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Comparative Study of Fatigue Analysis of Horizontal Axis Wind Turbine Blade Materials

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***Abstract*—Wind energy is one of the most promising form of renewable energy. Wind power accounts for 10% of India's total installed power capacity which makes it fourth largest wind power producing nation in the world. The blade is the most crucial component of a wind turbine and its maintenance costs a fortune. Large scale wind turbine blades are primarily made of fibre reinforced composites. In present study, a finite element model of a Horizontal Axis Wind Turbine Blade is developed for a given aerofoil. Comparison of stress, deflection and fatigue behavior has been studied for E-Glass/Epoxy and Carbon fibre/Epoxy blade materials through finite element method and results obtained for both the materials are presented.**

Keywords—Horizontal Axis Wind Turbine (HAWT) blades; glass fibres; carbon fibres; aerofoil; NACA 63415

I. INTRODUCTION

Wind energy is a widely accepted alternative to conventional form of energy. With fossil fuels depleting at an alarming rate, world is more reliable on renewable sources of energies than ever before. Wind energy is considered as most environmentally friendly form of energy as it emits least amount of greenhouse gases and has least water consumption demand[1]. With 34,293 MW of installed wind power capacity[2] India is the fourth largest producer of wind power in the world[3] and it is eyeing to double its capacity by the end of 2022[2]. Thus, continuous efforts are made towards improvement of wind power generating technologies.

Electricity from wind power is generated using wind turbines. The blades are considered as the most critical component of a wind turbine. They must be carefully designed by balancing structural and aerodynamic requirements[4]. For the major part of history, composites made from glass fibres impregnated in epoxy resin were used in manufacturing of wind turbine blades. The blades made were of adequate quality and economically cheaper. But with the increasing sizes of blades, a stiffer and lighter substitute to glass fibres was required. Carbon fibres proved to be exceptional in both these areas. The cost associated with carbon fibres was much greater than that of glass fibres, but it compensated for it by significantly lower weight which helped in transportation, handling and installation of blades.

In recent times most of the blades are manufactured by combining suitable fibres and matrix materials to form composites[5]. Composites must be stiff and lightweight and must meet the design criterions of the blade. The manufacturing of blades from these composites must be economically feasible. In present time, most of the large scale blades are made from carbon fibres, but glass fibre are still majorly used due its economic advantages.

II. WIND TURBINES AND TURBINE BLADES

A. Wind Turbines

Wind turbines are the devices used to convert kinetic energy of wind into electricity. They operate by using kinetic energy of the wind, which pushes the blades of the turbine and spins a motor that converts the kinetic energy into electrical energy. They vary in sizes depending upon their power producing capacity.

The two most common wind turbines studied in the literature[6], [7] are:

- Horizontal Axis Wind Turbines (HAWTs)
- Vertical Axis Wind Turbines (VAWTs)

B. Wind Turbine Blades

The rotor blades are fitted on the main shaft in a horizontal hub. The blades are so arranged that their axis of rotation is parallel to the direction of the wind. The number blades may vary but most of the commercial wind turbines has three blades each. The length of the blade depends of the power to be generated and its section is designed to obtain optimum lift to drag ratio. The blade is divided into three parts namely, root, mid span and tip[8]. Figure. 3 below shows a typical HAWT blade.

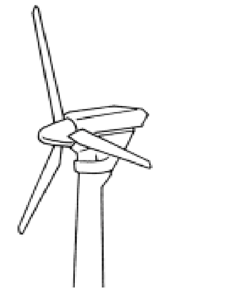

Figure 1: HAWT

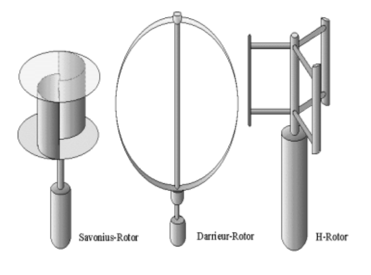

Figure 2: VAWT

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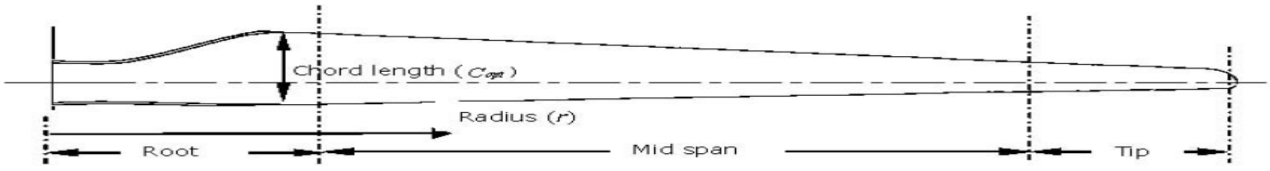

Figure 3: HAWT Blade

III. MATERIALS AND METHODOLOGY

A. Materials

In this study, e-glass (electric glass) fibres and carbon fibres in epoxy matrix are selected as blade materials for aerofoil section as they are most commonly used in blade manufacturing.[9] A tri-axial (-45o/0/45o) layup is assumed for both the materials based on prevailing manufacturing technologies.[10] The mechanical properties of Aerofoil blade section of HAWT from literature[11] are listed in Table 1.

TABLE 1: MECHANICAL PROPERTIES OF COMPOSITE MATERIALS OF HAWT BLADE

Property	**E-glass**	**Carbon**
E_{11} (GPa)	24.20	65.00
E_{22} (GPa)	8.97	22.50
G_{12} (Gpa)	4.97	13.46
ν_{12}	0.39	0.29
ν_f	0.4	0.2
w_f	0.61	0.6
ρ (g/cm^3)	1.70	1.75

Where, E_{11} is the axial Young's modulus, E_{22} is the transverse Young's modulus, G_{12} is the in-plane shear modulus, ν_{12} is the Poisson's ratio, ν_f is the fibre volume fraction, w_f is the fibre weight fraction and ρ is the density of the material.

For the present study a NACA 63415 Aerofoil section has been adopted. The problem details are listed in Table 2.

TABLE 2: PROBLEM DETAILS

Aerofoil Profile	NACA 63415
Blade Length	55 meters
Rated Power	2 MW
Rated Wind Speed	10.5 m/s
Hub Height	120 meters
Tip Speed Ratio	7.7
Maximum Chord Length	6.9 meters

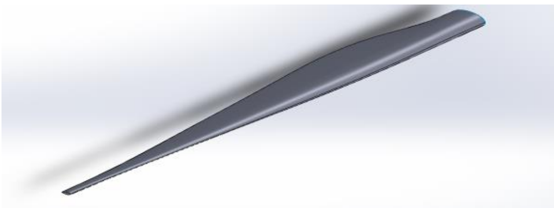

Figure 4: HAWT Blade Model

B. Methodology

First of all, the HAWT Blade was pre-processed in Finite Element Analysis (FEA) based software using shell feature. Material properties and stack up details were defined for composite materials. Then material properties were assigned to the HAWT Blade. A 4-D four-noded quadrilateral meshing has been adopted for the blade profile. Load case details and appropriate boundary conditions were defined and analysis was done under cyclic loads for analyzing fatigue behavior of the HAWT blade. The HAWT Blade model, material stack-up details and meshing of the blade in FEA based software are shown in figures 4,5 and 6 respectively.

IV. RESULTS AND DISCUSSION

Finite element method based analysis has been performed for two blades. The comparison between E-glass/epoxy and Carbon fibre/Epoxy has been done for the HAWT Blade. The results for Maximum stresses and displacement obtained based on the analysis are tabulated in Table 3.

TABLE 3: STRESS AND DISPLACEMENT RESULTS

	Maximum Displacement (mm)	Maximum Principal Stress (MPa)	Maximum Von-Mises Stress (MPa)
E-Glass/Epoxy	64	534.25	484.5
Carbon Fibre/Epoxy	36	534.25	484.4

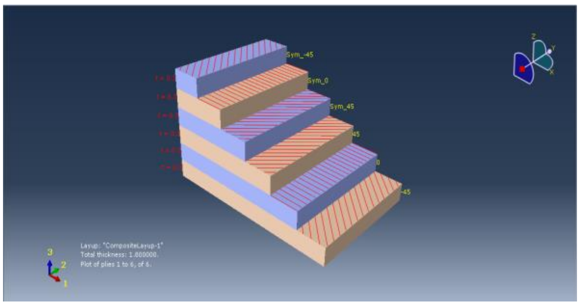

Figure 5: Ply Stack-up for -45/0/45 fibre orientation

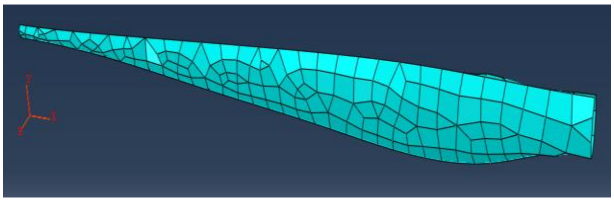

Figure 6: Blade Meshing

An online Fatigue Analysis tool was used for fatigue analysis of both the materials to computational constraints of the system for FEA Software analysis.

An Educational licence of 60 days was obtained from the developers of the online analysis portal www.fatiguenet.com.

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Stress analysis was performed for E-Glass/Epoxy and Carbon Fibre/Epoxy composite blades using an online Fatigue Analysis Tools (www.fatiguenet.com). The Stress Amplitude vs Reversal Cycles to Failure were obtained using the online portal.

The **E-Glass/Epoxy composite** took **3.8 x 10^6 cycles** to failure at Constant stress Amplitude, while **Carbon Fibre/Epoxy composite** took **6.63 x 10^7 cycles** to failure.

V. CONCLUSION

The obtained results for carbon fibres showed a remarkable reduction in displacement of the blade as compared to conventional E-glass fibres. A reduction of around 44% was observed in carbon fibres against glass fibres. As carbon fibres are more stiff, it creates a more effective load bearing mechanism due to composite layup. It can also be observed that by only changing the material a significant change in displacement can be obtained. Thus, material plays a crucial role in overall behaviour of the blade structure.

For the same geometry of blade, no change in stress distribution was obtained between both the materials. A variation of thickness of the blade may significantly vary the stress distribution over the blade.

Blade made from E-Glass/Epoxy shows a decrease in reversal cycles to failure by almost 10^7 cycles as compared to Carbon Fibre/Epoxy.

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