Design And Material Optimization of Wind Turbine Blade

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Abstract- *Wind turbine is a device which converts kinetic energy from the wind into electrical power. Wind turbines generate electricity through asynchronous machines thatare directly connected with the electricity grid. Composite wind turbine blades have high strain energy because it has less Young's modulus and density compared to Aluminum turbine blade. Due tolight weight and non-corrosiveness in nature the life and durability is high.*

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

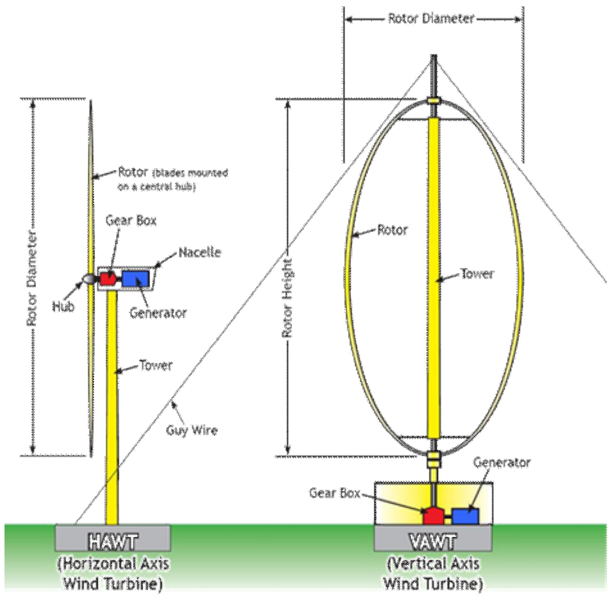
A wind turbine is a machine that converts kinetic energy from the wind into electrical power. There are mainly two types of wind turbine: horizontal axis and vertical axis. The horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT) are classified or differentiated by the axis of rotation of the rotor shafts.

1. Horizontal Axis wind turbines
2. Vertical Axis wind turbines

Components of A Wind Turbine

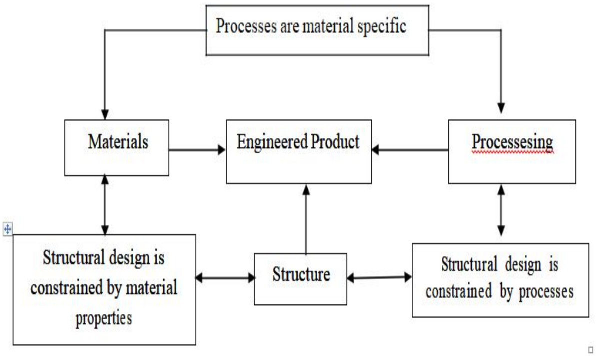
Wind turbine usually has six main components: the rotor, the gearbox, the generator, the control and protection system,

Rotor, Gear box, Generator, Control and Protection System, Tower, Foundation.



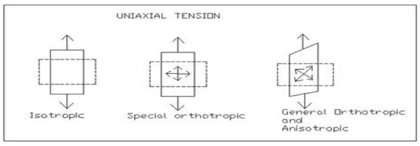
Wind turbine component

All engineered products can be defined in terms of the materials from which they are made, the manufacturing technique with which they were processed and the structure (shape, **topology, structural layout, etc…) on which they rely in order to bare their function. The strong**interaction between these three fundamental aspects of engineered products can be visualized as **a "Holy Trinity" of design in which material, structure and process each have their own**distinctive nature, but form the engineered product when combined. In the early steps of the design process, engineers are confronted with the fact that materials, processes and structures are **"spiritually" united and must be treated collectively. Ultimately, the role of the engineer is to**find the best structure for a specific function within the constraints imposed by the materials (cost, strength and stiffness limits, etc.) and processes (cost, size and shape limits, etc.) readily available at the time of design.

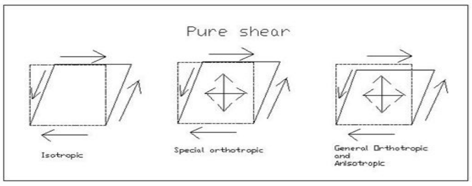


Mechanical Behavior of the Materials:

Tensile normal stresses applied in any direction of the applied stresses and contractions in the two transverse directions. Similar behavior is observed in orthotropic materials only if the normal stresses are applied in one of the principal material directions. However, normal stresses applied in any other direction create both extensional and shear deformations. In an anisotropic material, a combination of extensional and shear deformations is produced by a normal stress acting in any direction. This phenomenon of creating both extensional and shear deformations by the application of either normal or shear stresses is termed "extension-shear coupling" and is not observed in isotropic materials



Mechanical Behaviors of the Materials



Differences in the Deformations of Materials

Unidirectional oriented fiber composites are a special class of orthotropic materials. If the fibers are in the 1-2 plane, elastic properties are equal in the 2-3 directions so that E22 = E33,μ12 = μ13 and G12 =G13. Further G23 can be expressed in terms of E22 and μ12. For anorthotropic or anisotropic material, the direction of shear stress is critically important in determining its strength and modulus, whereas for isotropic material, the mechanical behavior is independent of the direction of shear stress.

Design Parameters of Aluminum Wind turbine blade

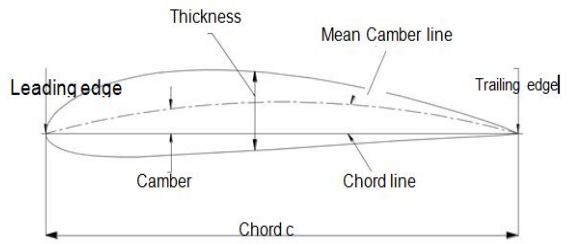
Parameter	**Value**
Material-selected – Aluminum	A360.0f
Tensile strength (N/mm^2)	370
Yield Strength (N/mm^2)	165
Young's modulus E (N/mm:)	71000
Density of the material (kg/mm^3)	$2.680*10^{-6}$
Poisson's ratio	0.33

S No.	Properties	Value
1.	Tensile modulus along X-direction (Ex), MPa	18800
2.	Tensile modulus along Y-direction (Ey), MPa	18900
3.	Tensile modulus along Z-direction (Ez), MPa	7830
4.	**Mass density of the material (ρ), kg/mm^3**	$2.46*10^{-6}$
5.	**Poisson's ratio**	0.23
6.	Specific heat J/g°	0.737
7.	Thermal conductivity/m-k	1.45
8.	Shear modulus, MPa	3189
9.	Tensile modulus along the material, MPa	4890
10.	Elastic modulus of the material, MPa	$8.69*10^5$

Material properties of S-2 Glass/Epoxy

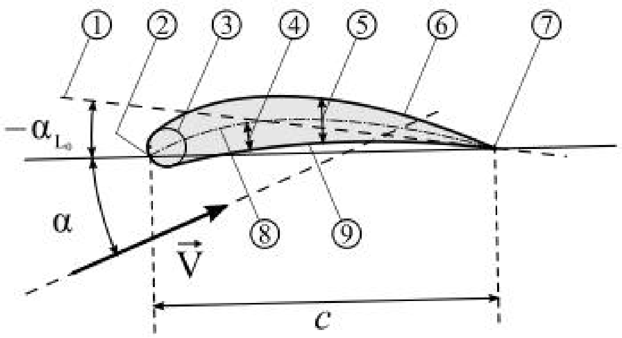
NACA4415: The NACA four-digit wing sections define the profile by:First digit describing maximum camber as percentage of the chord. Second digit describing the distance of maximum camber from the airfoil leading edge in tens of percents of the chord. Last two digits describing maximum thickness of the airfoil as percent of the chord.

For example, the NACA 4415 airfoil has a maximum camber of 4% located 40% (0.4 chords) from the leading edge with a maximum thickness of 15% of the chord. Four-digit series airfoils by default have maximum thickness at 30% of the chord (0.3 chords) from the leading edge.



Airfoil nomenclature, The Shape shown here is an NACA 4415 airfoil.

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.



L = N cos α – A sin α
D = N **sin α + A cos α**

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
The formula for the shape of a NACA 00xx foil, with "xx" being replaced by the percentage of thickness to chord, is:

$$y_t = \frac{t}{0.2} c \left[0.2969 \sqrt{\frac{x}{c}} + (-0.1260)\left(\frac{x}{c}\right) + (-0.3516)\left(\frac{x}{c}\right)^2 + 0.2843\left(\frac{x}{c}\right)^3 + (-0.1015)\left(\frac{x}{c}\right)^4 \right]$$

The simplest asymmetric foils are the NACA 4-digit series foils, which use the same formula as that used to generate the 00xx symmetric foils, but with the line of mean camber bent.

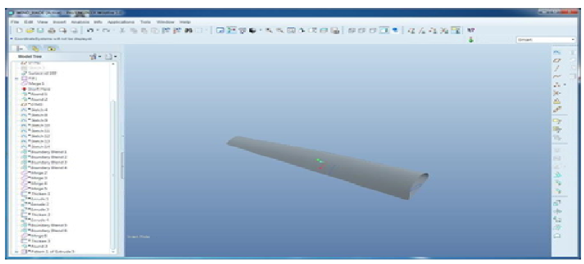
The formula used to calculate the mean camber line is:

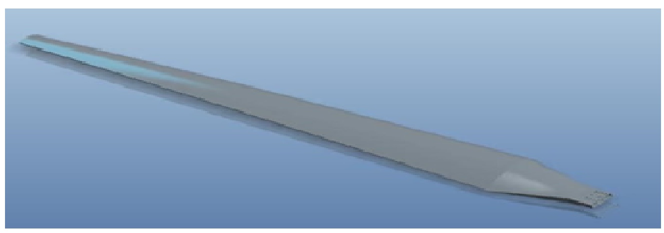
II. MODELS OF WIND TURBINE BLADE

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

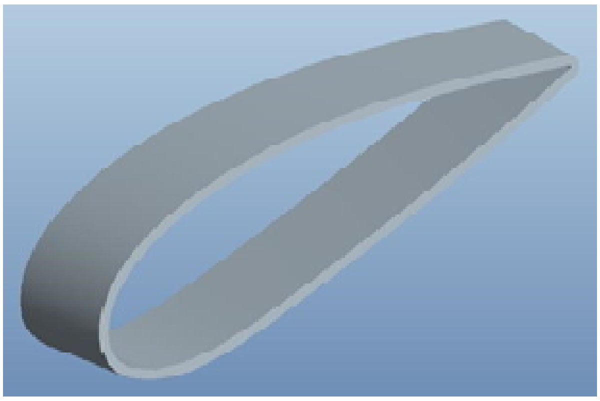
$$y_c = \begin{cases} m \frac{x}{p^2}\left(2p - \frac{x}{c}\right) & 0 \le x \le pc \\ m \frac{c-x}{(1-p)^2}\left(1 + \frac{x}{c} - 2p\right), & pc \le x \le c \end{cases}$$

2-D MODEL

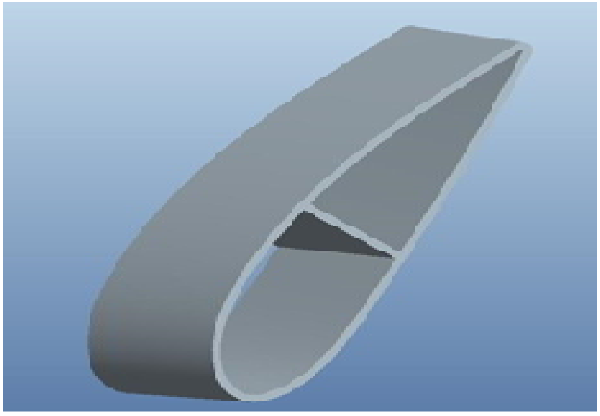




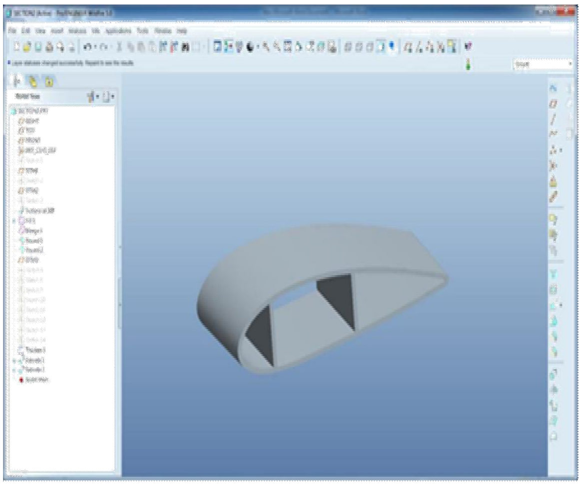
Designing of wind turbine blade first segment



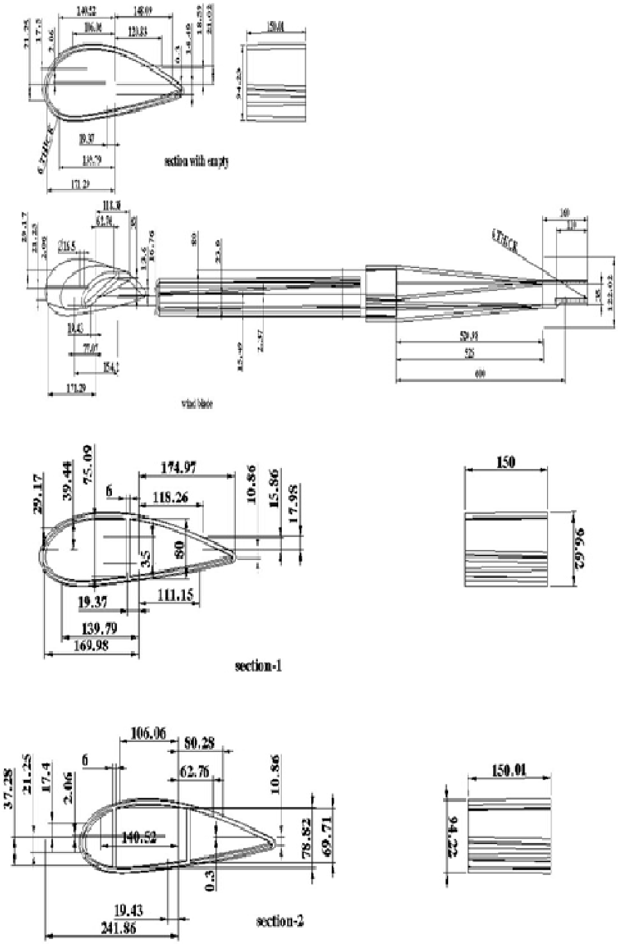
standard blade section for analysis purpose



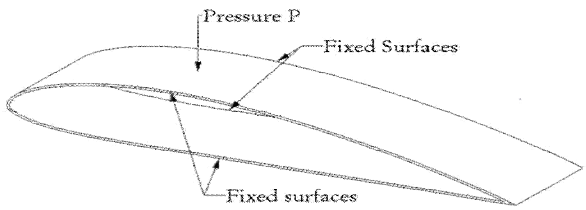
single rib blade section for analysis purpose



Two rib blade section for analysis purpose



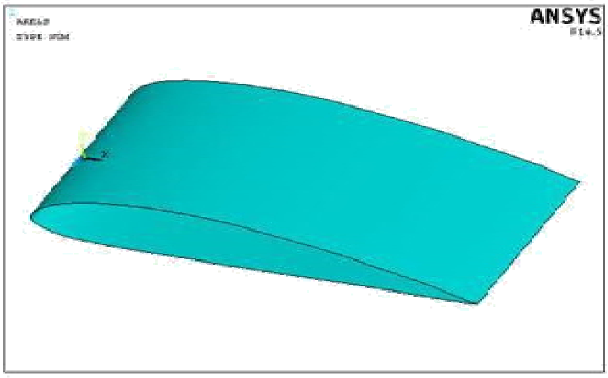
Drafting of Blade Sections



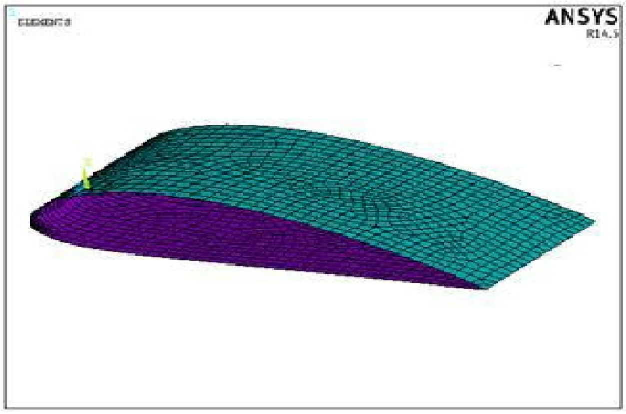
Boundary Conditions applied on the wind turbine blade

Structural Analysis using Aluminum Alloy:

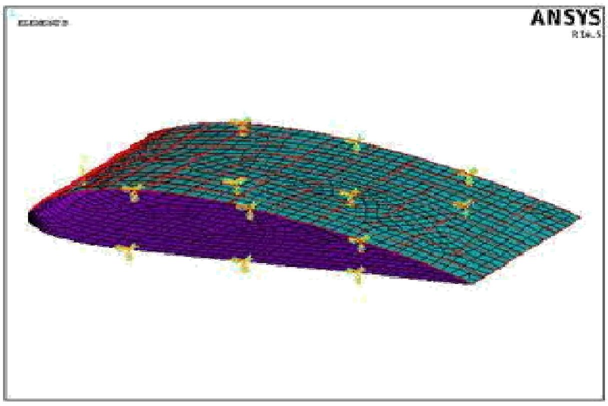
Wind turbine blade model is imported from Pro-E in the format of IGES (Initial Graphical Exchange Specification) in Ansys software.



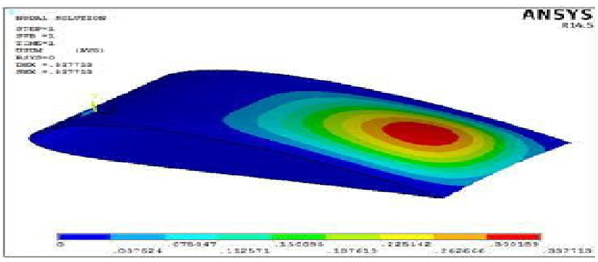
Imported IGES Model of Wind turbine blade



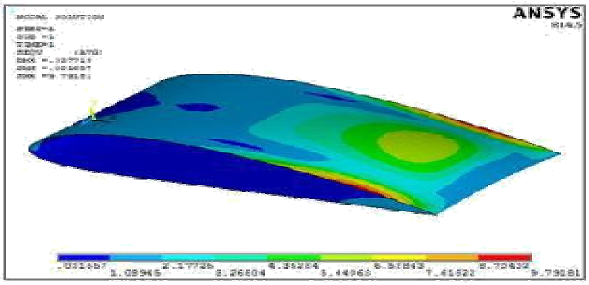
wind turbine blade model after Meshing



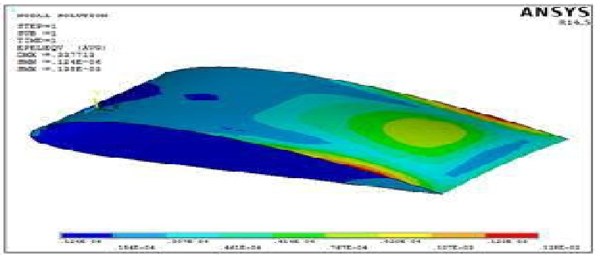
Structural loads applied on wind turbine blade



Displacement at maximum load



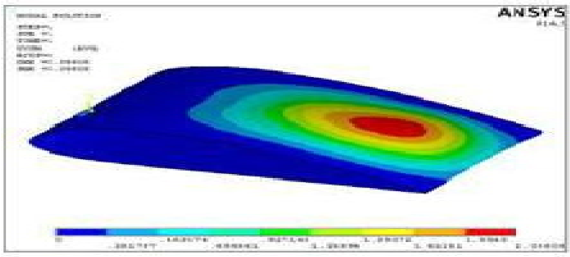
Von-misses stress at maximum load



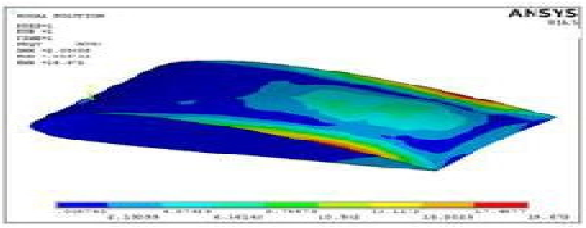
strains at maximum load

Structural Analysis of E–Glass Epoxy Wind turbine blade:

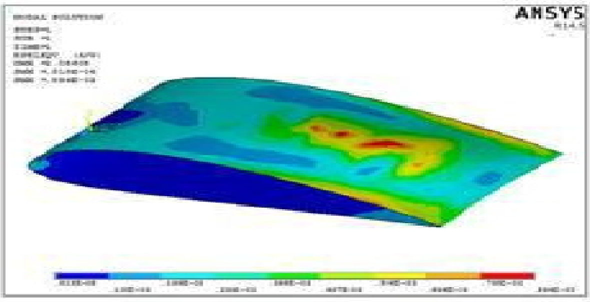
Initially the IGES model imported from the Pro-e Wildfire 5.0. Default Shell 8node 281 element was used to mesh the components. After solving the problem maximum displacement, von-misses stress and strain of an E-Glass Epoxy wind turbine blade is observed at the maximum load conditions.



Maximum Displacement value at maximum load=2.08608mm



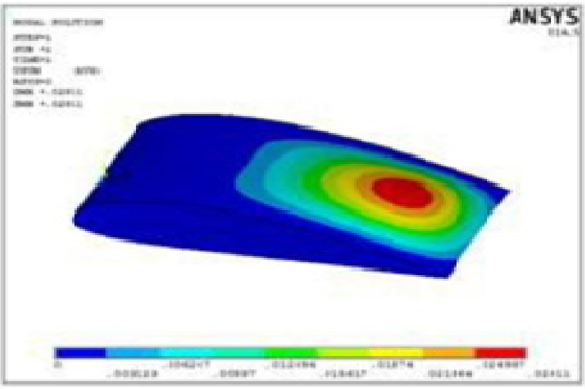
Maximum Von-misses stress at maximum load=19.673N/mm^2



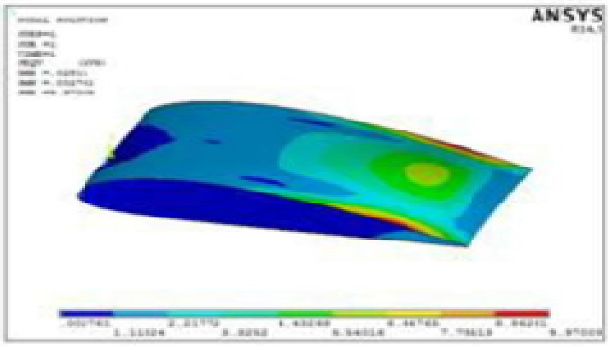
Maximum Strain at maximum load conditions=0.00894

Structural Analysis S-glass epoxy on Wind turbine blade:

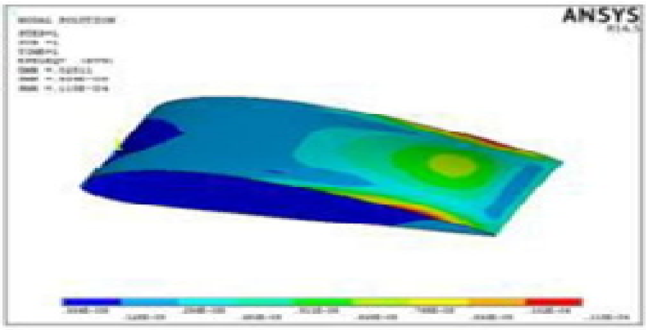
Initially the IGES model imported from the Pro-e Wildfire 5.0. Default Shell 8node 281 element was used to mesh the components. After solving the problem maximum displacement, von-misses stress and strain of an S-2 Glass Epoxy wind turbine blade is observed at the maximum load conditions.



Maximum Displacement value at maximum load=0.02811mm



Maximum Von-misses stress at maximum load=9.97009N/mm^2



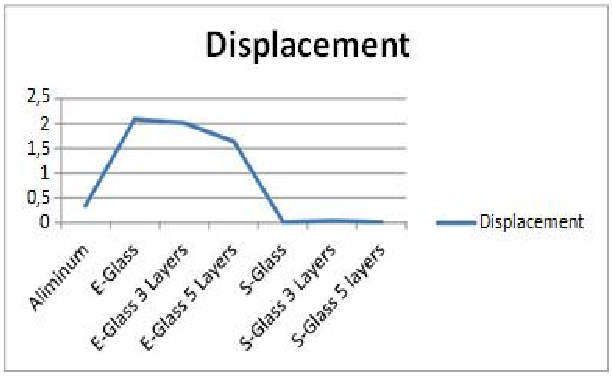
Maximum Strain at maximum load conditions=0.000115

Static Analysis of Wind turbine blade:

Deflections, Stresses and Strains of Aluminum & composite wind turbine blade at a velocity of air **200 Kmph** are obtained from Static Analysis.

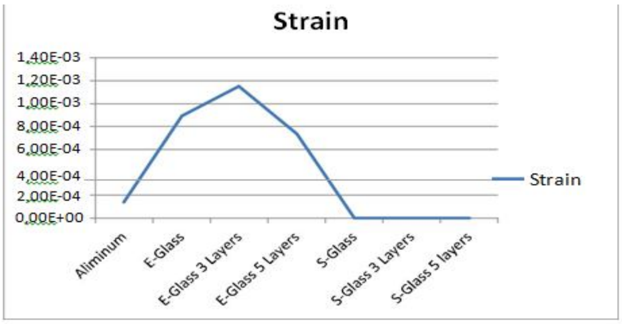
Material and layer	Displacement	Stress	Strain	F o S
Aluminum	0.337713	9.79181	1.38E-04	16.85
E-Glass	2.08608	19.673	8.94E-04	12.707
E-Glass 3 Layers	2.00537	15.979	0.001151	15.645
E-Glass 5 Layers	1.62793	17.3184	7.35E-04	14.435
S-Glass	0.002811	9.97009	0.115 e-04	459.8
S-Glass 3 Layers	0.028315	10.0518	0.116 e-04	456.137
S-Glass 5 layers	0.0028112	10.0017	0.115 e-04	458.422

Compare the deflections of wind turbine blade at 200Kmph with different materials are obtained from static analysis.



Displacement of the wind turbine blade at 200Kmph

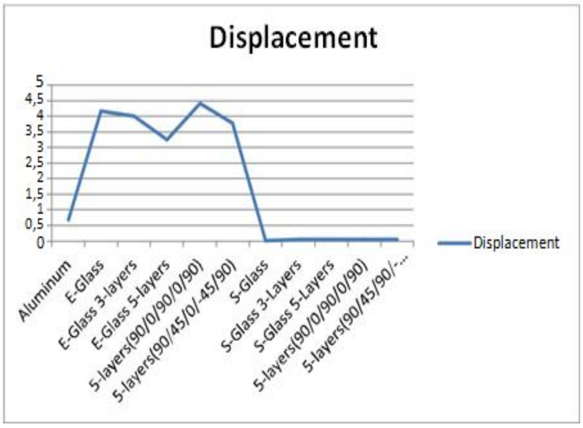
Compare the stresses of wind turbine blade at 200Kmph with different materials are obtained from static analysis



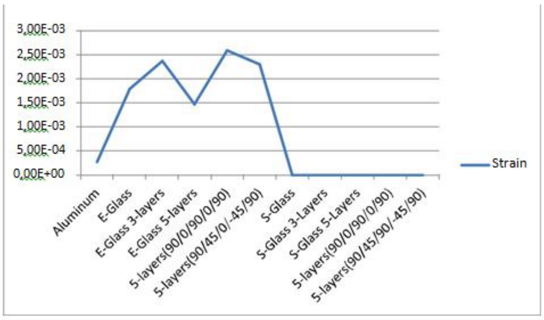
Deflections, Stresses and Strains of Aluminum & composite materials of wind turbine blade at a velocity of air **400 Kmph** are obtained from Static Analysis

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

Compare the deflections of wind turbine blade at 400Kmph with different materials are obtained from static analysis.



Displacement of the wind turbine blade at 400Kmph



Strain of the wind turbine blade at 400Kmph

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

	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

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

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 90^0-45^0-0^0-45^0-90^0 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 thecombination of composites and also analysis can be done on air foil profile optimization

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