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Investigation on the Design, Structural and Modal Analysis for Polymer Matrix Composites at 10º and 20º Twist

J Anto Michael Ronson, C Sudhakar
Department of Mechanical Engineering, National Engineering College, Kovilpatti 628503

Abstract: Finite element evaluation of large (over 0.5MW) nominal power Horizontal Axis Wind Turbine (HAWT) is performed using ANSYS in this project. The strategy is based on the combination of an aerodynamic module, which provides the three dimensional pressure distribution on the blades as input data in order to compute both, blade deformation and stress intensity over the blades.This project also determines the natural frequency of the blade using modal analysis. The material used here are polymer-matrix composites, they are Glass/epoxy, Kevlar/epoxy, Carbon/epoxy and E-glass/epoxy. The stress intensity and displacement for different materials are compared and the best is highlighted which increases the life of the blade. This provides future scope for alternative materials for wind turbine blade.

Index Terms— Finite Elemet analysis, Polymer Matric Composite, Wind Turbine Blade, Energy Calculation, Material Analysis

I. Introduction:

Wind Energy is a renewable source of energy.Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the energy and convert it into useful work. The factors which determine the output from a wind energy converter includes;the wind speed,the cross – section of the wind swept by the rotor,the overall conversion efficiency of the rotor, transmission system and generator or pump.

II. Blade design calculation:

The energy available in the wind,

$E = ½ (mv^2) = ½ (\rho Av) v^2$

$\mathbf{E = ½ (\rho A v^3)}$

Power developed in the wind mill

$\mathbf{P = ½ (C_p \rho A v^3)}$ **………1**

Where,

C_p – Power coefficient (beltz limit - 0.593)

A – Area of the rotor in m^2

ρ - Density of air 1.29 kg/m^3

v – Velocity of wind in m/s.

2.1. Calculation of Rotor diameter:

From eq (1)

For 0.5MW power,

$A = 756.505\ m^2$

D = 30m (approx.)

Therefore, **Radius of rotor R = 15 m.**

This radius of the rotor is equal to length of the blade.Therefore, length of the blade L=15 m

2.2. Calculation of chord length:

Chord length at root end of the blade,

$\mathbf{C_R = 4D / \lambda^2 B}$ **………2**

Where, λ – tip speed ratio,B – no of blades

$C_R = 4 \times 30 / 7^2 \times 3 = 0.8163$ m

2.3. Tip speed ratio,

$\mathbf{\lambda = R\,\omega / V_{wind}}$ **………3**

$\mathbf{\omega = 2\pi N/60}$ **………4**

Where,V_{wind} – velocity of wind, N–no of rotation of blade per min

Solving eq (3) and eq (4)

N = 54 rpm

Chord length at tip end of the blade,

$\mathbf{C_r = 4d / \lambda^2 B}$

$= 4 \times 3 / 7^2 \times 3 C_r = 0.08163$ m

III. Wind turbine Blade

Step 1:

The co-ordinates for the two dimensional aerofoil sketch is taken from National Renewable Energy Laboratory website (NREL).S818 was chosen for Modeling of wind turbine blade.

Step 2:

The 2D aerofoil sketch of the turbine blade was drawn using CATIA software.

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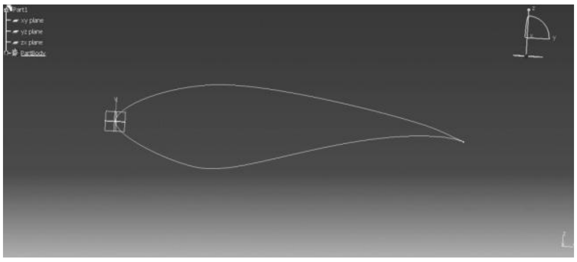

Fig 1: Two dimensional view of Aerofoil Sketch

Step 3:

The sketch was imported in PRO-E to convert that 2D into compute 3D blade.

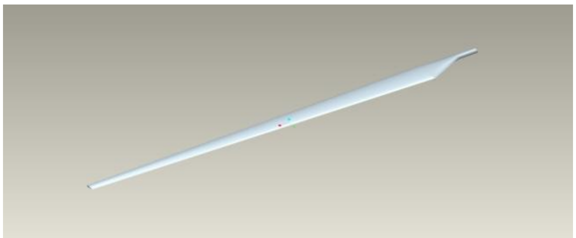

Fig 2 :Three Dimensional view of Wind Turbine Blade

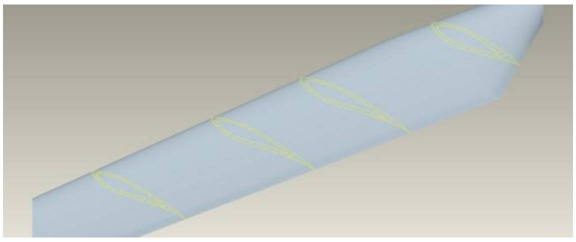

Fig 3: Three Dimensional Sectional view of Wind Turbine Blade

The Geometric properties of the blade :

Section / property	Hollow section
Volume	52.5 m^3
Surface Area	36.32 m^2
Mass	756.68 kg

Table2. Properties of blade

Step 4:

The drawn blade is edited for various Twist angles (10 degree, 20 degree) for analyzing the best design. The wind turbine blade drawn was converted into IGS file and imported in ANSYS for further analysis.

3.1. Material selection for Blade :

Material used for analyzing of wind turbine is polymer matrix composite. They are

- Glass fiber/epoxy
- Kevlar/epoxy
- E-glass/epoxy
- Carbon/epoxy

Fiber	**Young's modulus (Gpa)**	**Poisson ratio**	**Shear modulus (Gpa)**
Glass/ epoxy	E1 =2.97	μ_{12} =0.17	G_{12} = 5.3
	E2 =2.97	μ_{23} =0.01	G_{23}=14.07
	E3 =2.97	μ_{31} =0.17	G_{31} = 5.3
Kevlar/ epoxy	E1= 87	μ_{12} =0.34	G_{12} = 2.2
	E2= 5.5	μ_{23} =0.37	G_{23} = 1.47
	E3= 5.5	μ_{31} =0.34	G_{31} = 2.2
Eglass/ epoxy	E1= 39	μ_{12} =0.28	G_{12} = 3.8
	E2=8.6	μ_{23} =0.06	G_{23} = 4.05
	E3=8.6	μ_{31} =0.28	G_{31} = 3.8
Carbon/ epoxy	E1= 147	μ_{12} =0.27	G_{12} = 7
	E2= 10.3	μ_{23} =0.54	G_{23} = 3.7
	E3= 10.3	μ_{31} =0.27	G_{31} = 7

Table 3. Young's Modulus,Poisson Ratio Shear Modulus of Fibers

Fiber	Density Kg/m^3
Glass/ epoxy	2200
Kevlar/ epoxy	1440
Eglass/ epoxy	2100
Carbon/ epoxy	2000

Table 4. Density of Fibers

IV. Structural Analysis:

4.1. Force acting on the blade:

The wind force acting on the wind turbine blade is

F= ½(ρv²D²/N) 5

F= 1.29 x 12^2 x 30^2 x 60 / 2 x 54

F= 92880 N

4.2. Pressure distribution on the blade:

Pressure = force / Area

P= F/A 6

P= 92880 x 2 / 36.32

Here, the area is divided by 2. Since, the pressure distribution acts on one side of the area of the blade.

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P= 5114.52 N/m²

4.3. Stress intensity on blade :

3D Model of the blade is imported from-PRO-E to ANSYS, for this analysis SOLID 187, 3-D 10-Node Tetrahedral Structural element is chose-nand analysed using Ansys Software.

4.3.1. Glass fiber / epoxy

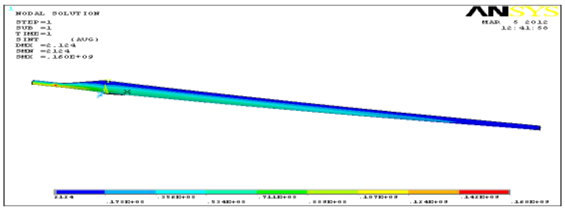

Fig 6: Stress Intensity For glass fiber / epoxy for 10º Twist

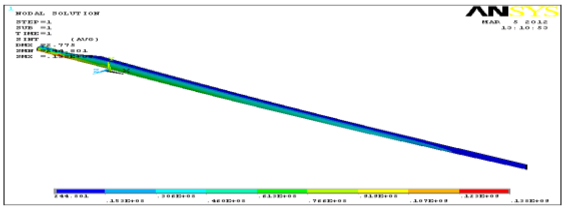

Fig 7: Stress Intensity For glass fiber / epoxy for 20º Twist

4.3.2. E-glass / epoxy

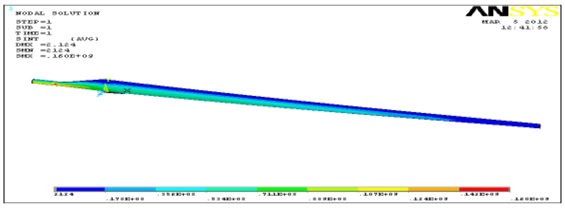

Fig 8: Stress Intensity For E-glass / epoxy for 10º Twist

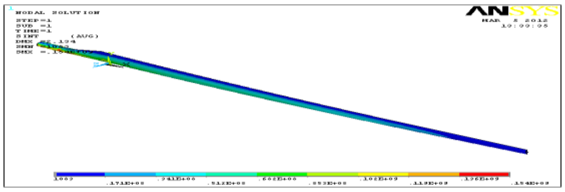

Fig 9: Stress Intensity For E-glass / epoxy for 20º Twist

4.3.3. Kevlar / epoxy

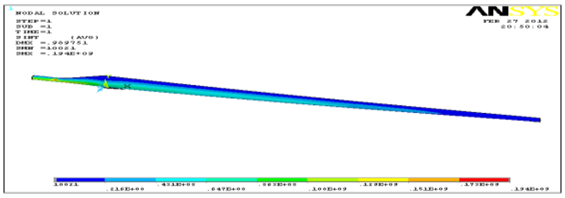

Fig 8: Stress Intensity For Kevlar / epoxy for 10º Twist

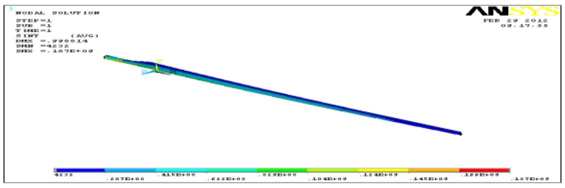

Fig 9: Stress Intensity For Kevlar / epoxy for 20º Twist.

4.3.4. Carbon / epoxy :

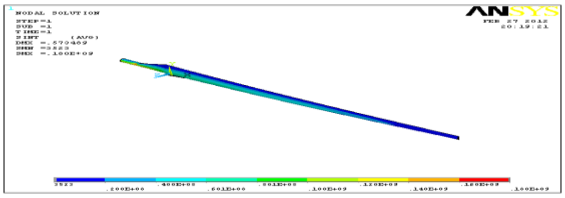

Fig 10: Stress Intensity For Carbon / epoxy for 10º Twist

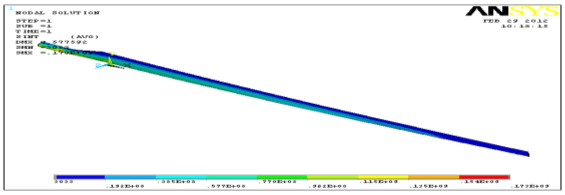

Fig 11: Stress Intensity For Carbon / epoxy for 20º Twist

4.4. Displacement along Y- axis in blade :

4.4.1. Glass fiber / Epoxy

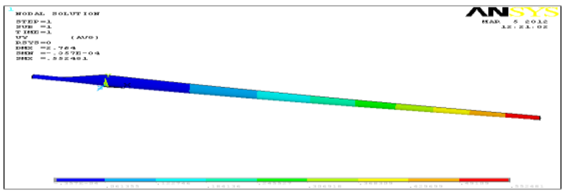

Fig 12: Displacement along Y-axis for glass fiber / epoxy for 10º Twist

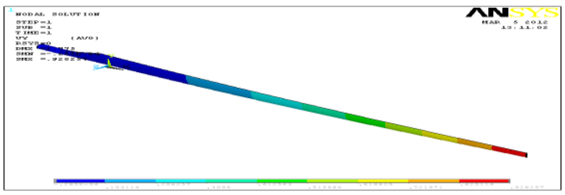

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Fig 13: Displacement along Y-axis for glass fiber / epoxy for 20º Twist

4.4.2.E-glass/Epoxy

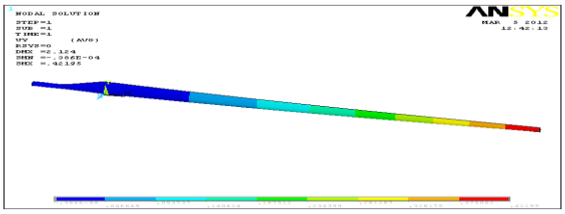

Fig 14: Displacement along Y-axis for E-glass/Epoxy for 10º Twist

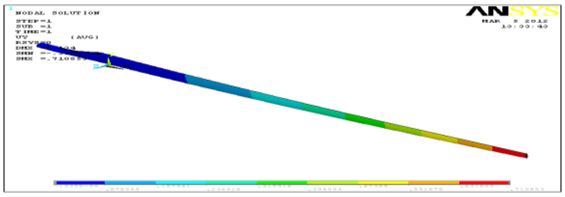

Fig 15: Displacement along Y-axis for E-glass/Epoxy for 20º Twist

4.4.3. Kevlar / Epoxy

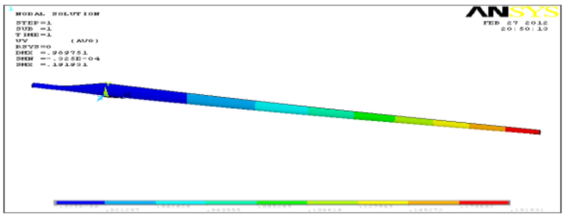

Fig 16: Displacement along Y-axis for Kevlar/Epoxy for 10º Twist

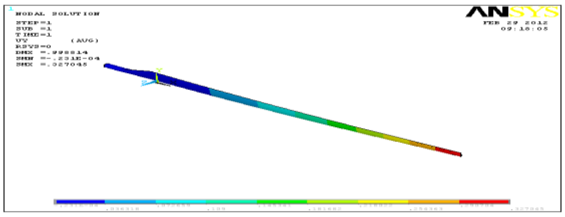

Fig 17: Displacement along Y-axis for Kevlar/Epoxy for 20º Twist

4.4.4. Carbon / Epoxy

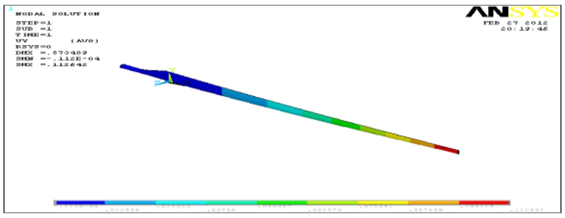

Fig 18: Displacement along Y-axis for Carbon/Epoxy for 10º Twist

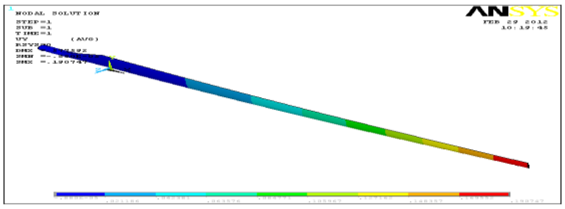

Fig 19: Displacement along Y-axis for Carbon/Epoxy for 20º Twist

V. Modal analysis – Natural frequency in blade for Glass fiber / epoxy -20º Twist

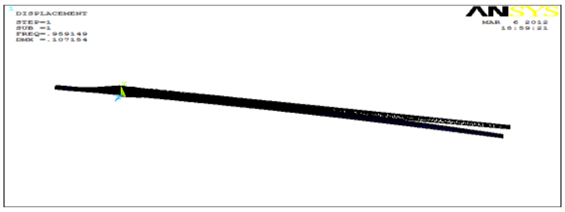

Fig 20 :Mode - 1

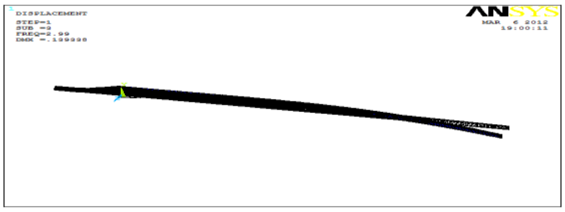

Fig 22 :Mode – 3

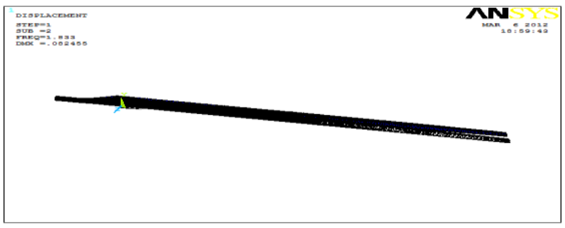

Fig 21 :Mode - 2

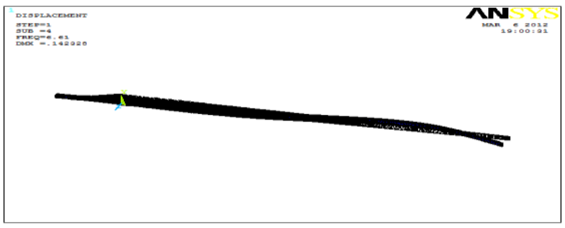

Fig 21 :Mode - 4

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Material	Angle of Twist (degree)	Stress intensity x e9 n/m²	Displacement along y-axis (m)
Glass fiber/ epoxy	10	0.144	0.5524
	20	0.138	0.9282
E-glass/ epoxy	10	0.16	0.4219
	20	0.154	0.7108
Kevlar/ epoxy	10	0.194	0.1919
	20	0.187	0.327
Carbon/ epoxy	10	0.18	0.1126
	20	0.173	0.1907

Material	Angle of Twist	Natural frequency at various nodes				
		1	2	3	4	5
Glass fiber/ epoxy	10	0.995	1.809	3.002	6.699	8.703
	20	0.959	1.833	2.989	6.61	8.772
E-glass/ epoxy	10	1.114	2.065	3.451	7.695	10.106
	20	1.114	2.085	3.455	7.579	10.147
Kevlar/ epoxy	10	1.962	3.357	5.91	12.416	17.303
	20	1.958	3.381	5.872	12.311	17.098
Carbon/ epoxy	10	2.193	3.915	6.756	14.628	19.689
	20	2.191	3.948	6.708	14.448	19.734

Table 5: Stress Intensity, Displacement along Y axis, Natural frequency at various nodes for Polymer matrix Composites at 10°,20° Angle of Twist

VI.Conclusion:

It is important to calculate the stress intensity and natural frequency of the blade in order to predict its performance and life. The stress distribution enables us to optimize and modify the design at lower cost. From this project it has been found that the glass fiber/epoxy with 20° Twist angle at the root produces lower stress intensity, but while considering the displacement carbon fiber/epoxy will be better suited with the same Twist angle. Hence the blade with 20° Twist angle is selected for wind mill.

From the Modal analysis of wind turbine blades for various materials, it is identified that Glass fiber / epoxy has less frequency at 20° Twist angle than other materials.

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