Design And Material Optimization Of Wind Turbine Blade

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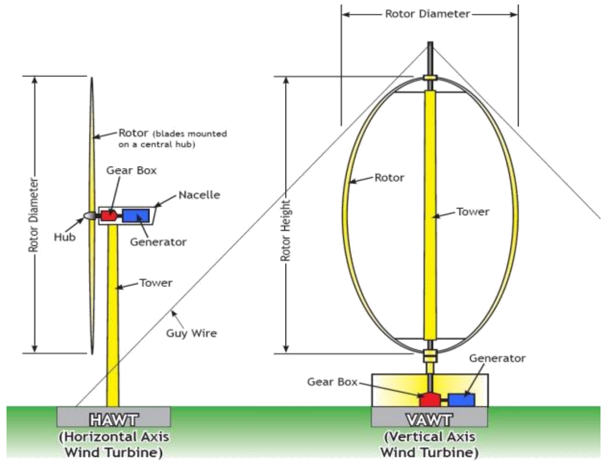
Abstract- *The goal of this project is to develop the geometry of the wind turbine blade, to improve the capacity, strength and to reduce weight. Initially literature survey and data collection has been done to understand the problem rectification methodology and selection of material. 3D model has been prepared using CMM points collected from NACA specifications. Different types of geometry's are implemented on the same and exported to Ansys for further study. A structural analysis is done on various geometric profiles of blade segment @200 Kmph and 400 Kmph (double velocity) for the validation. It is observed that the deflections of composite turbine blade are greater and stresses are less as compared to aluminum turbine blade for the same loading conditions. A 15% reduction in weight can be obtained by replacing an aluminum turbine blade with a composite turbine blade.*

I. INTRODUCTION

A wind turbine is a machine that converts kinetic energy from the wind into electrical power. There are mainly two types of wind turbine: horizontal axis and vertical axis. The horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT) are classified or differentiated by the axis of rotation of the rotor shafts. Horizontal Axis wind turbines- Horizontal axis wind turbines, also known as HAWT type turbines have a horizontal rotor shaft and an electrical generator which is both located at the top of a tower. Vertical Axis wind turbines- abbreviated as VAWTs, are designed with a vertical rotor shaft, a generator and gearbox which are placed at the bottom of the turbine, and a uniquely shaped rotor blade that is designed to harvest the power of the wind no which direction is it blowing.



Humans had the first approach with wind power thousands of years ago, propelling their sailboats with it. Since the 7th century AD, wind was used by windmills to pump water or mill grains in Persia. Wind energy has been adopted for pumping water from wells for steam trains, and it is still able to provide it for isolated houses or off-grid locations. Only at the end of 19th century the concept of modern wind turbine arises, converting the kinetic energy of the wind into electricity.

The new designs focus on other aspects than "size". For instance, improving the efficiency of the blade reduces the fatigue loads, increasing the life cycle of the components, as well as more accurate internal blade design can reduce the amount of material utilised, making the rotor lighter and cheaper. Advanced aerodynamic technologies are also embraced to achieve better and cheaper results. Development of smart rotors, winglets, flaps, gurney flaps, micro tabs and vortex generators is a daily basis topic. All these technologies are meant to control or limit the harmful loads, leading to less fatigue and therefore longer life cycle or less materials.

Enercon E-48, blade tip winglet

Properties of E-Glass & S-Glass

Properties that have made E-glass so popular in fiber glass and other glass fiber reinforced composite include:

- Low cost
- High production rates
- High strength
- High stiffness
- Relatively low density
- Non-flammable
- Resistant to heat
- Good chemical resistance
- Relatively insensitive to moisture
- Able to maintain strength properties over a wide range of conditions Good electrical insulation

Problem Description

Wind turbines are playing key role in Eco friendly power generation, but wind turbines are having some constrains to produce more than 20mw of power.

1.Weight of the blade.
2.Length of the blade constrained due to failure or breakage
3.Unwanted high velocity of air courses breakage.
4.Cost of aluminum/traditional material blades.

Because of theses above problem wind energy constrained to power limits.

Design selected for Wind turbine blade

Initially NACA 4415 cambered airfoil was selected for creating the geometry model. The coordinate points are taken from the NACA specifications.

Selection of Modeling and Analysis software

Different geometry modeling of Aluminum, E-Glass/Epoxy and S-2 glass composite wind turbine blade shapes is done using Pro-E Wildfire 5.0 and Creo 2.0. Static Model analysis of Aluminum, E-Glass/Epoxy and S-2 glass composite wind turbine blade is done using ANSYS 14.5 software.

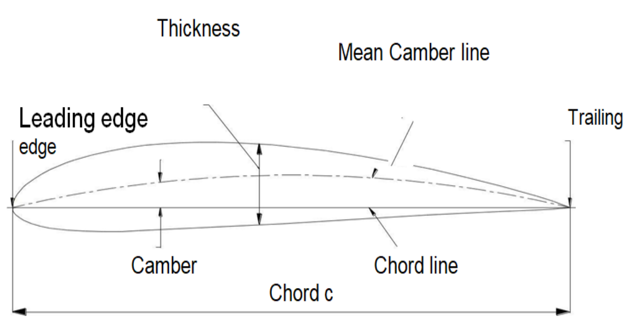
Material selection

E-glass/Epoxy and S-2 glass composite materials are selected for wind turbine blade design. E-glass/Epoxy and S-2 glass are high quality glasses, which is used as standard reinforcement fiber for all the present systems well complying with mechanical property requirements and helps in weight reduction of the blade.

Material properties used for Analysis

Initially the different geometries of wind turbine blade with Aluminum, E- Glass/Epoxy and S-2 glass is modeled in Pro-e Wildfire 5.0. and Creo 2.0. They are imported into Ansys 14.5 in IGES format. For aluminum wind turbine blade the element used to analyze is Solid-Brick 8node 185. Material properties for aluminum wind turbine blade are Isotropic.

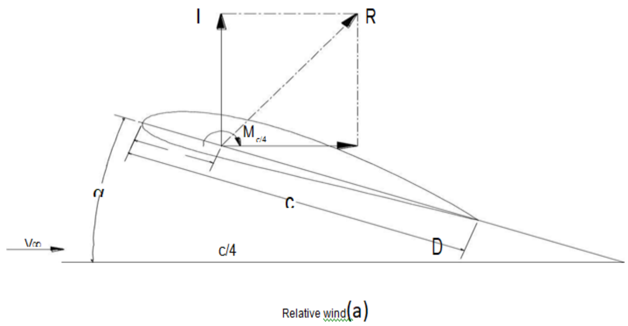
For E-Glass and S-Glass wind turbine blade the element used to analyze is Shell 8 node 281. This element is suitable for large deflection modes as well as analysis of elastic and plastic deformation. Material properties for composite material are orthotropic. Section of the shell is done in Lay-up method by adding layer by layer.

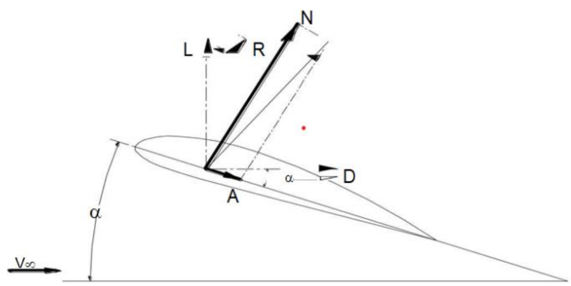


The NACA four-digit wing section

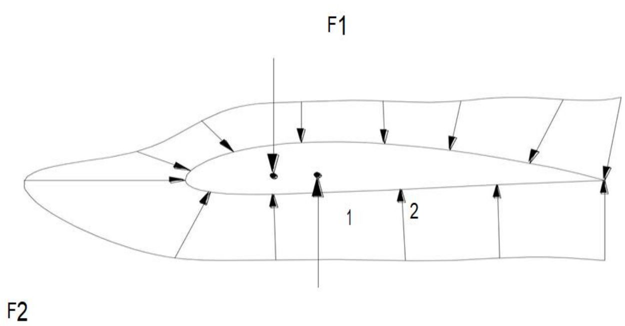
The cross-sectional shape obtained by the intersection of the wing with the perpendicular plane is called an airfoil. The major design features of an airfoil is the mean camber line, which is the locus of points halfway between the upper and lower surfaces, as measured perpendicular to the mean camber line itself. The most forward and rearward points of the mean camber line are the leading and trailing edges, respectively.

Lift, drag, moments, angle of attack, and relative wind
Normal and axial force

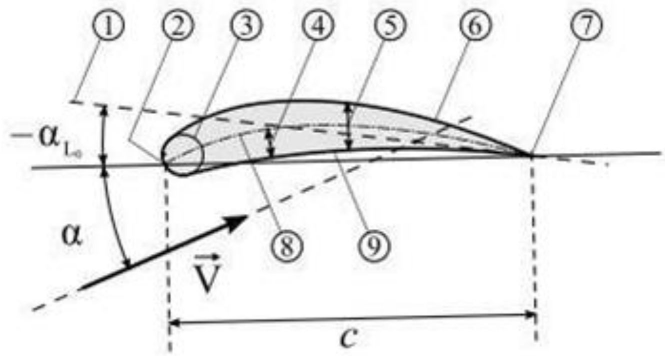




In addition to lift and drag, the surface pressure and shear stress distributions create a moment M which tends to rotate the wing. To see more clearly how this moment is created, consider the surface pressure distribution over an airfoil, as sketched in Fig. (We will ignore the shear stress for this discussion). Consider just the pressure on the top surface of the airfoil. This pressure gives rise to a net force F1 in the general downward direction.



The NACA 0015 airfoil is symmetrical, the 00 indicating that it has no camber. The 15 indicates that the airfoil has a 15% thickness to chord length ratio: it is 15% as thick as it is long.

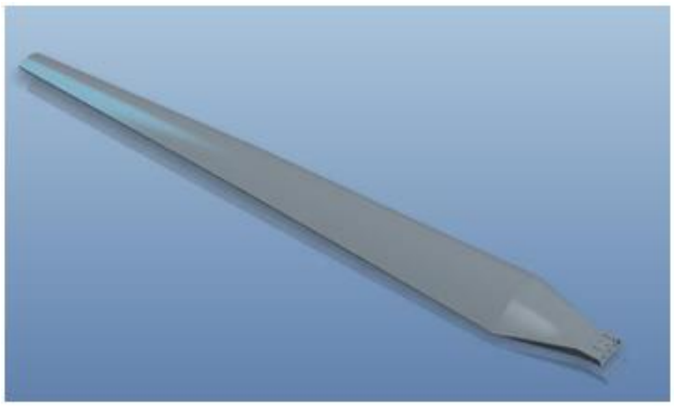


Profile geometry – 1: Zero lift line; 2: Leading edge; 3: Nose circle; 4: Camber; 5: Max.

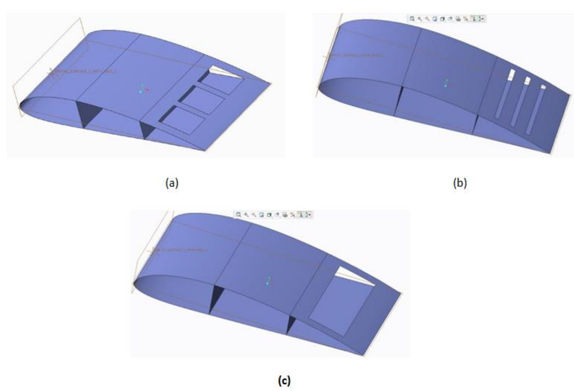
Thickness; 6: Upper surface; 7: Trailing edge; 8: Camber mean-line; 9: Lower surface Equation for a symmetrical 4-digit NACA airfoil

Model:

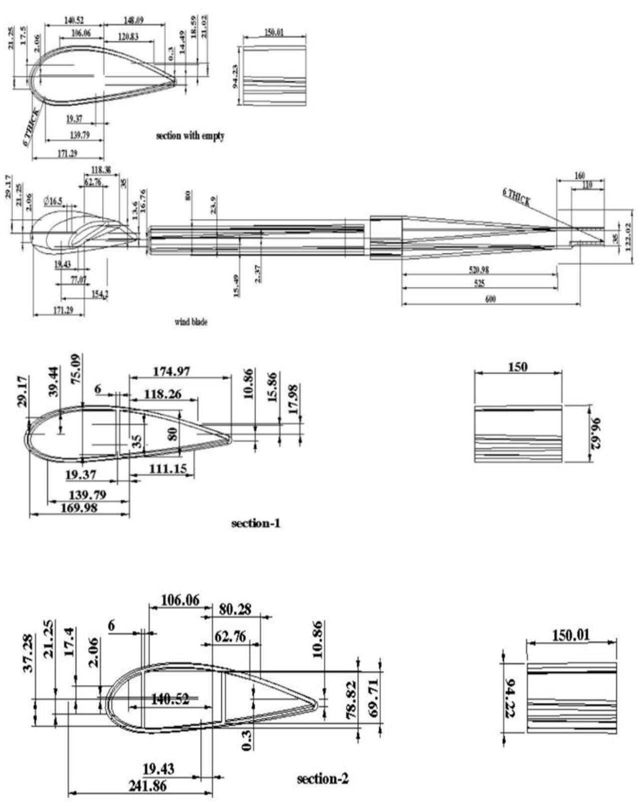
Aluminum, E-Glass/Epoxy and S-2 Glass composite wind turbine blades are modeled using Pro-E Wildfire 5.0. and Creo 2.0. Isometric view of Composite Wind turbine blades and detailed dimensions of part of the Composite wind turbine blade



designing of wind turbine blade



a,b,c shows the two rib blade section with internal cuts



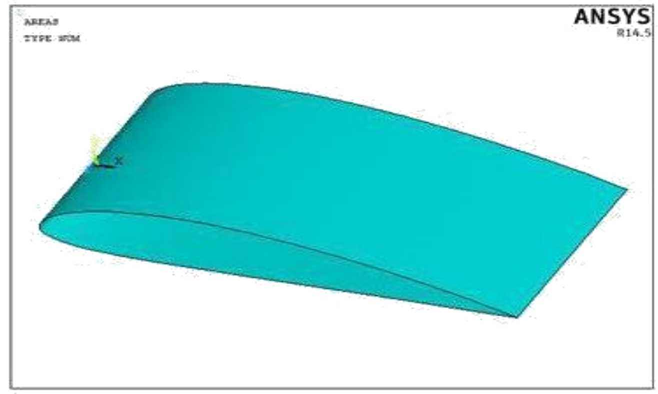
A wide range of objective functions (variables within the system) are available for minimization or maximization:

- Mass, volume, temperature
- Strain energy, stress strain
- Force, displacement, velocity, acceleration
- Synthetic (User defined)

There are multiple loading conditions which may be applied to a system. Some examples are shown:

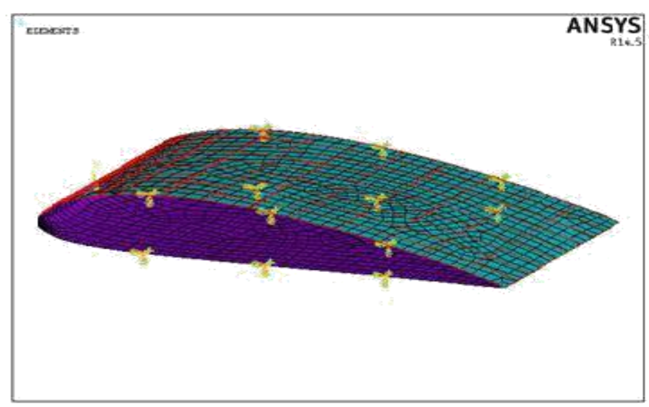
- Point, pressure, thermal, gravity, and centrifugal static loads
- Thermal loads from solution of heat transfer analysis
- Enforced displacements
- Heat flux and convection
- Point, pressure and gravity dynamic loads

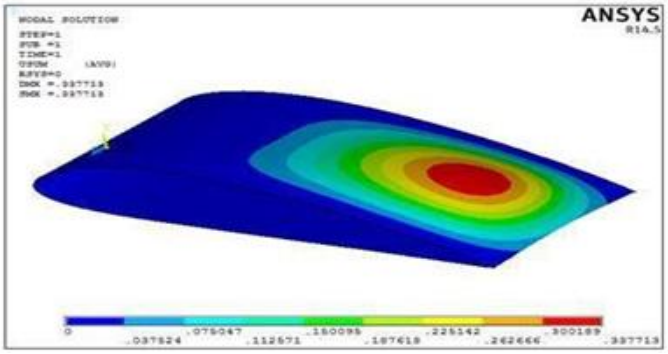
Each FEA **Structural Analysis:**



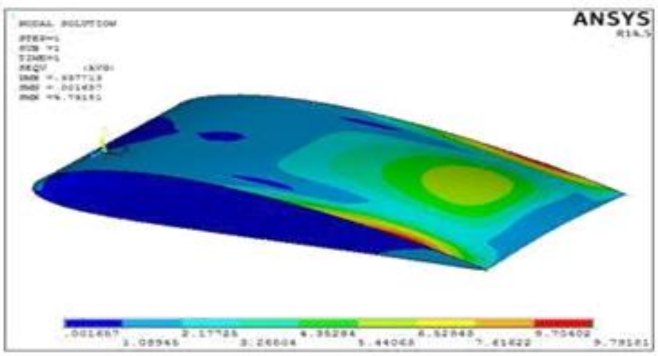
Tetra Hydra Mesh. Meshing is used to deconstruct complex problem into number of small problems based on finite element method.

Movement of the turbine blade is totally fixed (all DOF), at both surfaces. A pressure of 0.00185 MPa is applied on the outer surface of the blade

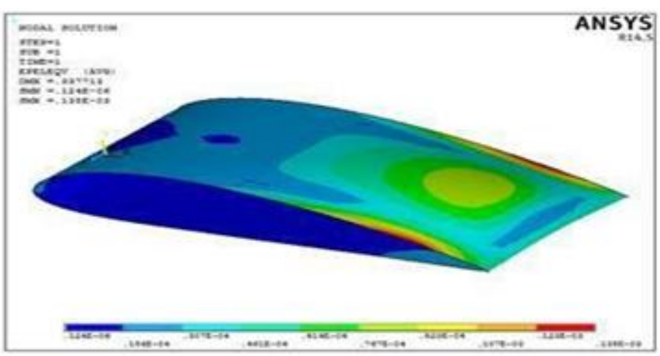




Maximum displacement of the wind turbine blade at maximum load= 0.337713 mm



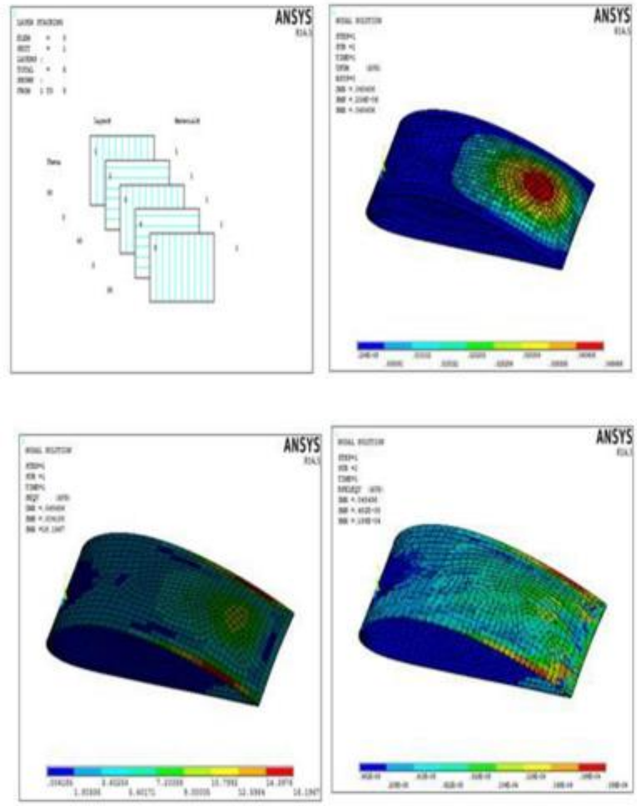
Maximum von-misses stress at the maximum load = 9.79181 N/mm2



Maximum strain value at the maximum load= 0.00138

Structural Analysis S-glass epoxy

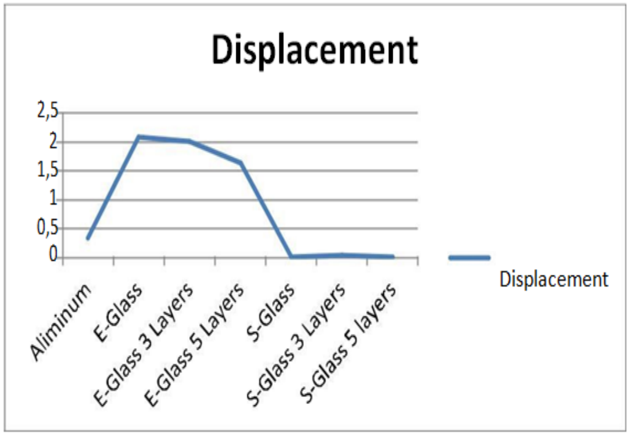
Initially the IGES model imported from the Pro-e Wildfire 5.0. Default Shell 8node 281 element was used to mesh the components. After solving the problem maximum displacement, von-misses stress and strain of an S-2 Glass Epoxy wind turbine blade is observed at the maximum load conditions.



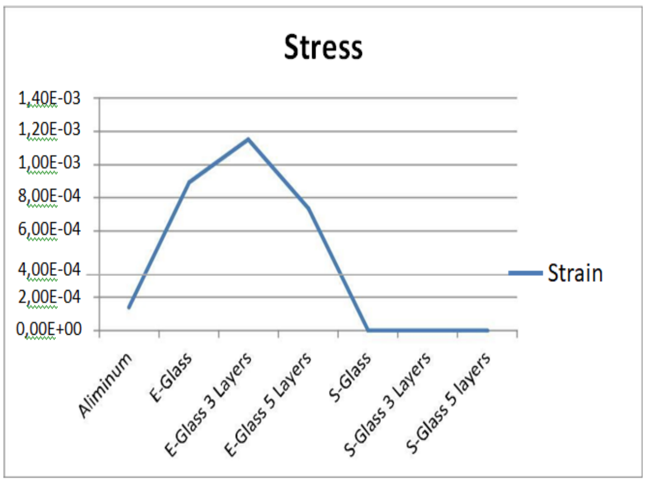
a) Maximum Displacement value at maximum load=0.028315mm
b) Maximum Von-misses stress at maximum load=10.0518N/mm2
c) Maximum Strain at maximum load conditions=0.000116.

II. RESULTS

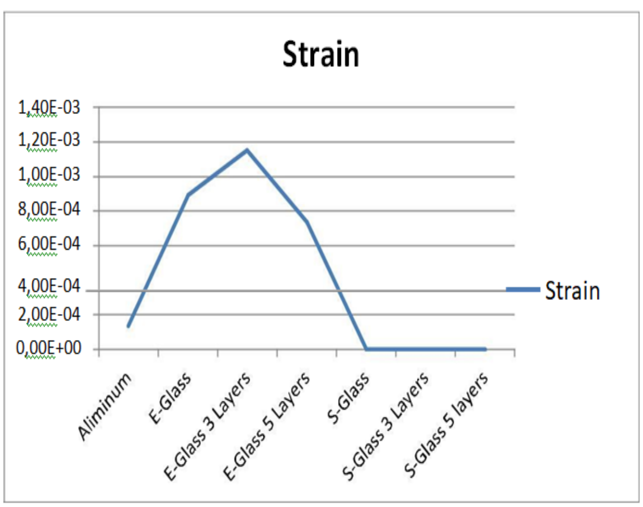
Material and layer	Displacement	Stress	Strain	F o S
Aluminum	0.337	9.79181	1.38E-04	16.85
E-Glass	2.086	19.673	8.94E-04	12.707
E-Glass 3 Layers	2.005	15.979	0.001151	15.645
E-Glass 5 Layers	1.627	17.3184	7.35E-04	14.435
S-Glass	0.002	9.97009	0.115 e-04	459.8
S-Glass 3 Layers	0.028	10.0518	0.116 e-04	456.137
S-Glass 5 layers	0.002	10.0017	0.115 e-04	458.422



Displacement of the wind turbine blade at 200Kmph

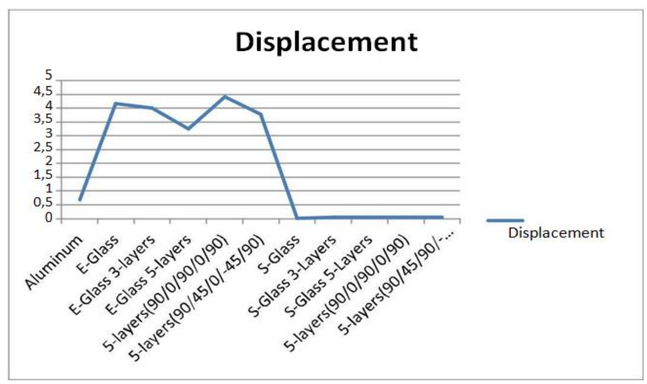


Stresses of the wind turbine blade at 200Kmph

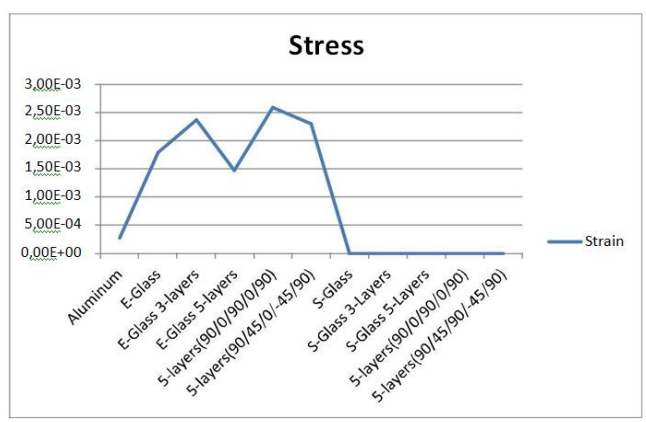


Strain of the wind turbine blade at 200Kmph

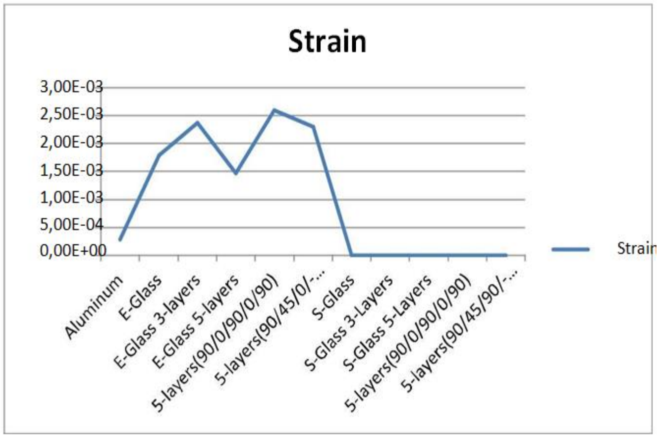
Material and layer orientation	Displacement	Stress	Strain	FOS
Aluminum	0.675426	19.5836	2.76E-04	8.4254
E-Glass	4.17217	39.3459	0.001788	6.3539
E-Glass 3-layers	4.0108	31.953	0.002368	7.8227
E-Glass 5-layers	3.25585	34.6369	0.00147	7.2177
E-Glass 5-layers(90/0/90/0/90)	4.41734	23.2458	0.002593	10.7546
E-Glass 5-layers(90/45/0/-45/90)	3.78125	30.3007	0.002297	8.25
S-Glass	0.0056221	19.9402	0.229 e-04	229.937
S-Glass 3-Layers	0.056626	20.0425	0.231 e-04	228.762
S-Glass 5-Layers	0.056225	20.0034	0.230 e-04	229.211
S-Glass 5-layers(90/0/90/0/90)	0.045456	16.1967	0.186 e-04	283.08
S-Glass 5-layers(90/45/90/-45/90)	0.041849	14.9113	0.172 e-04	229.21



Displacement of the wind turbine blade at 400Kmph



Stress of the wind turbine blade at 400Kmph



Strain of the wind turbine blade at 400Kmph

Static analysis results of Wind turbine blade with single rib at 400 Kmph

	Displacement	Stress	Strain	FOS
Aluminum	0.678239	19.6324	2.77E-04	8.4044
E-Glass	4.18134	41.3497	0.001977	6.045
E-Glass 3-layers	3.74294	36.2315	0.002712	6.9
E-Glass 5-layers	3.21004	32.9017	0.001399	7.598
5 layers orient1(90/0/90/0/90)	4.34778	19.0973	0.002606	13.09
5 layers orient 2(90/45/0/-45/90)	3.69929	25.8504	0.002392	9.671
S-Glass	0.056386	19.9866	0.230 e-04	110.883
S-Glass 3-Layers	0.056785	20.122	0.232 e-04	227.86
S-Glass 5-Layers	0.056387	20.0229	0.230 e-04	228.98
5 layers orient 1-(90/0/90/0/90)	0.045535	16.1875	0.186 e-04	283.24
5 layers orient 2(90/45/90/-45/90)	0.041923	14.9246	0.172 e-04	307.21

Static analysis results of Wind turbine blade with dual rib at 400 Kmph

	Displacement	Stress	Strain	FOS
Aluminum	0.677106	19.5149	2.75E-04	8.1988
E-Glass	4.18606	39.1605	0.002039	6.383
E-Glass 3-layers	4.13278	37.1455	0.002295	6.7302
E-Glass 5-layers	3.3101	34.2888	0.001563	7.291
5 layers orient1(90/0/90/0/90)	4.41657	36.6808	0.002763	6.8155
5 layers orient 2(90/45/0/-45/90)	3.84854	27.2399	0.002342	9.1777
S-Glass	0.054583	19.8493	0.222 e-04	230.99
S-Glass 3-Layers	0.056677	20.0277	0.230 e-04	228.932
S-Glass 5-Layers	0.056282	19.9297	0.229 e-04	230.058
5 layers orient 1-(90/0/90/0/90)	0.045499	16.1408	0.186 e-04	284.062
5 layers orient 2(90/45/90/-45/90)	0.041888	14.8598	0.171 e-04	308.55

Deflections, Stresses and Strains of Aluminum & composite materials of wind turbine blade at a velocity of air 400 Kmph with dual rib and modified models are obtained from Static Analysis

Material and layer orientation	Displacement	Stress	Strain	FOS
S-Glass 5layers (90/45/0/-45/90) 3 Rectangular	0.236123	51.9901	5.98E-05	88.189
S-Glass 5layers (90/45/0/-45/90) Rectangular	0.159827	46.6698	5.37E-05	98.243
S-Glass 5layers (90/45/0/-45/90) 3 sections	0.076612	24.2525	2.79E-05	189.052

III. CONCLUSIONS

This project work deals with wind turbine blade optimization for the purpose of improvement in strength, capacity and reduction of weight.

- Initially literature survey was done to understand the problems and rectification methodology.
- 3D models are prepared using NACA Airfoil data, to conduct analysis in Ansys.
- In case one: Static structural analysis was done on airfoil segment by varying materials (aluminum, E-glass, s-glass) and by applying reinforcement angles for the composite materials @ 200kmph (general air velocity in India).

- In case two analyses was done @ 400kmph to understand structural behaviors at un-natural air velocity.
- In the next case single single rib and two rib segments was analyzed with variation in reinforcement angle values.
- In the next case different stress reliving slots are designed on airfoil segments are analyzed.
- Comparison tables along with FOS are prepared for all analysis results.
- As per obtained results this project work concludes that s-glass epoxy(CRFP) along with 900-450-00-450-900 of reinforced layer orientation with double ribs 3 sectioned profile is giving optimum quality for the air foil design.
- By using above said design it can bear approximate 11 times load than general/traditional material design blade profiles.
- So the length can be increased up to huge level to improve power generation.And also s-glass density is 15% lower than aluminum and e-glass materials.

IV. FUTURE SCOPE OF WORK

Further analysis can be done on CFD, vibrations and kinematics to study wind turbine blade vibrations due to high rotation and also reduction of vibrations materials with the combination of composites and also analysis can be done on air foil profile optimization.

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