigated the condition for the optimal pitch that produces the highest power output by numerical simulation of horizontal axis wind turbines with untwisted blades in steady-state conditions. The blades were fixed around the rotating frame using the rotating frame technique. The computed results were in good agreement with the experimental findings. Ferhat Kurtulmus, Ali Vardar, and NazmiIzli investigated the angle of attacks for four different blade profiles and Re Numbers and lift-drag rate correlations. Lift, drag, moment, and minimum pressure coefficients were calculated using Snack 2.0 computer software. The most convenient angle of attack was determined in the range of 3o and 9o for all evaluated blade profiles and all Re rates in the provided highest sliding rates. The highest drag rates are found in the Re 20000 range, according to the results. Using the snack 2.0 computer programme, Nazmi Izli, Ali Vardar, and Ferhat Kurtulmu conducted various simulation programmes to find lifting and drifting coefficients for 14 different Reynold numbers and four different NACA profiles. Out of all correlations, the most convent angle of attack and 14 different Reynold Numbers, lifting numbers, and angles of attack have been revealed and depicted in chart form. A correlation between the lifting and drifting rates has also been discovered for the 14 different Reynolds numbers. SHEN Zhen-Guo-Liang-W3-211 airfoil in the blade model development and conducted a small low-speed tunnel, and varied the installation angles between 6-14oC and a wind velocity ranges from 8-15 m/s. The results showed that under all conditions, the wind power utilization factors of the tested wind turbines are more acceptable when a gurney flap is added. F. Wang, L. Bai, J. Fletcher, J. Whiteford, and D. Cullen investigated wind energy capture improvements at low wind speeds using physical methods such as boundary layer theories and wind tunnel experiments and computer modelling using CFD. Validation of a CFD model and optimization of a scoop design. The scoop's final design increases airflow speed and resulting in wind turbine power output.

Experimenting with power curves, a good agreement with the CFD model was discovered. To better understand the physical and numerical attributes that determined modal performance, Scott J Schreck and Michael C. Robinson looked at full-scale turbine blade aerodynamic blades and current modelling methodologies. By selecting the appropriate orientation and size of the airfoil cross-sections based on low oncoming wind speed and given a constant rotation rate, RS Amano and R.J Malloy. Investigated the possibility of increasing turbine blade efficiency at higher wind speeds while maintaining efficiency at lower wind speeds. To achieve efficiency at higher wind speeds, a swept blade profile was implemented. CFD was used to investigate performance. The results of wind tunnel testing were described by P. Migliore. In the open-jet test section, aeroacoustics tests were conducted on a typical small wind turbine blade.

Tim Fischer investigated the impact of the rotor-nacelle-integrated assembly's design on obtaining the optimal structure at a lower cost. The characteristics and control of the turbine are used in an integrated approach to simultaneously reduce aerodynamic and hydrodynamic loads, which is especially important in terms of fatigue. The research of T K Barlas and G A M Van Kuik focused on active rotor control and smart structures for load reduction. The goal of the work is to provide a perspective on the current state and future directions of the specific research area, which includes unsteady load specifications, modern load reduction control, and detailed active aerodynamic control. Preliminary performance evaluation and novel computational and experimental research approaches are reviewed as feasibility improves. The study was conducted by W. Devenport, R.A. Burdisso, H. Camargo, E. Crede, M. Remillieux, M. Rasnick, and P. Van Setters to increase the knowledge of wind turbine aeroacoustics. According to Indian wind conditions, Nitin Tenguria devised an optimization approach for a HAWT blade of a VESTAS 1.65 MW horizontal axis wind turbine. The optimization approach was created using BEM theory. The NACA 634221 airfoil was employed, and the data were analyzed using the airfoil's characteristics. Computer software creates a power coefficient curve using different factors such as tip speed ratio, lift and drag coefficient, chord distribution, and twist distribution. The results were compared to the reference data from the literature and determined to be satisfactory. S. Lan, B. Quintero, and Y.

Lopez investigated the aeromechanical evaluation of HAWT Blades using a strategy based on combination of an aerodynamic module that provides the three-dimensional distribution on the blades and a strategy based on the combination of an aerodynamic module that provides the three-dimensional distribution on the blades. For determining blade deformation, strain and stress distributions across the blade, pressure forces are used as input data. The three-dimensional non-linear lifting surface theory techniques are combined in the aerodynamic module. Juan Mendez and David Greiner demonstrated a technique for calculating the chord and twist distributions in wind turbine blades. Depending on the Weibull wind distribution at a certain location, the distributions are estimated to maximize the mean predicted power. Chord and twist distributions are optimized using BEM theory. The implementation is confirmed by comparing power predictions to Riso test turbine experimental data.

The performance test on the new set of planned, built blades employing NREL S822 and NREL S823 airfoils was carried out by Donny R. Cagle, Anthony D. May, Brian D. Vick, and Adam J. Holman. For the new blades, the system's maximum power coefficient was 0.41. When the turbine was turned with new blades instead of Bergey blades, the water pumping capacity was doubled. The natural frequencies of the rotor blades of the NACA 4415 and NASA / Langley LS (1) 421 MOD series of wind power plants were researched by K. Turgut Gursel, Tufan Coban, and AydoganOzdamar. To discover the natural frequencies, Rayleigh's approach was utilized, followed by the finite element method. The stimulation of external forces is also used to perform resonance studies on both rotor blades.

K.R. Ajao and I.K. Adegun used Blade Element and Momentum Theory to examine the rotor aerodynamics of a wind turbine. The study focuses on the mechanics of wind turbine power extraction in close and distant wake zones. The extended Fokker-Planck equation, a partial differential equation fulfilled by the probability density function, is used to describe turbine power. The aerodynamics of horizontal axis wind turbine waves were examined by L.J. Vermeer, J.N. Sorensen, and A. Crespo. The experimental and numerical efforts linked to wind turbine power extraction physics are reviewed, focusing on observations under controlled situations. Dr S. P. Vendan, S. Aravind Lovely, M. Manibharathi, and C. Rajkumar developed a low-speed wind turbine for use in urban areas. For wind turbine blade analysis, the NACA 63415 Airfoil is used. The CFD study uses STAR-CCM+ at different angles of attack ranging from 00 to 160 degrees. For low Reynolds numbers, lift and drag coefficients are determined, and the pressure distributions are displayed.

The findings suggest that NACA 63415 is suitable for wind turbine blades. Franck Bertagnolio, Niels S rensen, Jeppe Johansen, and Peter Fuglsang confirmed the findings of tests using the 2D Navier-Stokes solver EllipSys2D on a variety of airfoil data. The research results comparing the available data and categorization suggest that the transition modelling is significantly responsible for the low quality. Finally, some suggestions are made for developing future airfoil design methods, including the EllipSys2D numerical code and transition modelling. Richard E. Wirz and Perry M. Johnson devised a multiplane inboard design for wind turbine blades that provides favourable aero-structural performance. The cross-sectional characteristics of a thick monoplane are compared using a biplane method. According to numerical simulations, the lift-to-drag ratio of a biplane is much larger than that of a thick monoplane. Finally, according to these findings, the biplane blade method is an appealing design for the next portion of wind turbine blades.

3. CONCLUSION

The research aimed to perform material-based synthesis to find the optimum materials; hence, composite and natural fibre was selected for this investigation. This analysis reveals that the Carbon fibre produced min stress at the stress concentration location where blades are attached to the hub, while the maximum stress was produced at the hemp fibre for the same boundary conditions. This analysis also reveals that stresses are maximum for E-glass material at the location of a minimum cross-section of the blade. In contrast, carbon fibre shows a little higher stress than jute & hemp fibre. The finding also shows that E-Glass & carbon fibre produced less deformation out of all materials, and Jute Fiber produced the max deformation. Henceforth, the proposed research would help to select the best materials according to their conditions and properties. Still, Carbon Fiber performs well as it shows a drastic decrease in deflection & marginal increase in stress compared to jute & hemp fibre. In the future alternative materials such as E-Glass can be used after a few modifications.

REFERENCE

[1] Yen Nakafuji. et al. "Active Load Control for Airfoils using Microtabs”, a Journal of Solar Energy Engineering, Volume 123, Issue 4, 282-289, November 2001.

[2] Chalothorn Thumthae and Tawit Chitsomboon, “Optimal Pitch for Untwisted Blade Horizontal Axis Wind Turbine”, The 2nd Joint International Conference on Sustainable Energy and Environment (SEE 2006), November 2006.

[3] Ferhat Kurtulmus. et al. "Aerodynamic Analyses of Different Wind Turbine Blade Profiles", Journal of Applied Sciences 7(5), pp 663670, 2007.

[4] Nazmi Izle. et al., "A Study on Aerodynamic Properties of Some NACA Profiles Used on Wind Turbine Blades”, Journal of Applied Science, Vol.7, pp 426-433, 2007.

[5] SHEN Zhen-Hua, YU Guo-Liang, “Influence of Airfoil's Camber on the Performance of Wind Turbines”, Journal of Power Engineering, ISSN:1000-6761.0.2007-01-029.

[6] Wang. et al. "The Methodology for Aerodynamic Study on a Small Domestic Wind Turbine with Scoop", a Journal of Wind Engineering and Industrial Aerodynamics, Volume 96, Issue 1, pp, 1-24, January 2008.

[7] Scott. et al. "Horizontal Axis Wind Turbine Blade Aerodynamics in Experiments and Modeling” October 2008.

[8] Amano, R.J. Malloy. "CFD Analysis on Aerodynamic Design Optimization of Wind Turbine Rotor Blades", World Academy of Science, Engineering and Technology 60, 2009.

[9] Migliore, “The Potential for Reducing Blade-Tip Acoustic Emissions for Small Wind Turbines”, NREL/SR-500-43472, February 2009.

[10] Tim Fischer “, Mitigation of Aerodynamic and Hydrodynamic Induced Loads of Offshore Wind Turbines”, 5th PhD seminar on wind energy in Europe, Durham University, European Academy of Wind Energy (EAWE), 30th September and 1st October-2009.

[11] Barlas and Van Kuik, "State of the Art and Prospectives of Smart Rotor Control for Wind Turbines”, A Journal Progress in Aerospace Sciences, Volume 46, Issue 1, PP 1–27, January 2010.

[12] Devenport. et al., "Aeroacoustic Testing of Wind Turbine Airfoils”, NREL/SR-500-43471, May 2010.

[13] Nitin Tenguria, “Aerodynamic Design of a HAWT Blade for Indian Wind Condition”, International Journal of Advances in Engineering, Science and Technology (IJAEST), ISSN: 2249-913X, Vol. 1 No. 1 November 2011.

[14] S. Lain. et al., "Aerodynamic and Structural Evaluation of Horizontal Axis Wind Turbines with Rated Power over 1 MW".

[15] Juan Mendez and David Greiner, "Wind blade chord and twist angle optimization by genetic algorithms".