STRUCTURAL ANALYSIS OF COMPOSITE WIND TURBINE BLADE

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Abstract The wind turbine blade is a very important part of the rotor. Wind turbine provides an alternative way of generating energy from the power of wind. Extraction of energy depends on the design of blade. At windy places where the wind speeds are so high, sufficient amount of energy can be harnessed by making use of wind turbines. The blades of such turbines are so designed that they generate lift from wind and thus rotate. In this work, the wind turbine blade is modelled in CATIA V5 and analyzed for five different materials like Structural steel, Epoxy carbon, s-glass, E-glass, Aluminium alloy. Then the work explores the finite element analysis of a Wind Turbine Blade using ANSYS software. The aim of the analysis is to validate the strength of the blade and compare the above materials to select the best material for the wind turbine blade.

Key Words*: *CATIA V5, ANSYS, Finite element analysis, NACA 2412

1. INTRODUCTION

Blade is the key component to harness wind energy. In this paper, finite element analysis is conducted on a wind turbine blade with NACA 2412 aerofoil design. The paper studies the analysis of an existing wind turbine blade. The blade optimization is carried out by considering parameter like shapes of aerofoil profile, stresses and deformation on blade. When designing a wind turbine, the aim is to attain the highest possible power output under particular atmospheric conditions and this depends on the shape of the blade as well as on its material.

The utilization of the energy in the winds requires the development of devices which convert that energy into more useful forms. This is typically accomplished by first mechanically converting the linear velocity of the wind into a rotational motion by means of a windmill and then converting the rotational energy of the windmill blades into electrical energy by using a generator or alternator. For purposes here, we can thus view the windmill as a mechanical device for extracting some of the kinetic energy of the wind and converting it into the rotational energy of the blade motion. This is accomplished, in detail, by having the blades oriented at some angle to the wind so that the wind blowing past the blades exerts an aerodynamic force on them and there by causes them to rotate. The dynamic and mechanical properties of a wind turbine can be modified by changing the composite material of the blade. Hence emphasis is given on the material of the blade. The results of analysis of different material are compared to evaluate the best possible one suited for practical application Airfoil taken is NACA 2412, this is cambered airfoil belongs to the four digit series of the NACA airfoil classification

2. .WINDMILL BLADE

2.1Functions

Among all the parts of wind turbines (blades, hub, gearbox, generator, nacelle, tower...),composite materials are used in blades and nacelles. The main requirements to nacelles, which provide weather protection for the components, are the low weight, strength and corrosion resistance. Typically, nacelles are made from glass fiber composites. Increasing the reliability and lifetime of wind blades is an important problem for the developers of wind turbines. The wind turbine blades are built as follows. A blade consists of two faces (on the suction side and the pressure side), joined together and stiffened either by one or several integral (shear) webs linking the upper and lower parts of the blade shell or by a box beam (box spar with shell fairings). The box beam inside the blade is adhesively joined to the shell. Figure 3.4 shows the schema of the section of the blade.

.Wind turbine blades are complex structures whose design involves the two basic aspects of

- Selection of the aerodynamic shape
- Structural configuration
- Material selection (to ensure that the defined shape is maintained for the expected life).
- Density of blade material
-

Figure 1 Modern windblade

Modern blades:

- Consist of different kinds of materials (typically composite materials in monolithic or sandwich configuration)
- Use various connection solutions between different substructures
- Include many material or geometric transitions

2.2 Main loads on blades

The main loads on the blades are generated by wind and by gravity. **Wind loads** mainly induce both *flap wise* and *edgewise bending*. These loads have both a static and a dynamic component (variations in wind speed and natural wind shear) that induce fatigue on the blade material. **Gravity loads** mainly induce edgewise bending, when the blade is horizontal. The rotation of the blades cause alternating edge-wise bending and thus fatigue of the material.

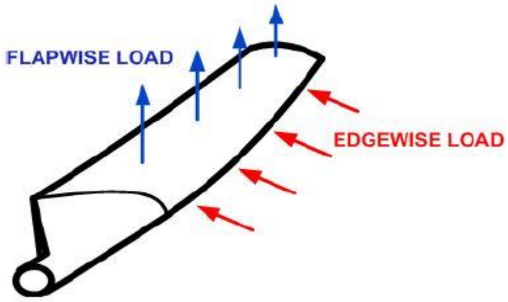


Figure 2 Load on blade

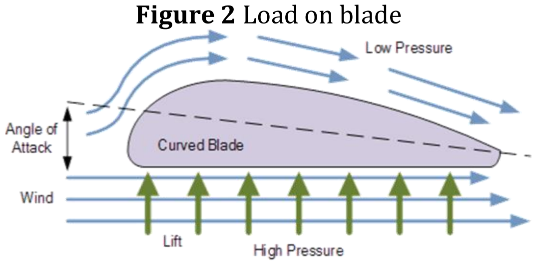


Figure 3 Aerodynamic force

In general, all turbines may be grouped as being either lift-based, or drag-based; the former being more efficient. The difference between these groups is the aerodynamic force that is used to extract the energy. Drag force is parallel to and lift is perpendicular to air flow. HWAT is a lift based wind turbine with good performance, so that it create a differential pressure between upper and lower surface, leading to a net force in the direction perpendicular to wind direction. Here the relative wind does not decrease; rather, it increases with rotor-speed. Thus, the maximum power limits of these machines are much higher than those of drag-based machines. The governing equation for power extraction is stated below: P=F.V

P=Power, F is force vector, and V is the velocity of moving wind turbine part

2.3 Cross Section Of Blade

Cross section of blade consist of;1)Outer shell(to ensure stability of the aerodynamic shape

2)Internal structural support of outer shell(webs)

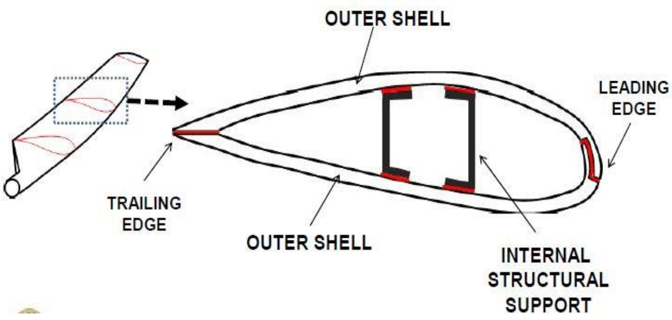
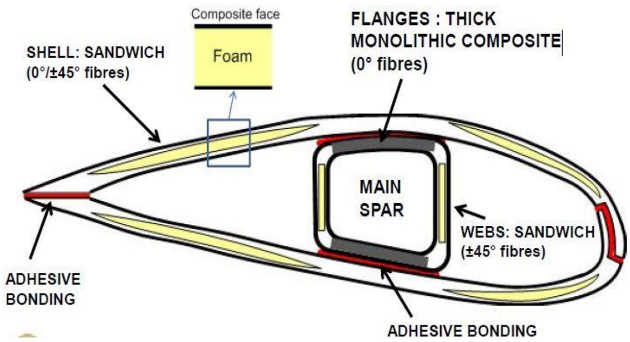


Figure 4 Section of blade

2.4Cross Section Concepts; Main Spar

The two aero shells are bonded to a load-carrying spar-beam (box-beam).The main spar and the wing shells are manufactured separately then joined in a separate process



Figure;5 Section with main spar

Table 1 Blade parts and their functions in maintaining the blade shapes

PART	FUNCTION	MATERIAL USED
Blade Shell	Maintaining The Blade Shape, Resisting The Wind And Gravitational Forces	Strong, Light Weight Composite
Unsupported Parts Of The Shell	Resisting The Buckling Load	Thickened Sandwich Structures With Light Core Materials And Multidirectional Face Laminates
Integral Web, Spar Or Box Beam	Resisting The Shell Buckling Shear Stresses Due to Flap wise Bending	Biaxial Lay-Ups At+/45o
Adhesive Layers Between Composite Plies, And The Web And Blade Shell	Ensure The Out-Of Plane Strength And Stiffness Of The Blade	Strong And Highly Adhesive Matrix

2.5 Growth of Blade mass with blade length

The growth rate of blade mass with length has been reducing in the past decades

Key drives for reduction :

- **Improved manufacturing processes**
- **Introduction of new materials**
- **More efficient use of materials and improved structural configurations**

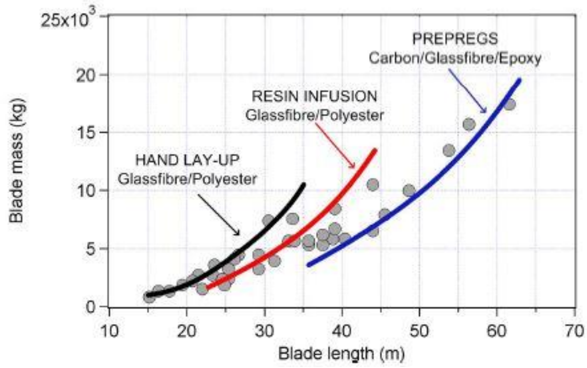


Figure 6 Growth of blade with blade length

2.6Required Properties of Wind Mill Blade

In general, ideal materials should meet the following criteria:

• Wide availability.

• Low density and low cost

• High strength to withstand strong loading of wind and gravitational force of the blade itself.

• High Corrosion and fatigue resistance to withstand cyclic loading.

• High stiffness

• High fracture toughness.

• The ability to withstand environmental impacts such as lightning strikes, humidity, and temperature.

• The blades must be stiff to prevent collision with the tower under extreme loads. Local stiffness must be also sufficient to prevent extreme loads and stability of components under compression (to avoid local or global buckling)

2.7 Composite Material

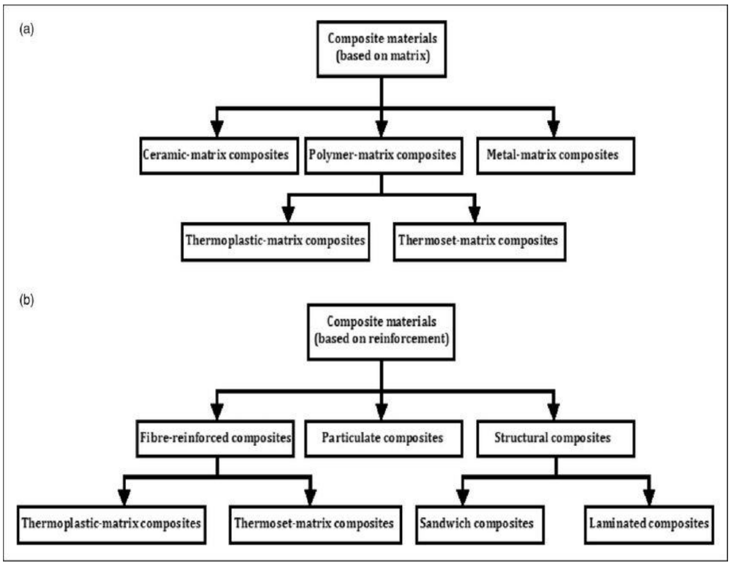


Figure 7 Classification Of Composite Material

A composite material consists of 2 or more materials combined to obtain properties different from those of individual materials. Composite materials consist of 2 phases

1) Matrix Phase

2) Reinforced Phase.

Matrix phase is sub divided into 3 they are;

2.7.1.1Polymer matrix composite (PMC)

- Thermosetting resins are the most widely used polymers, Epoxy and polyester are commonly mixed with fiber reinforcement

2.7.1.2 Metal matrix composite (MMC)

- Include mixtures of ceramics and metals such as cemented carbides , aluminium or magnesium reinforced by strong, high stiffness fibers

2.7.1.3Ceramic matrix composite (CMC)

- Least common composite matrix. These are used for high temperature application

Based on reinforcement it is classified into 3 sub –division

2.7.2.1.Fiber- reinforced composite

In this, one is fiber phase and other is matrix phase. The fiber phase helps to enhance strength and stiffness, whereas matrix phase binds fiber together and acts as a barrier to crack propagation

They are mainly 3 sub-division under FRC based on Polymer matrix composite(PMC)

Matrix Polymer Composite

It is divided into 3;

a) Glass fiber reinforced composite (GFRC)

b) Carbon fiber reinforced composite (AFRC)

c) Aramid fiber reinforced composite (AFRC)

2.7.2.1.a Glass Fiber Reinforced Composite (GFRC)

The most common reinforcement for polymer matrix composite is a glass fiber. Most of fiber are based on silica (sio2),with addition of oxides of ca, B, Na, Fe& Al. It is divided into 3 main classes;

1) E-glass

2) C-glass

3) S-glass

2.7.2.2 Particulate composite

- Particle reinforced composite support high tensile, compressive and shear stresses
- Particles are used to increase the modulus of the matrix, to decrease the permeability of the matrix, or to decrease the ductility of matrix.
- It is also used to produce inexpensive composite

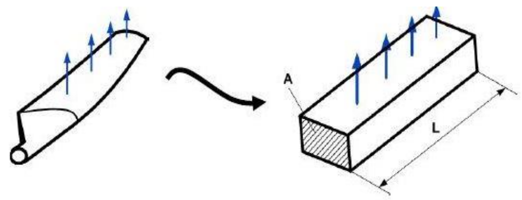
2.7.2.3. Structural composite

- It is of 2 type ;laminar and sandwiched
- Laminar is stacking sequence, balanced ,in-plane stiffness, whereas sandwich is of low density, honeycomb core and large bending stiffness

2.8 Why Composite material?

In order to ensure the required shape stability, strength and damage resistance of the wind turbine rotor blades, the blades are produced from long fiber reinforced polymer laminates.

In these composites, long fibers ensure longitudinal stiffness and strength, while the resin matrix is responsible for fracture toughness, delamination strength and out-of-plane strength and stiffness of the composite



Mass of beam $M = AL\rho$

Stiffness of beam $S = \frac{F}{\delta} = \frac{KEI}{L^3}$

$$M = \left(\frac{12S}{KL}\right)^{1/2} (L^3) \left(\frac{\rho}{E^{1/2}}\right)$$

To minimise given mass for a given stiffness S we have to maximize $\frac{E^{1/2}}{\rho}$

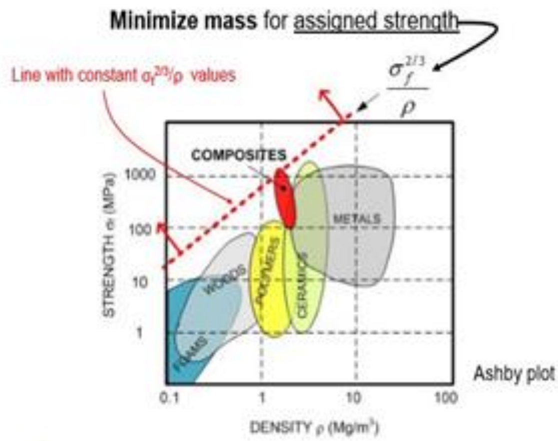


Figure 8 youngs modulus vs density

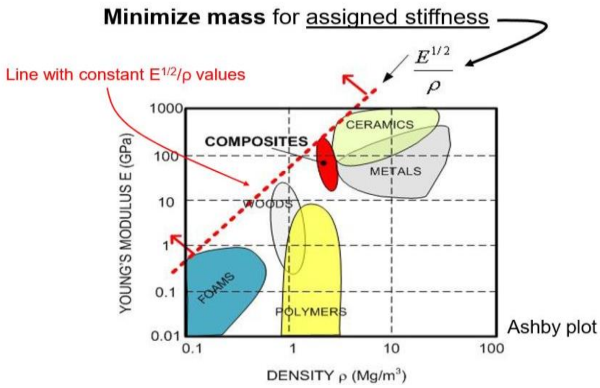


Figure 9 Strength vs density

3. AEROFOIL DESIGN

NACA 2412(National Advisory committee for Aeronautics)

Airfoil taken is NACA 2412, this is cambered airfoil belongs to the four digit series of the NACA airfoil classification, the general characteristics of this airfoil are:-

NACA FOUR DIGIT SERIES

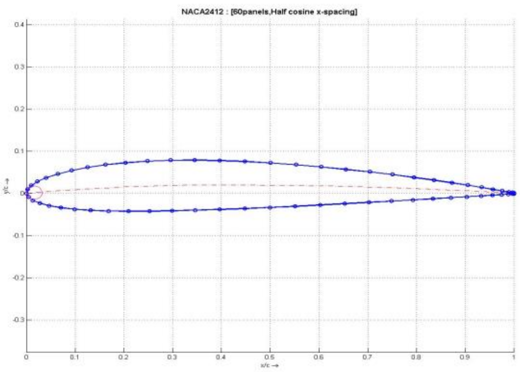
The NACA four-digit wing sections define the profile by:

1. First digit describing maximum camber as percentage of the chord.

2. Second digit describing the distance of maximum camber from the airfoil leading edge in tens of percents of the chord.

3. Last two digits describing maximum thickness of the airfoil as percent of the chord.

NACA 2412 is the airfoil of NACA 4 digit series. From its designation we get the NACA 2412 airfoil has a maximum camber of 2%located 40% (0.4 chords) from the leading edge with a maximum thickness of 12% of the chord. Four-digit series airfoils by default have maximum thickness at 30% of the chord (0.3 chords) from the leading edge. NACA 2412 is slow speed airfoil; this airfoil is used in single engine Cessna 152, 172 and 182 airplanes



Figure; 10 2d View Of NACA 2412

3.1. MATERIAL SELECTION

One of the main objectives of project work is to find out suitable material for windmill blade. Usually the blade used is fiber-reinforced material. The material used for the current experiment are structural steel, , Epoxy carbon, E-glass, S-glass, Aluminium alloy.

3.1.1. Structural steel

Table 2 Properties of structural steel

Properties	values
Density(g/cm3)	7.85
Young's modulus(Gpa)	80
Poisson's ratio	0.29
Shear moduls	31.008
Tensile stress(MPa)	450
Shear stress(MPa)	515

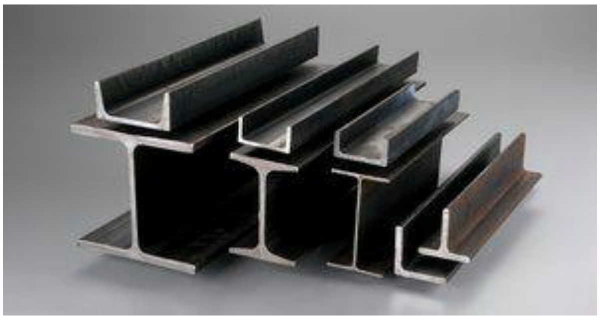


Figure 11 Structural Steel

3.1.2 .E-Glass

- E-glass (i.e., borosilicate glass called "electric glass" or "E-glass"for its high electric resistance) Family of glassed with a calcium aluminium borosilicate composition and a maximum alkali composition of 2%.these are used when strength and high electrical resistivity are required.

Table.3 Properties of e-glass

Properties	values
Density(g/cm3)	2.6
Young's modulus(Gpa)	85
Poisson's ratio	0.23
Shear moduls	36
Tensile stress(MPa)	2050
Shear stress(MPa)	80

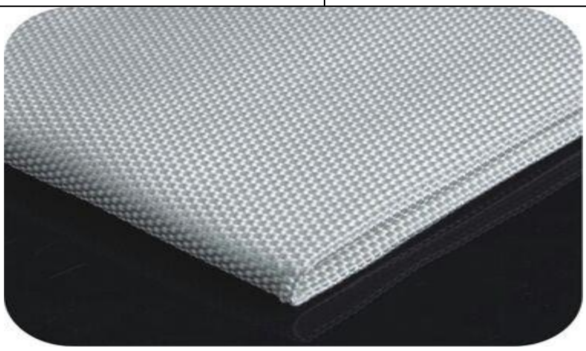
Figure; 12 E-glass

3.1.3 S-Glass

S-glass (i.e. high strength glass, S means "Strength" here) developed in the 1960s for military applications, has 40% higher tensile and flexural strengths, and 10...20% higher compressive strength and flexural modulus, than the E-glass.It contain magnesium alumina silicate mostly used where high strength, high stiffness, extreme temperature resistance and corrosive resistance is needed

Table 4. Properties of s-glass

Properties	values
Density(g/cm3)	2.495
Young's modulus(Gpa)	93
Poisson's ratio	0.23
Shear moduls	39
Tensile stress(MPa)	4800
Shear stress(MPa)	80



Figure;13

3.1.4 .Epoxy –carbon

In this composite carbon acts as a high performance fiber material, because it has highest specific modulus and high specific strength of all reinforcing fiber material. CFRC is a strong, light and very expensive material. it is extensively used in racing cars. High cost of this material is compensated by its excellent strength to weight ratio.

Table 5 Epoxy –carbon

Properties	Values
Density(g/cm3)	1.518
Young's modulus(Gpa)	123.34
Poisson's ratio	0.27
Shear moduls	3080
Tensile stress(MPa)	1632
Shear stress(MPa)	80

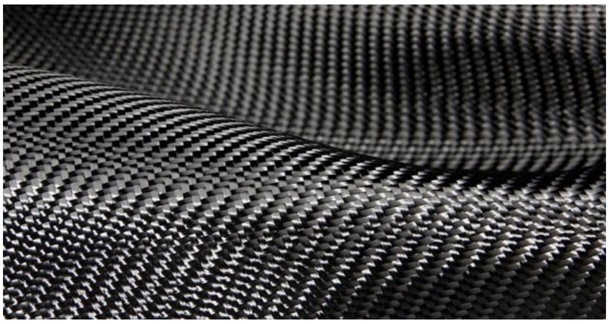


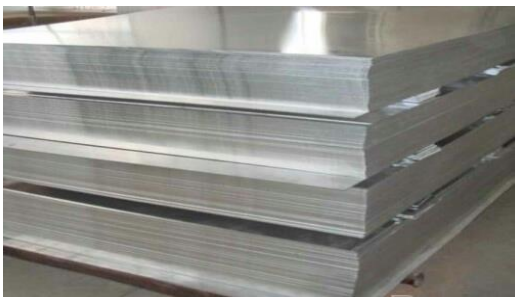
Figure 14

3.1.5. Aluminum alloy

Aluminium have been mostly used in aerospace manufacturing mainly due to high strength to weight ratio..Aluminium alloy typically have an elastic modulus of 70GPa, which is about one third of elastic modulus of steel and steel alloy it has high tensile strength, weld ability and corrosion resistance.

Table;6 Properties of aluminium alloy

Properties	Values
Density(g/cm3)	2.7
Young's modulus(Gpa)	7.73
Poisson's ratio	0.33
Shear moduls	26.0
Tensile stress(MPa)	324
Shear stress(MPa)	207



Figure;15

4. PROJECT METHODOLOGY

The project is performed in 3 states are theoretical analysis, Creating solid Model and Finite Element Analysis.

4.1) Theoretical Analysis

Theoretical analysis is performed by studying the concept of design and material used in the blade. The function of the windmill is to convert mechanical energy to electrical energy by the extraction of energy from wind.

4.2) Creating geometric model in CATA V5

A 3D geometric model of wind mill blade is created in CATIA V5.And import it into ANSYS for further analysis.

4.3) Finite elemental analysis

There are 3 main steps, namely; pre-processing, solution, post processing. In pre-processing (model definition) includes: define the geometric domain of the problem, the element type(s) to be used, the material properties of the element, the geometric properties of the element(length, area),the element connectivity(mesh the model),the physical constraints(boundary conditions) and the loadings.

In solution phase, the governing algebraic equations in matrix form are assembled and unknown values of the primary field variable are computed. The compound results are then used by back substitution to determine additional, delivered variable, such as reaction forces, element stresses and heat flow. Actually, the feature in this step such as matrix manipulation ,numerical integration and equation solving are carried out automatically by commercial software. In post processing, the analysis and evaluation of the result conducted in this step.

The 3D model of wind mill blade is created in CATIA V5 Software and it is imported in ANSYS

5. GEOMETRIC MODELLING

5.1 Specification Of Wind Mill Blade

TABLE 7

Profile	NACA 2412
Root chord length	1651mm
Tip chord length	650mm
Length of blade	10700mm
Hub diameter	337.5mm
Hub length	1465mm
Hub to blade(neck)	1475mm

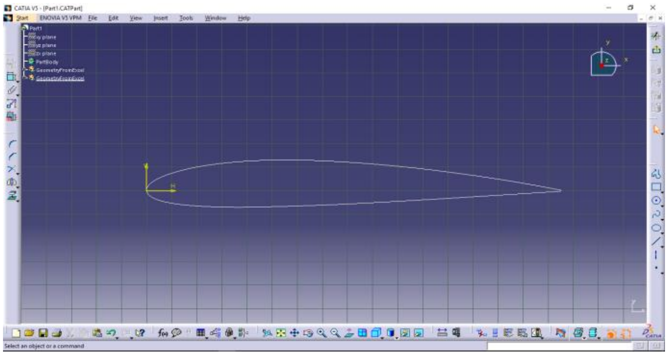
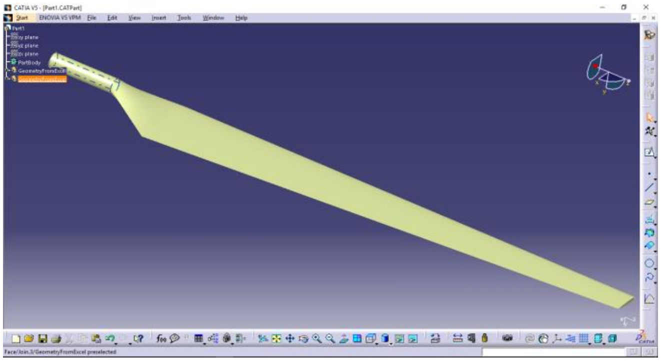


Figure 16 2d View Of Naca 2412



Figure; 17 Isometric view

TABLE 8 Coordinates of aerofoil

Name	NACA 2412	AIRFOIL SURFACE		CAMBER LINE		CHORD LINE	
Chord(mm)	650	X(mm)	Y(mm)	X(mm)	Y(mm)	X(mm)	Y(mm)
Radius(mm)	0	650	0.845	0	0	0	0
Thickness(%)	100	617.5	7.41	8.125	1.625	650	0
Origin(%)	0	585	13.52	16.25	2.34		
Pitch(deg)	0	520	24.375	32.5	3.64		
		455	33.67	48.75	4.875		
		390	41.34	65	6.11		
		325	47.06	97.5	8.1575		
		260	50.7	130	9.8475		
		195	51.22	162.5	11.2125		
		162.5	49.855	195	12.22		
		130	47.19	260	13		
		97.5	42.965	325	12.675		
		65	36.595	390	11.7		
		48.75	32.24	455	9.88		
		32.5	26.845	520	7.3125		
		16.25	19.435	585	4.095		
		8.125	13.975	617.5	2.145		
		0	0	650	0		
		8.125	-10.725				
		16.25	-14.755				
		32.5	-19.565				
		48.75	-22.49				
		65	-24.375				
		97.5	-26.65				
		130	-27.495				
		162.5	-27.43				
		195	-26.78				
		260	-24.7				
		325	-21.71				
		390	-17.94				
		455	-13.91				
		520	-9.75				
		585	-5.33				
		617.5	-3.12				
		650	-0.845				

6. FINITE ELEMENTAL ANALYSIS

6.1 Meshing (Pre-Processing)

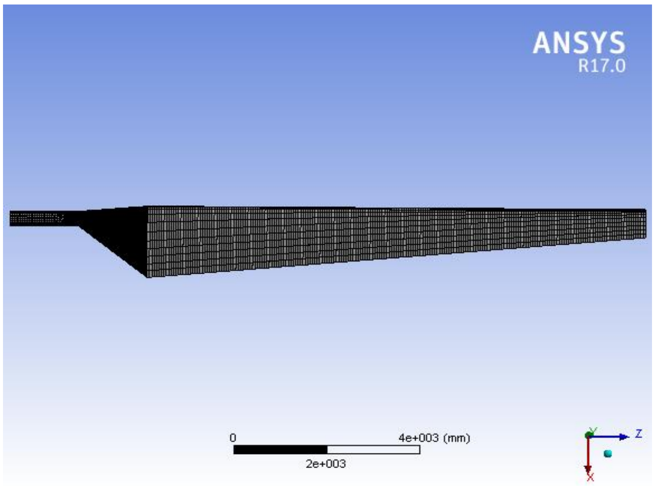


FIGURE 18 Meshing

TABLE 9. Meshing details

Object Name	Mesh
Statistics	
Nodes	6650
Elements	6698
Mesh Metric	Orthogonal Quality
Min	3.5269e-002
Max	1.
Average	0.97546
Standard Deviation	9.8991e-002

6.2 BOUNDARY CONDITION

1. Blade Root Is Fixed

2. Pressure Is Applied Normal To Flap Area and Edge Area

3. At The Middle Of The Blade Displacements Among X & Z Directions Are Constrained

$F=(\Pi*P*V^2*D^2)/9=364554N$ P=1.29Kg/M3

PEDGE=0.032842mpa V=10m/S

PFLAP=0.019288mpa D=30m
Total surface area= 3*107 mm2

Object Name	*Face Meshing*
Definition	
Suppressed	*No*
Mapped Mesh	*Yes*
Method	*Quadrilaterals*

6.3 ANALYSIS RESULT (POST PROCESSING)

6.3.1 Analysis using structural steel as Blade material

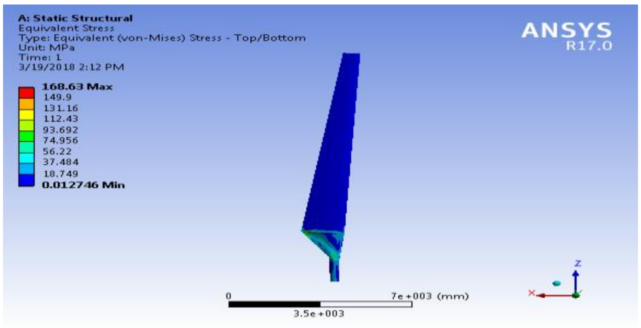


Figure 19 Von-Mises Stress Distribution of Structural Steel

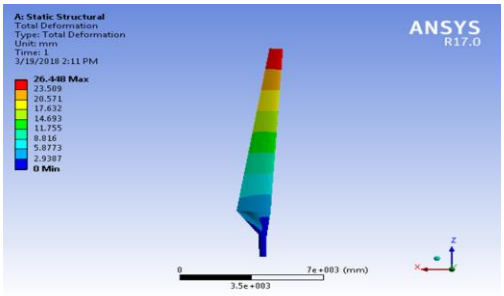


Fig 20 Total deformation of structural steel

6.3.2 Analysis using Epoxy carbon as Blade material

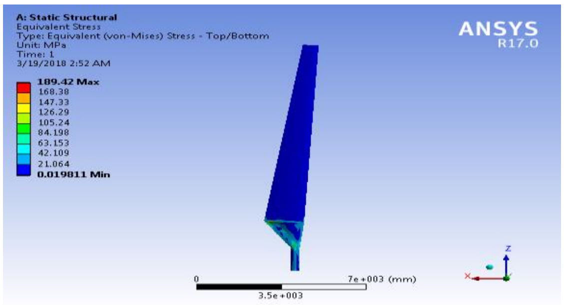


Fig 21 Von-Mises Stress Distribution of Epoxy carbon

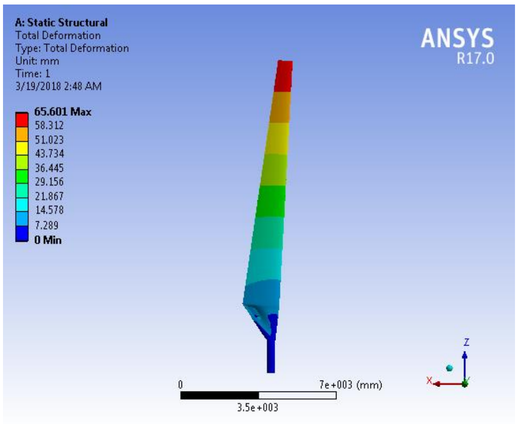


Fig 22 Total deformation of Epoxy carbon

6.3.3 Analysis using E-glass as Blade material

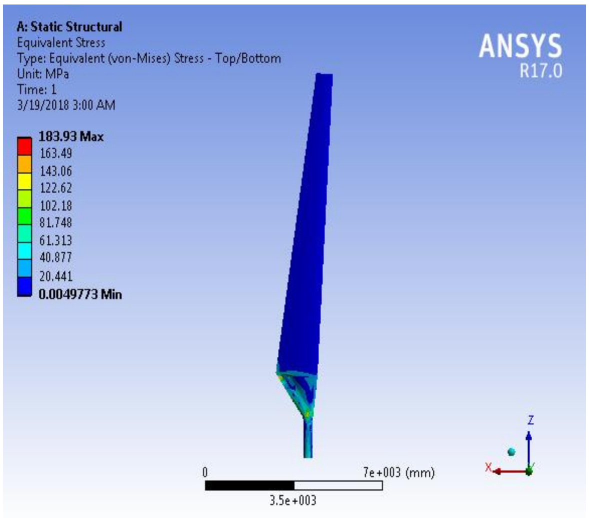


Fig 23 Von-Mises Stress Distribution of E-glass

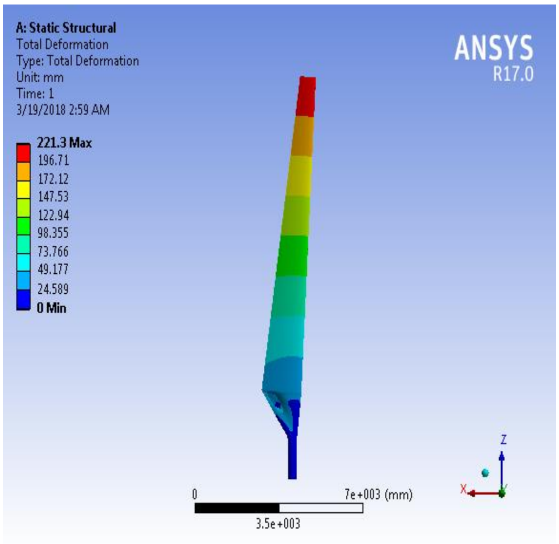


Fig24 Total deformation of E-glass

6.3.4. Analysis using S-glass as Blade material

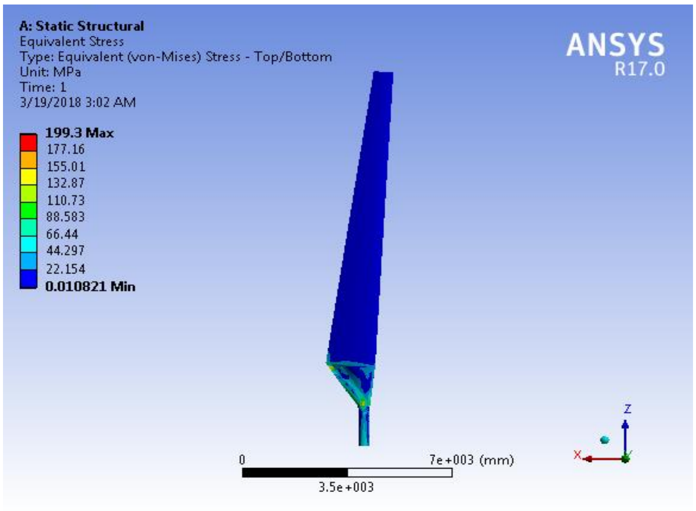


Fig25 Von-Mises Stress Distribution of S-glass

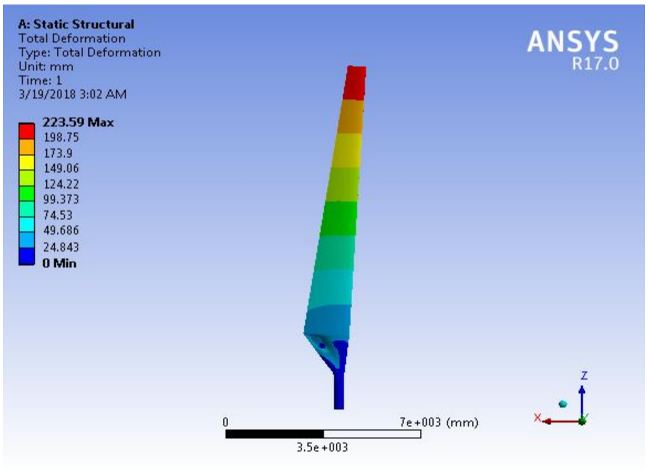


Fig 26 Total deformation of S -glass

6.3.5.Analysis using Aluminium alloy as Blade material

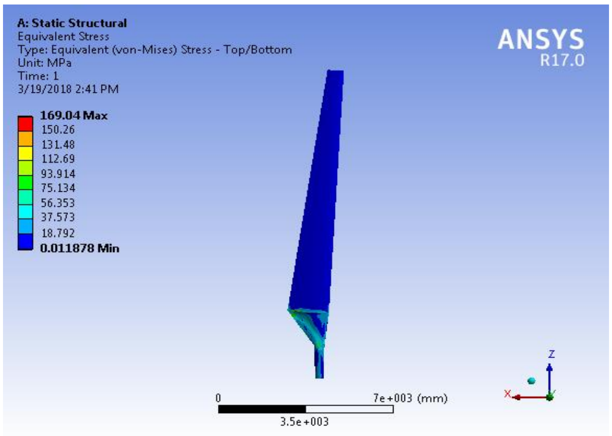


Fig 27 Von-Mises Stress Distribution of Aluminium alloy

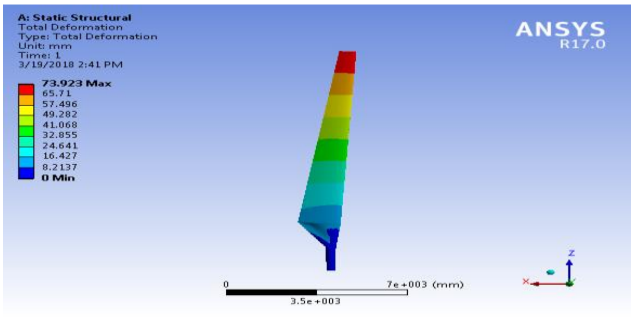


Fig28 Total deformation of Aluminium alloy

6.4ANALYSIS RESULT

6.4.1. Comparison Of Von-Mises Stress

Table 10 Comparison of Stress

SL.NO	MATERIAL	STRESS (MPa)
1	STRUCTURAL STEEL	168.63
2	EPOXY-CARBON	189.42
3	E-GLASS	183.93
4	S-GLASS	177.66
5	ALUMINIUM ALLOY	169.04

SL.NO	MATERIAL	DEFORMATION(mm)
1	STRUCTURAL STEEL	26.448
2	EPOXY CARBON	65.601
3	E-GLASS	221.3
4	S-GLASS	220.17
5	ALUMINIUM ALLOY	73.923

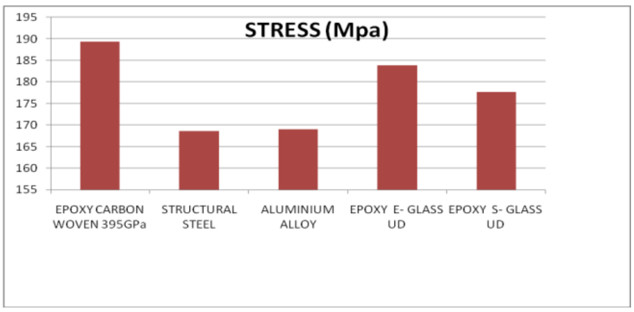


Chart 1 Bar Graph Showing Comparison Of Stress

6.4.2. Comparison of Deformation

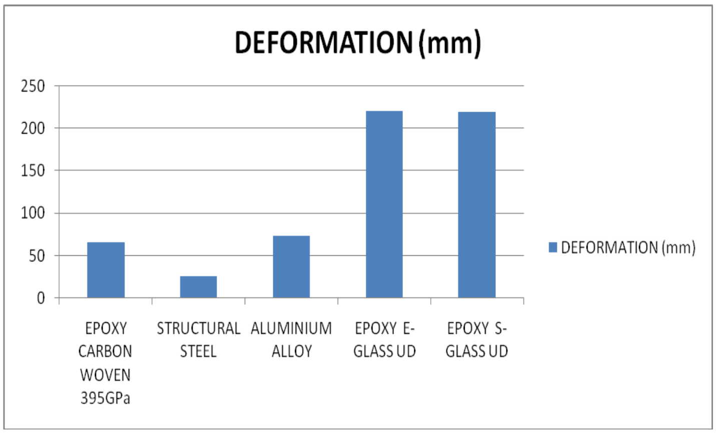


Chart 2 Bar Graph Showing Comparison of Deformation

Table 11 Comparison Of Deformation

MATERIAL	DEFORMATION (mm)	STRESS (Mpa)	MASS(Kg)
EPOXY CARBON WOVEN 395GPa	65.601	189.42	132.95
STRUCTURAL STEEL	26.448	168.63	705.18
ALUMINIUM ALLOY	73.923	169.04	248.83
EPOXY E-GLASS UD	221.3	183.93	179.66
EPOXY S-GLASS UD	220.17	177.66	179.66

6.4.3. Comparison Of Mass

Table 12 Comparison Of Mass

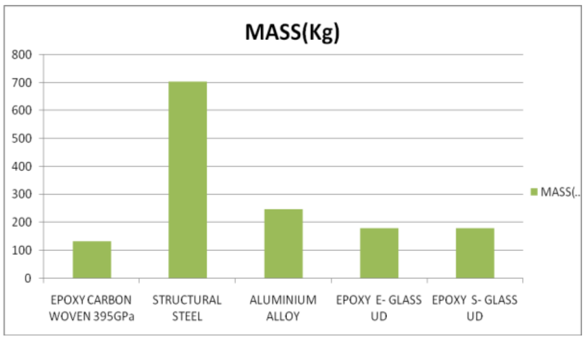


Chart 3 bar graph showing comparison of mass

6.5 Comparison

Table 7.4 comparison of analysis result

SL.NO	MATERIAL	MASS(KG)
1	STRUCTURAL STEEL	705.18
2	EPOXY-CARBON	132.95
3	E-GLASS	179.66
4	S-GLASS	179.66
5	ALUMINIUM ALLOY	248.83

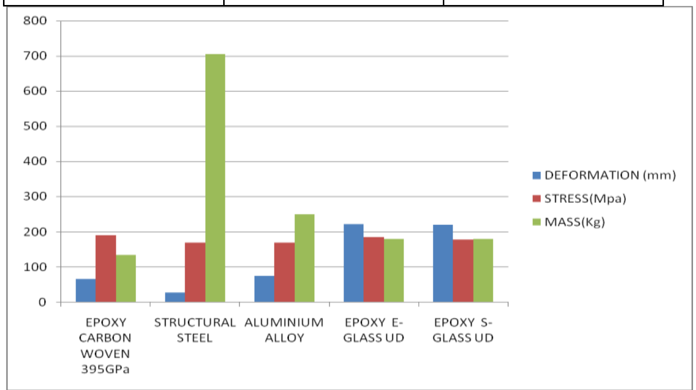


Chart 4 Bar graph showing comparison of all 3 properties

8. CONCLUSION

The design and static analysis of composite wind mill blade had been carried out in this work. Comparison between different composite materials are made under same load condition .Stress, strain and deformation are calculated using ANSYS. The results obtained from the ansys implies that the Epoxy carbon and structural steel show overall least value in stress and deformation, but in case of mass structural steel shows a drastic variation Thus it can be conclude that epoxy carbon is more suitable in making windmill blade.

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