DESIGN AND STRUCTURAL ANALYSIS OF WIND TURBINE BLADE

A PROJECT REPORT

Submitted by

ADIHASS.A	**(821716114002)**
ARUN KUMAR.K	**(821716114007)**
DHEVARAJ.S	**(821716114010)**
EZHILARASAN.N	**(821716114011)**

in partial fulfilment for the award of the degree

of

BACHELOR OF ENGINEERING

IN

MECHANICAL ENGINEERING

SIR ISSAC NEWTON COLLEGE OF ENGINEERING AND
TECHNOLOGY, PAPPAKOIL, NAGAPATTINAM - 611102

ANNA UNIVERSITY::CHENNAI 600 025

APRIL 2020

ANNA UNIVERSITY::CHENNAI 600 025

BONAFIDE CERTIFICATE

Certified that this project report **“DESIGN AND STRUCTURAL ANALYSIS OF WIND TURBINE BLADE”** is the bonafide work of

ADIHASS.A	**(821716114002)**
ARUN KUMAR.K	**(821716114007)**
DHEVARAJ.S	**(821716114010)**
EZHILARASAN.N	**(821716114011)**

who carried out the project work under my supervision.

SIGNATURE	**SIGNATURE**
Mr. P. MALAISELVARAJA,M.E.,	**Mr. J. SILAMBARASAN,M.E.,**
HEAD OF THE DEPARTMENT	**SUPERVISOR**
Sir Issac Newton College of	ASSISTANT PROFESSOR
Engineering & Technology	Sir Issac Newton College of
Pappakovil, Nagapattinam-611102	Engineering & Technology
	Pappakovil Nagapattinam-611102

Submitted for the Anna University Viva- Voce Examination held on___________________

INTERNAL EXAMINER EXTERNAL EXAMINER

ACKNOWLEDGEMENT

At the outset I think the almighty for his showers of blessings and his divine help which enables me to complete the project successfully I extend my sincere thanks to **Mr.T.ANANTH M.B.A.,(Ph.D)** Chairman, Sir Issac Newton College of Engineering and Technology, for offering the means of attending my most cherished goal.

I extend my deepest gratitude to Principal **Dr.G.GIFTSON SAMUEL M.E., Ph.D.,** Sir Issac Newton College of Engineering and Technology, for giving permission to do the project work successfully.

It gives immense pleasure to extend my sincere and heartful thanks to our Head of the Department **Mr.P.MALAISELVARAJA M.E.,** Assistant Professor, Department of Mechanical Engineering, for his encouragement of appreciation, untiring patience, steadfast, inspiration and valuable help for the successful completion of the project.

I record my sincere and deep sense of gratitude to my Project Coordinator **Mr.P.MALAISELVARAJA M.E** Assistant Professor, Department of Mechanical Engineering and to my supervisor, **Mr.J.SILAMBARASAN M.E.,** Assistant Professor, department of Mechanical Engineering for his guidance and encouragement, which has helped me a lot in completing this project successfully.

I also extend my sincere thanks to staff members of Mechanical Engineering Department. I am extremely thankful to my parents for enlighten me by providing professional education and for their prayerful support that makes me to complete the project successfully.

LIST OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

ABSTRACT

The efficiency of a wind turbine blade depends on the drag, lift, and torque produced by the blade. These factors are affected by the size and shape of the blades. Horizontal-axis wind turbine was developed a high wind speed location. A hybrid composite structure using glass and carbon fiber was created a light-weight design

Structural analysis for wind turbine blades is investigated with the aim of improving their design, minimizing weight. The wind turbine blade was modelled by using Catia. The wind turbine blade has a power output of 500 KW of blade length 16 m with the wind velocity 12 m/sec.

The types of aerofoil used for structural analysis is NREL airfoil and S828. By varying the blade thickness from 0.05 m and 0.06 m, the static and dynamic analysis has been done by using Ansys software. In static analysis the maximum stress and deformation is analysed. In this analysis the material used are carbon fibre and glass fibre. The results show that carbon fibre can withstand more stress than glass fibre.

CHAPTER 1
INTRODUCTION

Wind turbine is convert kinetic energy from wind to mechanical and finally convert it to electrical energy by combine some equipment. Airfoil is most important parameter in wind turbine design for generate high rate of energy production. There are several technique is reviewed for design an airfoil and optimization of airfoil shape for maximum coefficient of lift force. And review CFD (Computational Fluid Dynamics) analysis which is very highly using for prediction of aerodynamic behaviour of airfoil.

The abbreviation “HAWT” is used to indicate “Horizontal Axis Wind Turbine” and the term “VAWT” is used for its vertical case. We will focus on HAWT systems in this study rather than VAWTs. The axis “horizontal” implies that the rotor main shaft of the machine is parallel to the ground; on the contrary “vertical” implies the rotor main shaft is perpendicular to the ground. HAWT rotors decelerate the air rather than accelerating, and their tip speeds are much lower than those of aircraft propellers. Rotor blades aerodynamic features are very important. It is necessary to put forward the power value that can be obtained from rotor blades, real rotor blades have to be produced.

One of the most important parts of a wind turbine is the flow visualization it provides. Sure lift, drag and efficiency can all be calculated with complex equations. However, it is the visual aspect of a wind turbine and the controllable environment it provides that allows you to physically see what will happen in multiple real life situations. You can create an environment where you can see how a plane will react when it is taking off, cruising and landing all in the confines of a test lab. Then, with the same machine, you can see how air flows over the body of a race car when it is zooming around a track to maximize its efficiency. The versatility and tangibility of a wind turbine is what makes.

Important part of aerodynamic research. Being such an important part of aerodynamic research, it is important to continue to promote wind turbine testing.

In this project, the ultimate goal is to honeycomb material to straighten airflow. The spinning fan creates a swirling motion in the air that produces an undesirable effect in the test section. The honeycomb eliminates this uneven air flow. The contraction cone increases the velocity of the air in the test section without creating turbulence in the airflow.

The test section is where objects are placed and analysed. The diffuser connects the test section to the fan and slows the airflow down, again without disturbing airflow. The drive section is the source of the wind and is chosen to produce the desired velocity in the test section. Research, design, build and test objects in a real wind turbine in order to more fully understand basic concepts of aerodynamics and recognize the capabilities and importance of wind turbine in solving practical engineering problems. In either case, there are 5 main components to the wind turbine.

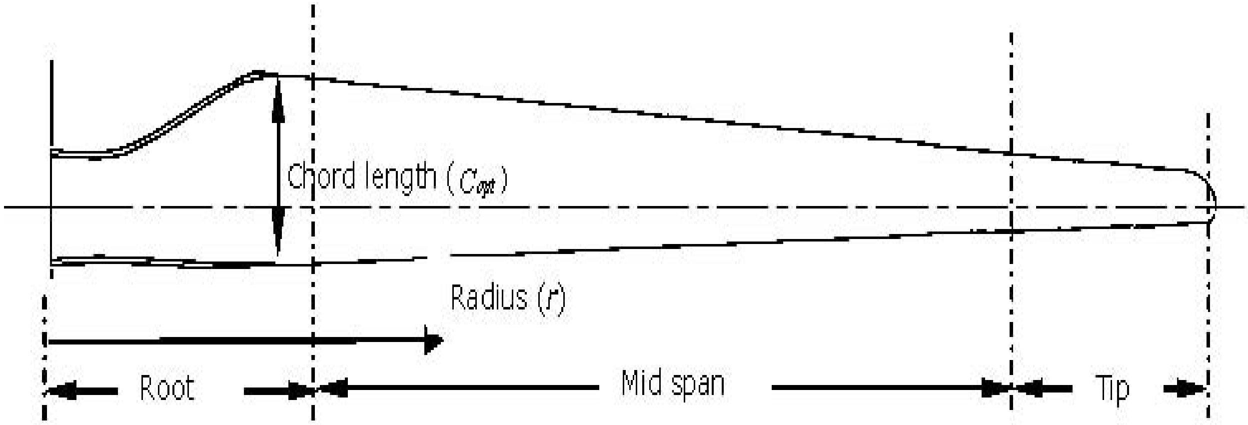


Fig.1.1 Blade components,

The wind is a free-flowing fluid stream. The energy extraction device (of any type) is submersed into this stream and can convert only a certain amount from the total available energy in the fluid stream, not all of it. Energy conversion from free-flowing fluid streams is limited because energy extraction implies decrease of fluid velocity (decrease of kinetic energy of the stream), which cannot fall down to zero, The stream should continue traveling and cannot stop entirely. Also, the turbine is an obstruction to the fluid flow. Some fluid may not pass through the turbine and may simply flow around.

1.1 TYPES OF WIND TURBINE

Two major types of wind turbine exist based on their blade configuration and operation. The first type is the horizontal axis wind turbine (HAWT). HAWTs sit atop a large tower and have a set of blades that rotate about an axis parallel to the flow direction. These wind turbine blades operates similar to the rotary air craft. The second major type of wind turbine is the vertical axis wind turbine (VAWT).

This type of wind turbine rotates about an axis that is perpendicular to the oncoming flow; hence, it can take wind from any direction. VAWTs consist of two major types, the Darrieus rotor and Savonius rotor. The Darrieus wind turbine is a VAWT that rotates around a central axis due to the lift produced by the rotating airfoil, whereas a Savonius rotor rotates due to the drag force created in blades. There is also a new type of VAWT emerging in the wind power industry which is a mixture between the Darrieus and Savonius designs.

1. Horizontal Axis Wind Turbine
2. Vertical Axis Wind Turbine

1.1.1 Horizontal Axis Wind Turbine

The blades of a HAWT work to extract energy from the wind by generating lift, resulting in a net torque about the axis of rotation. To accomplish this task efficiently, especially for large HAWTs, active pitch controllers are used to ensure that each blade is adjusted to maintain an optimal angle of attack for maximum power extraction for a given wind speed. However, in HAWT contains more complex parts like control system and it require more moving parts and effort to install than a VAWT assembly where the only moving part is the rotor and the majority of components are located at the base of the turbine.

1.1.2 Vertical Axis Wind Turbine

Now days VAWTs have been gaining popularity due to interest in personal green energy solutions. Small companies all over the world have been marketing these new devices such as Helix Wind, Urban Green Energy, and Wind spire. VAWTs target individual homes, farms, or small residential areas as a way of providing local and personal wind energy.

This produces an external energy resource and opens up a whole new market in alternative energy technology. Because VAWTs are small, quiet, easy to install, can take wind from any direction, and operate efficiently in turbulent wind conditions. VAWT is relatively simple its major moving component is the rotor and the more complex parts like the gearbox and generator are located at the base of the wind turbine. This makes installing a VAWT a painless undertaking and can be accomplished quickly.

Manufacturing a VAWT is much simpler than a HAWT due to the constant cross section blades. Because of the VAWTs shows simple manufacturing process and installation, they are perfectly suited for residential applications. An S-VAWT generates electricity through drag force rather than lift force like the D-VAWT. As the wind hits the concave portion of the blade (the bucket), it becomes trapped and pushes the blade around, advancing the next bucket into position. This continues as long as the wind is blowing and can overcome the friction of the shaft about which the blades rotate. A Savonius rotor typically rotates with a velocity equivalent to the speed of the free stream velocity, or a tip speed ratio of one.

Because of its lower rotation speed, Savonius rotors shows lower efficiencies and are not capable of providing adequate electricity, but it is used to reduce the overall dependence on other energy resources. However, due to the Savonius wind turbine simplicity, manufacturing is very easy; some have even been built using large plastic blue poly drums with the capability of providing up to 10% of a household's electricity In drag-based wind turbine, the force of the wind pushes against a surface, like an open sail.

It works because the drag force of the open, or concave, face of the cylinder is greater than the drag force on the closed or convex section. Vertical axis wind turbine are classified in to two major types; Savonius turbine type and Darrieus turbine type.

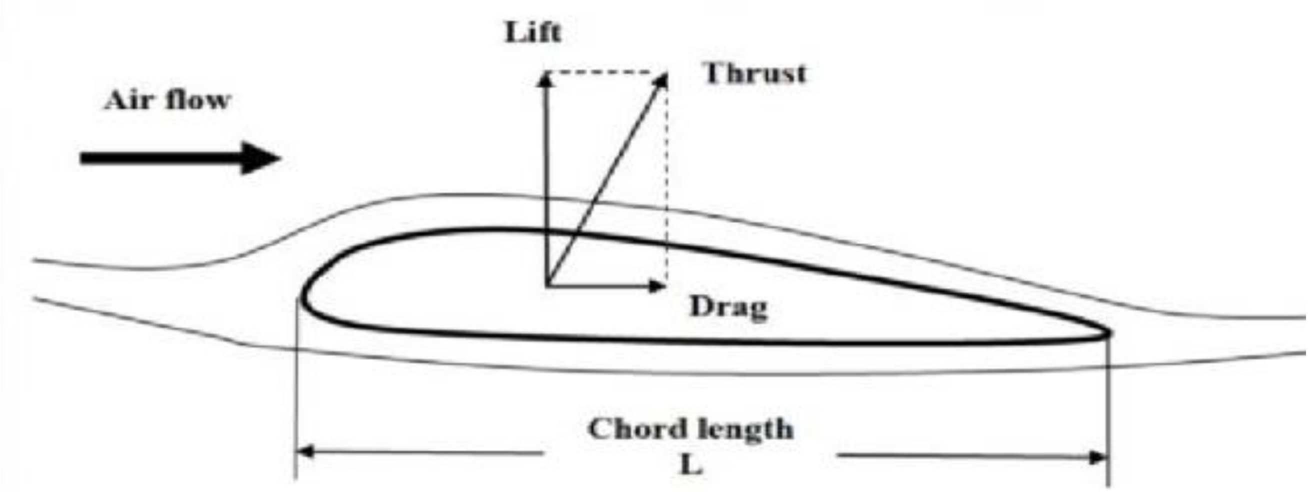


Fig.1.2 Forces acting on airfoil

1.2 LIFT AND DRAG

Lift on a body is defined as the force on the body in a direction normal to the flow direction. Lift will only be present if the fluid incorporates a circulatory flow about the body such as that which exists about a spinning cylinder.

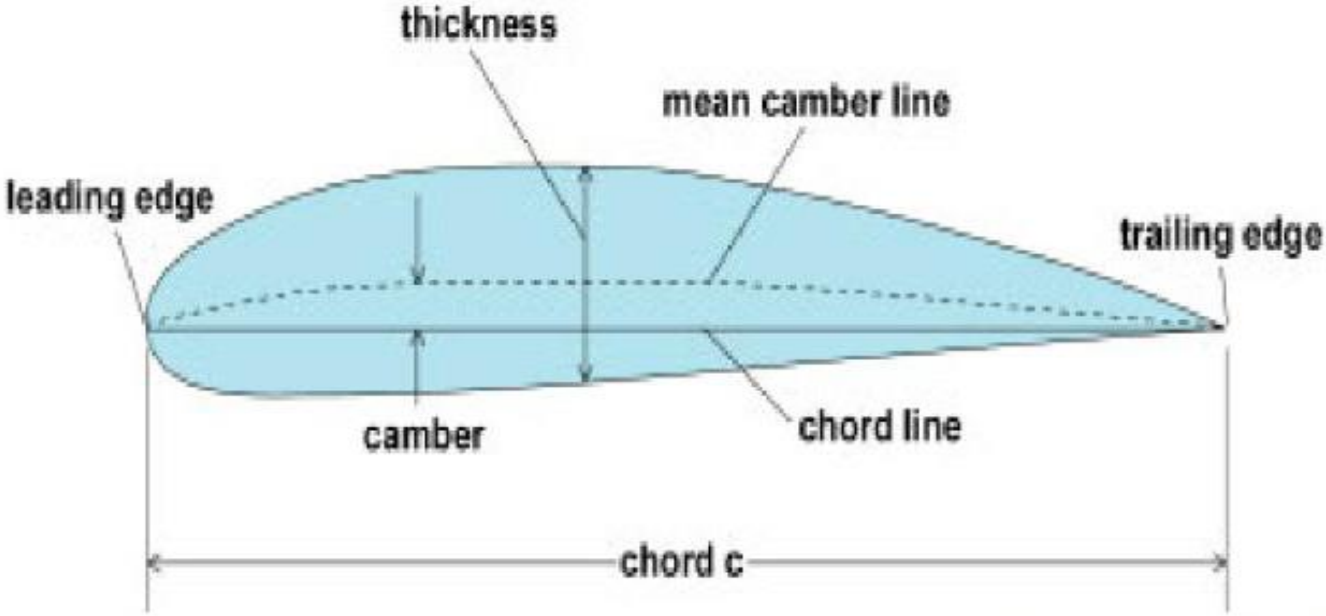


Fig.1.3 Airfoil profile

The velocity above the body is increased and so the static pressure is reduced. The velocity beneath is slowed down, giving an increase in static pressure. So, there is a normal force upwards called the lift force. Lift is the aerodynamic force that allows airplanes and helicopters to fly.

The drag on a body in an oncoming flow is defined as the force on the body in a direction parallel flow direction. For a windmill to operate efficiently the lift force should be high and drag force should be low. For small angles of attack, lift force is high and drag force is low. If the angles of attack (α) increases beyond a certain value, the lift force decreases and the drag forces increases.

1.3 AIRFOIL

An airfoil means a two dimensional cross-section shape of a wing whose purpose is to either generate lift or minimize drag when exposed to a moving fluid. The word is an Americanization of the British term aerofoil which itself is derived from the two Greek words Aeros ("of the air") and Phyllon ("leaf"), or "air leaf".

One of the most spectacular things to view is the structure and the body of an aero plane. Its concept has always been scintillating and technical. It all started with the answer to how birds can fly. All of us do know that only when an object overcomes the earth’s natural gravitational pull, it tends to fly. The wing of an aircraft helps in gliding it through the wind and also in its landing and takeoff. The shape of such an important component of the aircraft makes a lot of impact on its movements. This shape is what is called an airfoil.

1.3.1 TYPES OF AIRFOIL

- Semi-symmetrical Airfoil
- Symmetrical Airfoil
- Flat Bottom Airfoil
- Supersonic Airfoil
- Supercritical Airfoil

Semi-symmetrical Airfoil:

Most of the full size planes have this type installed. Its thinner than the symmetrical airfoil and has lesser drag. It has a fully curved top and a half curved bottom.

Symmetrical Airfoil:

They are curved on both sides, equally. Generate high lifts with change in speed and power. They are generally thick and hence are very strong. The plane maintains its altitude with change in speed.

Flat Bottom Airfoil:

Flat bottoms are usually seen in trainer flights. They look extremely thin. Its bottom is flat and top is curved. Flat bottom are speed sensitive. They are similar to symmetrical airfoil. When power and speed is added it produces great lift.

Supersonic Airfoil:

A supersonic airfoil is used to generate lift at supersonic speeds. Its need arises when an aircraft is operated consistently in supersonic range.

Supercritical Airfoil:

A supercritical is designed to delay the drag in the transonic speed rangeare a few to name. A supercritical is designed to delay the drag in the transonic speed range. They have a flat upper surface, a highly cambered aft and a greater leading edge radius.

Advantages of airfoil

1. Cambered airfoil (asymmetric) are the kind which can generate a lift at a zero angle of attack.
2. It can increase traction of a vehicle by creating a down force.
3. The angles of attack can be increased by symmetrical airfoil.

1.4 Selection of profile

Wind turbine profile is very important aspect for the wind turbine blade. As, it is very important in the deciding the amount of aerodynamic loads, a turbine blade can withstand; it also decides the various aerodynamic aspects of the blade. Various standards are there, which set up various shapes of the blade like NACA series, NERL Series etc.

Blade element momentum theory is very useful in finding out the characteristics of blade like chord length and angle of twist of a given aerofoil cross section and the speed of rotation at finite number of locations along the span of the blade. But, BEM is not entirely accurate if the data for the airfoil cross sections used are not corrected for the rotational aspects. This is the reason, why computational fluid dynamics (CFD) is used for the analysis of a new blade design as it provides proper and accurate design. Thus, selection of profile is mainly based upon computational flow dynamics. The naca airfoil s828 series selected.

1.5 Airfoil profile

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

Profile lines

1. Chord
2. Camber
3. Length
4. Midline

1.6 Airfoil Nomenclature

Chord length – length from the LE to the TE of a wing cross section that is parallel to the vertical axis of symmetry

Mean camber line – line halfway between the upper and lower surfaces

Leading edge (LE) is the front most point on the mean camber line,

Trailing edge (TE) is the most rearward point on mean camber line

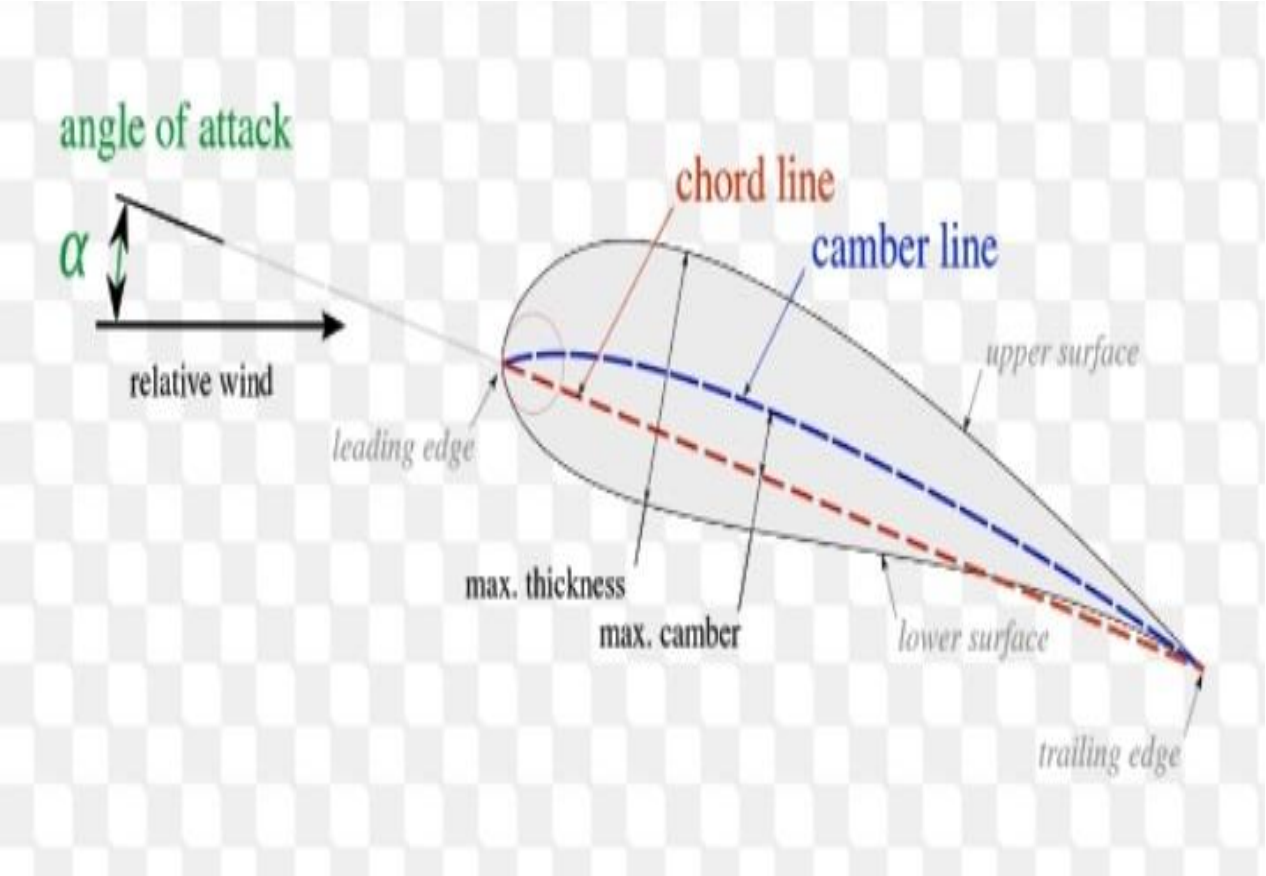


Fig. 1.4 Angle of attack

Camber – maximum distance between the mean camber line and the chord line, measured perpendicular to the chord line.

0 camber or uncambered means the airfoil is symmetric above and below the chord line.

Thickness – distance between upper surface and lower surface measured perpendicular to the mean camber line.

1.7 OBJECTIVE

- To reduce the weight of the blade
- To Improve the stiffness of the blade
- To Improve the life of the blade

CHAPTER 2

LITERATURE SURVEY

1. "Structural design and analysis of a 10MW wind turbine blade"., Year of published 2018, author by Michael S. Selig and Bryan D. McGranahan.

Horizontal axis wind turbine was developed for use in high wind speed location.

A hybrid composite structure was created yielding a light- weight design with a low tip deflection by using glass and car bon fibre plies.

The design is able with regard to tip deflection, maximum and minimum strains, and critical buckling load.

2. Arvind Singh Rathore, Siraj Ahmed ," Aerodynamic Analyses of Horizontal Axis Wind tunnel By Different Blade Airfoil Using Computer Program. Year of Published by 2016

Structural layouts for wind turbine blades was designed to improve the blade design, minimize the weight, and reduce the cost of wind energy.

To achieve this, the topology optimization method is used which is used to transforms along the blade, changing from the design with spar caps at the maximum thickness.

3. Eke G.B., Onyewudiala J.I. "Optimization design, modelling and dynamic analysis for composite wind turbine blade". Published by December 2014.

To achieve the dynamic performance analysis of composite blade, a modelling method which combining solid works with ANSYS are used.

Finite element method is used to perform the dynamic analysis for the blade.

4. Dr. Eng. Ali H. Almukhtar., " Structural design of a composite wind turbine blade using finite element analysis". Year of published 2013

Finite Element Analysis method is used to design the blade structure of composite wind turbine blade. Program was developed by using Blade Element theory and panel code prediction method.

5. Michael S. Selig and Bryan D. McGranahan .," Wind Tunnel Aerodynamic Tests of Six Airfoils for Use on Small Wind Tunnels" . year of published January 31, 2013.

The composite laminate theory and finite element method is used to determine the optimal structural lay-up of composite wind turbine blade through analysing their stress and strain.

The optimal structural design has low stress and strain value

6. Thumthae C, Chitsomboon T .,"Research on structural lay-up optimum design of composite wind turbine blade", year of published 2011.

The composite laminate theory and finite element method is used to determine the optimal structural lay-up of composite wind turbine blade through analysing their stress and strain.

The optimal structural design has low stress and strain value.

7. Mandas N, Cambuli F, Carcangiu CE .,"Structural investigation of composite wind turbine blade considering structural collapse in full-scale static test"., published 2010.

The actual collapse testing method which is under the flap-wise loading was investigated for a large full-scale composite wind turbine blade.

A video metrics technique is used to measure the integral deformation and the local deformation of the wind turbine blade.

8. “Structural optimization study of composite wind turbine blade”., author Thumthae C, Chitsomboon T., year of published 2009.

2MW composite wind turbine blade is designed based on modified Blade Element

Momentum theory by using one way fluid structure interaction method.

This method is used to reduce the mass of the optimized wind turbine blade compare to the initial blade.

9. “A simulation model for wind turbine blade fatigue loads”., Kunz, Peter J., Kroo, Ilan M. published 2009.

To determine the blade-root fatigue damage of a medium size wind turbine for the flap wise motion of a single rotor blade.

And this method is also used to simulate the effects of turbulence intensity, mean wind speed, wind shear, vertical wind component, dynamic stall, stall hysteresis, and blade stiffness.

10. Ramsay, R.R. and G.M. Gregorek, ‘Structural optimization study of composite and turbine blade”. Published 2009

To design a 2 MW wind turbine blade with wind speed 12.5 m/s and blade length 31 m.

composite wind turbine blade is based on the modified Blade Element Momentum (BEM) theory.

The result shows procedure leads to significant weight and structural strength of the blade and the strain of the blade is analysed.

11.“Fatigue of composite for wind turbine”. Tangler”., J. and J.D. Kocure‘. published 2010.

The paper will highlight some fatigue and lifetime aspects on wind turbine rotor blades made of composite materials.

A review was given on fatigue aspects of fibre reinforced plastics used in wind turbine rotor bladesthis material may serve as information for a safe fatigue design.

High fibre contents may lead to a steeper slope of the fatigue curves, a shear web may be more fatigue-critical than a spar cap and stiffness reduction in the leading and the trailing edge.

CHAPTER 3

SELECTION OF MATERIAL

Hybrid composite materials are the great potential for engineering material in many applications. Hybrid polymer composite material offers the designer to obtain the required properties in a controlled considerable extent by the choice of fibers and matrix. The properties are tailored in the material by selecting different kinds of fiber incorporated in the same resin matrix. In the present investigation, the mechanical properties of carbon and glass fibers reinforced epoxy hybrid composite were studied. The vacuum bagging technique was adopted for the fabrication of hybrid composite materials. The mechanical properties such as hardness, tensile strength, tensile modulus, ductility, and peak load of the hybrid composites were determined as per ASTM standards. The mechanical properties were improved as the fibers reinforcement content increased in the matrix material.

1. Materials used in the construction of the blade
2. Engineering properties of the materials; i.e., Young’s modulus, Poisson’s ratio, failure strains
3. Materials lay-up and orientation of the layers
4. Materials used in the construction of shear webs and dimensions and positions relative to the airfoil geometries

3.1 Fibre types

- Glass fibre
- Carbon fibre

3.1.1 Glass fiber

Carbon fibres are about twice as strong as glass and three times stiffer. Their extra stiffness also allows the surrounding resin to withstand fatigue better by reducing the strain in the resin.

Unfortunately carbon fibres are much more expensive, so they tend to be used only where their properties are essential for the performance of the blade.

In general this means carbon is used only on some of the largest turbines (over about 80m diameter), and even then only on the spar caps. The reason why larger blades need carbon more than smaller ones is that it is much harder to achieve sufficient stiffness on a long blade without adding excessive weight.

The extra weight not only means greater cost of material but also lower natural frequency (so the tower passing frequency can be a problem) and higher fatigue loading due to edgewise bending (which it will be remembered is caused by the weight of the blade flexing it one way then the other as it rotates). For these reasons the extra cost per kilogramme of carbon can be economically justified if it allows the global weight of a blade to be reduced significantly.

Indeed the weight of the blade theoretically increases with the cube of its length, while the power output only increases with the square of the length. If we accept the approximation that cost of manufacture is proportional to weight, this means that it becomes hard to justify making turbines larger unless the savings on cost per kilowatt due to having less towers, less generators, etc can offset the additional blade cost. To get past this hurdle it is necessary to make blades lighter, which either means making them thicker (and therefore less aerodynamically efficient) or using carbon.

3.1.2 Carbon fiber

The rigid composite material made from carbon fiber used in aerospace and other applications, see Carbon-fiber-reinforced polymer. Fabric made of woven carbon filaments Carbon fibers or carbon fibres (alternatively CF, graphite fiber or graphite fibre) are fibers about 5–10 micrometres in diameter and composed mostly of carbon atoms.

To produce a carbon fiber, the carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber as the crystal alignment gives the fiber high strength-to-volume ratio.

Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric. The properties of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low.

Thermal expansion, make them very popular in aerospace, civil engineering, military, and motorsports, along with other competition sports. However, they are relatively expensive when compared with similar fibers, such as glass fibers or plastic fibers.

Carbon fibers are usually combined with other materials to form a composite. When combined with a plastic resin and wound or molded it forms carbon-fiber-reinforced polymer (often referred to as carbon fiber) which has a very high strength-to-weight ratio, and is extremely rigid although somewhat brittle. However, carbon fibers are also composited with other materials, such as with graphite to form carbon-carbon composites, which have a very high heat tolerance.

3.2 PROPERTIES OF FIBRE:

- High strength
- High stiffness
- Good rigidity
- Corrosion resistant
- Fatigue resistant
- Good tensile strength
- Light weight

Good vibration damping and toughness.

Material properties are generated by coupon testing and reduced by partial safety factors appropriate to the material and manufacturing method. On provision of the preliminary aerodynamic profile flap wise loads due to aerodynamic lift are used to calculate the preliminary laminate design, hence confirm that the design can be made to work structurally within the chosen aerodynamic shape.

Given the preliminary laminates, the mass of the blade can be used to estimate edgewise fatigue loading. Blade shells are checked for buckling resistance and torsional stiffness.

Manufacturing processes and material selection are defined with the implications on weight and cost. Further loading/laminate iterations converge on a final design which is then checked by Finite Element Analysis for stiffness, buckling stability and strength including fatigue.

Property	**Composite Material**	
	E-glass	**Carbon**
Young’s modulus (Gpa)	7.62	1.28
Poisson’s ratio	0.3	0.3
Shear modulus (Gpa)	2.968	4.9231
Density(kg/m^3)	2540	1770

Table 3.1 Properties of fibre

3.3 BLADE LOADS

Multiple aerofoil sections and chord lengths, specified stochastic load cases and an angle of twist with numerous blade pitching angles results in a complex engineering scenario. To simplify calculations, it has been suggested that a worst case loading condition be identified for consideration, on which all other loads may be tolerated. The worst case loading scenario is dependent on blade size and method of control. For small turbines without blade pitching, a 50 year storm condition would be considered the limiting case. For larger turbines ($D > 70$ m), loads resulting from the mass of the blade become critical and should be considered.

In practice several load cases are considered with published methods detailing mathematical analysis for each of the IEC load Cases. For modern large scale turbine. Blades the analysis of a single governing load case is not sufficient for certification. Therefore multiple load cases are analysed. The most important load cases are dependent on individual designs. Typically priority is given to the following loading conditions:

- emergency stop scenario
- extreme loading during operation
- parked 50 year storm conditions

Under these operational scenarios the main sources of blade loading are listed below:

1. Aerodynamic
2. Gravitational
3. Centrifugal
4. Gyroscopic
5. Operational

The load magnitude will depend on the operational scenario under analysis. If the optimum rotor shape is maintained, then aerodynamic loads are unavoidable and vital to the function of the turbine, considered in greater detail. As turbines increase in size, the mass of the blade is said to increase proportionately at a cubic rate.

The gravitational and centrifugal forces become critical due to blade mass and are also elaborated. Gyroscopic loads result from yawing during operation. They are system dependant and generally less intensive than gravitational loads.

3.3.1 Aerodynamic Load

Aerodynamic load is generated by lift and drag of the blades aerofoil section , which is dependent on wind velocity (*VW*), blade velocity (*U*), surface finish, angle of attack (α) and yaw. The angle of attack is dependent on blade twist and pitch. The aerodynamic lift and drag produced are resolved into useful thrust (*T*) in the direction of rotation absorbed by the generator and reaction forces (*R*). It can be seen that the reaction forces are substantial acting in the flatwise bending plane, and must be tolerated by the blade with limited deformation.

Aerodynamic forces generated at a blade element. For calculation of the blade aerodynamic forces the widely publicised blade element momentum (BEM) theory is applied Working along the blade radius taking small elements (δr), the sum of the aerodynamic forces can be calculated to give the overall blade reaction and thrust loads.

3.3.2 Gravitational and Centrifugal Loads

Gravitational centrifugal forces are mass dependant which is generally thought to increase cubically with increasing turbine diameter . Therefore, turbines under ten meters diameter have negligible inertial loads, which are marginal for 20 meters upward, and critical for 70 meter rotors and above. The gravitational force is defined simply as mass multiplied by the gravitational constant, although its direction remains constant acting towards the centre of the earth which causes an alternating cyclic load case.

The centrifugal force is a product of rotational velocity squared and mass and always acts radial outward, hence the increased load demands of higher tip speeds. Centrifugal and gravitational loads are superimposed to give a positively displaced alternating condition with a wavelength equal to one blade revolution.

3.3.3 Structural Load Analysis

Modern load analysis of a wind turbine blade would typically consist of a three dimensional CAD model analysed using the Finite Element Method . Certification bodies support this method and conclude that there is a range of commercial software available with accurate results. These standards also allow the blade stress condition to be modelled conservatively using classical stress analysis methods. Traditionally the blade would be modelled as a simple cantilever beam with equivalent point or uniformly distributed loads used to calculate the flap wise and edgewise bending moment.

3.3.4 Flap wise Bending

The flap wise bending moment is a result of the aerodynamic loads, which can be calculated using BEM theory. Aerodynamic loads are suggested as a critical design load during 50 year storm and extreme operational conditions .Once calculated, it is apparent that load case can be modelled as a cantilever beam with a uniformly distributed load. This analysis shows how bending occurs about the chord axis creating compressive and tensile stresses in the blade cross section.

When calculating the second moment of area it is apparent that increasing the distance from the central axis of bending gives a cubic increase. When substituted into the beam bending equation it can be seen that a squared decrease in material stress can be obtained by simply moving load bearing material away from the central plane of bending. It is therefore efficient to place load bearing material in the spar cap region of the blade at extreme positions from the central plane of bending .

3.3.5 Edgewise Bending

The edgewise bending moment is a result of blade mass and gravity. Therefore this loading condition can be considered negligible for smaller blades with negligible blade mass. Simple scaling laws dictate a cubic rise in blade mass with increasing turbine size. Therefore for increasing turbine sizes in excess of 70 m diameter, this loading case is said to be increasingly critical.

The bending moment is at its maximum when the blade reaches the horizontal position. In this case the blade may once again be modelled as a cantilever beam. The beam now has a distributed load which increases in intensity towards the hub as the blade and material thicknesses increase. the plane of central bending is now normal to the chord line

3.3.6 Fatigue Loads

The major loading conditions applied to the blade are not static. Fatigue loading can occur when a material is subjected to a repeated non continuous load which causes the fatigue limit of the material to be exceeded. It is possible to produce a wind turbine blade capable of operating within the fatigue limit of its materials. However, such a design would require excessive amounts of structural material resulting in a heavy large.

Fatigue loading conditions are therefore unavoidable in efficient rotor blade design. Fatigue loading is a result of gravitational cyclic loads . which are equal to the number of rotations throughout the lifetime of the turbine, typically 20 years.

3.3.7Structural Blade Regions

The modern blade can be divided into three main areas classified by aerodynamic and structural function.

3.4 The blade root.

The transition between the circular mount and the first aerofoil profile—this section carries the highest loads. Its low relative wind velocity is due to the relatively small rotor radius. The low wind velocity leads to reduced aerodynamic lift leading to large chord lengths. Therefore the blade profile becomes excessively large at the rotor hub. The problem of low lift is compounded by the need to use excessively thick aerofoil sections to improve structural integrity at this load intensive region. Therefore the root region of the blade will typically consist of thick aerofoil profiles with low aerodynamic efficiency.

The mid span.

Aerodynamically significant—the lift to drag ratio will be maximised. Therefore utilising the thinnest possible aerofoil section that structural considerations will allow.

The tip.

Aerodynamically critical—the lift to drag ratio will be maximised. Therefore using slender aerofoils and specially designed tip geometries to reduce noise and losses. Such tip geometries are as yet unproven in the field, in any case they are still used by some manufacturers.

CHAPTER 4

BLADE DESIGN

4.1 Introduction of Catia

Catia is an acronym for computer aided 3 Dimension interactive application. It is one of the leading 3 D software used by organization in multiple industries ranging from automobile, aerospace to consumer products. Catia is a multiplatform 3 D software suite developed by Dassult system encompassing CAD, CAM as well as CAE. Dassult is a French engineering giant active in the field of aviation , 3D design , 3D digital mock- ups and product life cycle management software. Catia is a solid modelling tool that unites the 3D parametric features with 2D tools and also address every design to manufacturing process in addition to creating solid model and assembly , Catia also provides generating orthographic, section, auxiliary, isometric or detailed 2D drawing views. It also possible to generate model dimension and create reference dimension in the drawing views. The bi-directional associative property of catia ensures that the modification made in the model are reflected in the drawing views and vice versa. The first release of catia was way backing 1977, and software suite is still going strong more than 30 years later while catia v6 is just being released the most popular version of catia is v5 which was introduced in 1998. That said , it is important to note that each version of catia introduces the considerable addition functionality . for example v4 introduces in 1992.

NREL’S S828 AIRFOIL GRAPHIC AND COORDINATES

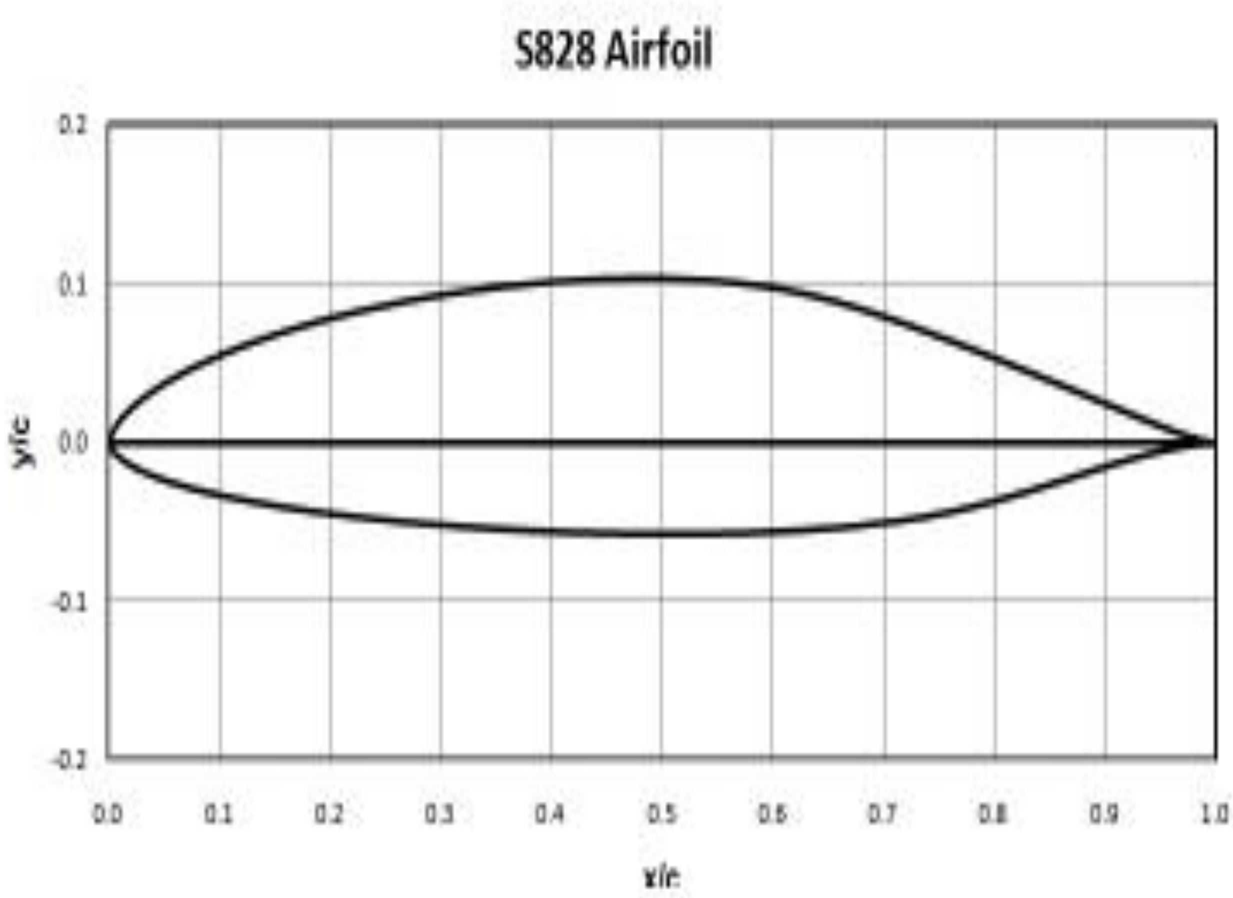


Fig. 4.1 S828 airfoil graphic design

4.2 Summary of structural design

Spar

Primarily the blade is loaded in bending, due to the aerodynamic lift forces (flap wise) and to a lesser extent the blade’s own weight (edgewise). To resist bending,

Unidirectional fibres running along the length of the blade are placed as far apart as possible in the flap wise direction. These are called spar caps and to be effective they must be joined by a shear web comprised of diagonal fibres.

Shells

The aerodynamic shape is formed by shells which are stiffened by using a sandwich construction. Thin skins, usually of glass reinforced plastic, are placed either side of a light weight foam core. The resulting sandwich construction is stiff enough to resist bending due to aerodynamic pressures and buckling. With diagonal fibres in the laminate, the shell provides the blade with the necessary torsional stiffness.

Root

Where the blade is bolted to the rotor hub, the spar must be circular and the laminate is locally thickened. For ease of manufacture, this part is often made separately and bonded to the spar and shells as a secondary operation.

Strength and Stiffness

The blade must be both strong enough not to break and stiff enough not to strike the tower. It must also be stiff and light enough so that its natural frequency of vibration does not coincide with the frequency at which the blades pass the tower, or resonance will occur, amplifying the vibrations until tower strike or fatigue failure occurs.

Fatigue

With a typical 20 year design life, the blades will flex about ten million times. This weakens the material (fatigue) so for normal operating loads, the blade must be designed to a lower stress than for extreme, one-off loading situations

4.3 Lift and Drag

Lift force is the force perpendicular to direction of the oncoming air flow as a consequence of the unequal pressure on the upper and lower airfoil surfaces.

Drag force is the force parallel to the direction of the oncoming air flow due both to viscous friction forces at the surface of the airfoil and to unequal pressure on the airfoil surfaces facing toward and away from the oncoming flow. Pitching moment acts about an axis perpendicular to the airfoil cross-section.

$$Lift = \frac{1}{2} * \rho * C_L * c * L * V_{rel}^2$$
$$Drag = \frac{1}{2} * \rho * C_D * c * L * V_{rel}^2$$

where ρ – Density of air - 1.225 kg/m3

c – Chord length

L – Length of the blade element

Relative velocity of air

$$V_{rel} = \sqrt{V_o^2 + (r\omega)^2}$$

4.4 SELECTION OF AIRFOIL

Calculating the rotor diameter for 500kw power and 12 m/s wind speed

$P=1/2\ C_p*\rho\ AV^3$

Where,

P-power of wind -kw

Cp-power coefficient

ρ-density of air- kg/m^3

A-swept area -m^{2}V-wind velocity m/s

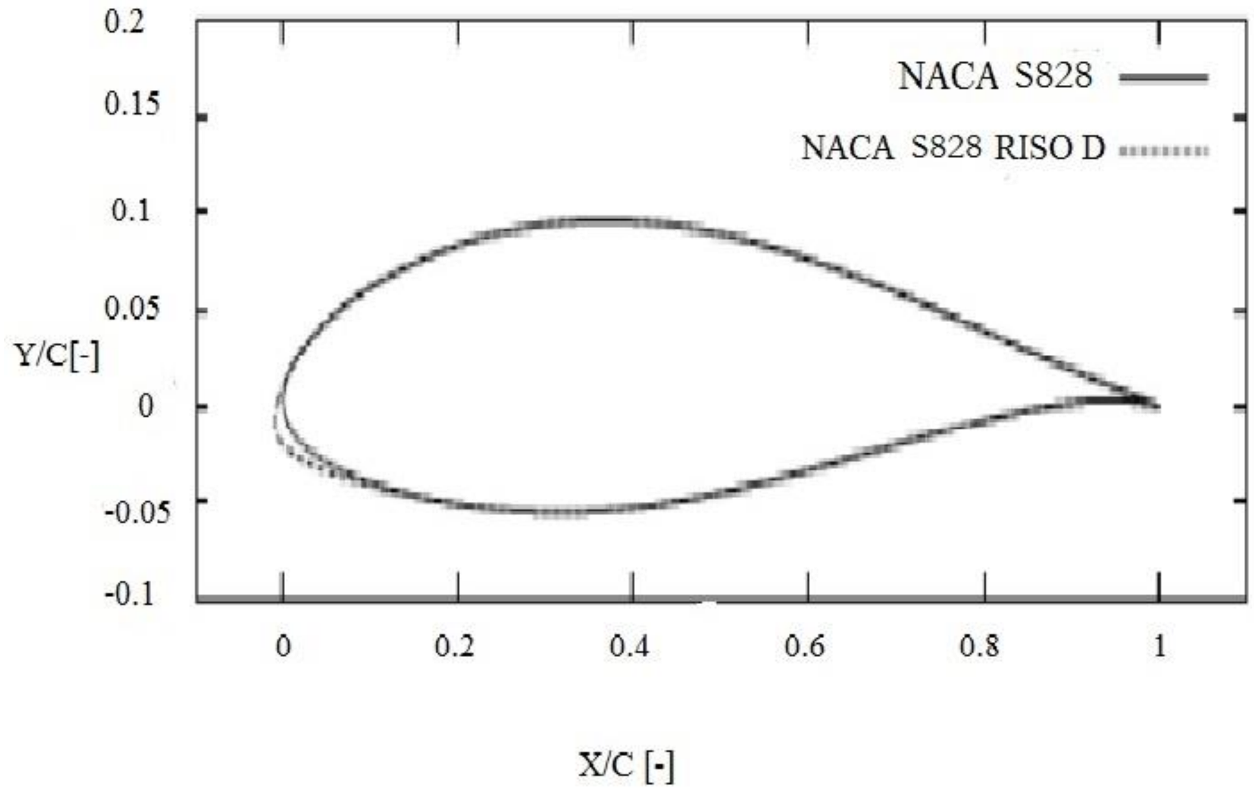


Fig.4.2 Blade design

4.5 NACA

NACA – National Advisory Committee for Aeronautics.

This methodology began to change in the early 1930s with the publishing of a NACA report entitled. The Characteristics of 78 Related Airfoil Sections from Tests in the Variable Density Wind Tunnel. In this landmark report, the authors noted that there were many similarities between the airfoils that were most successful, and the two primary variables that affect those shapes are the slope of the airfoil mean camber line and the thickness distribution above and below this line. They then presented a series of equations incorporating these two variables that could be used to generate an entire family of related airfoil shapes. As airfoil design became more sophisticated, this basic approach was modified to include additional variables, but these two basic geometrical values remained at the heart of all NACA airfoil series.

- precursor to NASA - National Aeronautics and Space Administration
- systematically investigated (and cataloged) effects of various airfoil profile

parameters on aerodynamic behaviour

- developed several series of airfoils and classification systems

many of these airfoils are still commonly used

- four digit series

first number is camber in percentage of chord

second number is location of maximum camber in tenths of chord measured from LE

last two digits give maximum thickness in percentage of chord

- five digit series

designed with location of maximum camber closer to the LE to achieve higher maximum lift coefficients

- six digit series

laminar- flow airfoils

- supercritical airfoils

designed to have reduced drag for high subsonic speeds designed to have drag-divergence Mach number delayed to as close to Mach 1.0 as possible.

4.6 NACA S828

The NACA S828 series are

NACA S828 AIRFOIL

x/c	y/c
1.000000	0 .000000
0.995917	0 .000405
0.984089	0 .002349
0.965587	0 .006498
0.941618	0 .012853
0.913148	0 .020950
0.880750	0 .030228
0.844781	0 .040401

0.805955	0 .051297
0.635449	0 .092080
0.399520	0 .084570
0.449770	0 .081940
0.000000	0 .000000
0.006010	-0 .011500
0.008630	-0 .013880
0.013800	-0 .017660
0.026520	-0 .024200
0.051710	-0 .033280
0.076770	-0 .039990
0.101770	-0 .045350
0.151660	-0 .053360
0.201480	-0 .058950
0.251250	-0 .062590
0.301000	-0 .064480
0.350740	-0 .064700
0.400480	-0 .063150
0.450230	-0 .060040
0.500000	-0 .055620
0.549810	-0 .050130
0.599650	-0 .043820
0.64 9530	-0.036910
0.69 9470	-0.029620
0.74 9450	-0.022240
0.765006	- 0 .062482
0.79 9490	-0.015130
0.722578	- 0 .073422
0.84 9570	-0.008670

0.964685	-0 .002780
0.983882	-0.000640
0.995904	- 0.000013
1.000000	0.000000

3D VIEW OF S828 BLADE MODEL

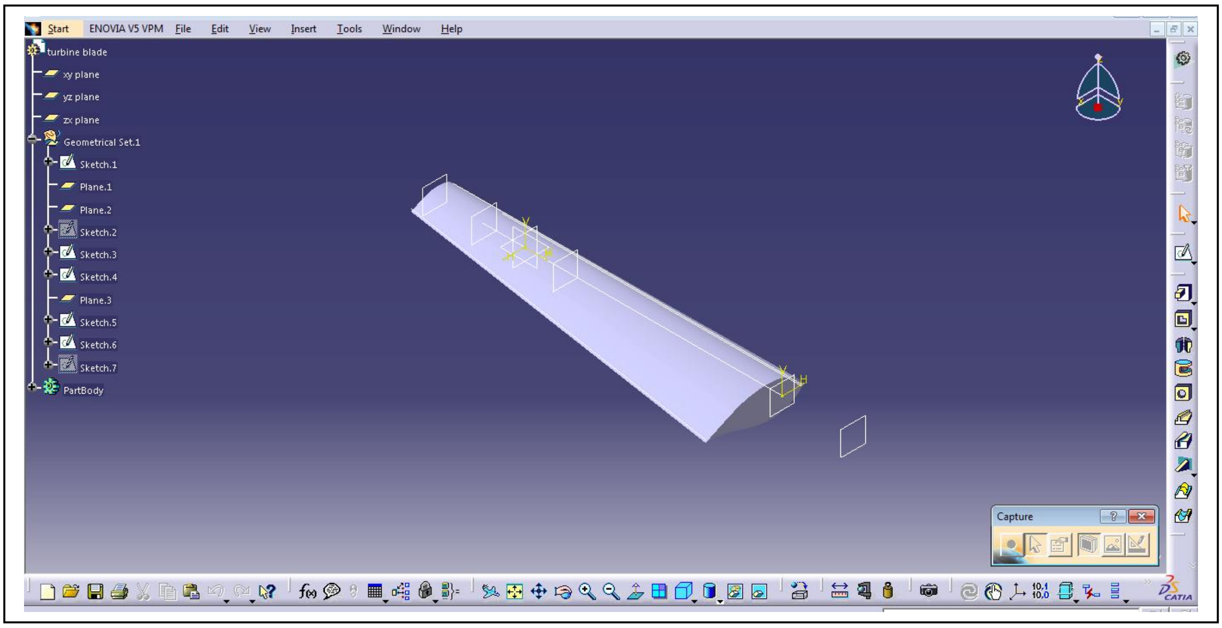


Fig.4.3 3D view of s828 blade model

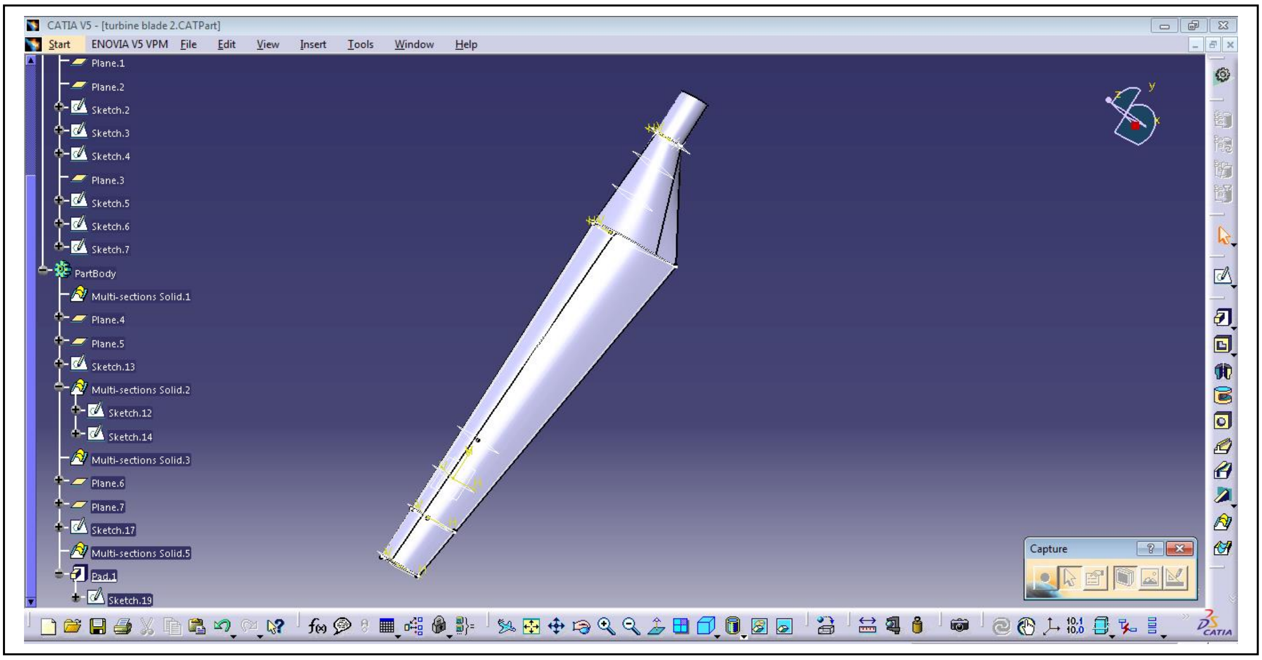


Fig.4.4 3D view of S828 blade model

CHAPTER 5

MODEL ANALYSIS

Creating the blade model and applying the loads directly from the ANSYS's GUI is an long process, and it needs many manual modifications every time the external shape, the materials lay-up and/or the load case changes. Smarter solutions have to be found, in order to optimise the available time. Between TU Delft and the Sandia National Laboratories, there is a mutual agreement of understanding. This means that their collaboration implies also exchanging of information and codes. Therefore, Sandia laboratories kindly provided a version of their software NuMAD (Numerical Manufacturing And Design tool).

This code is a pre-processor that allows defining both outer shape of the blade and material lay-out. It automatically creates and exports the ANSYS model, and it is extremely easy to utilise. It also has a GUI (Graphical User Interface), useful to easily spot errors and mistakes in the model definition. It does not have any parametric feature, and due to the nature of this analysis, a parametric approach is considered essential. Any time one laminate thickness changes, it has to be manually modified along the complete span wise length.

Furthermore, all the loads and the constraints have to be manually applied to the FE nodes. It is a useful tool to create the final model of a blade, but faster and more flexible options are needed for this kind of study. Therefore, NuMad in not going to be adopted in this analysis. The model for the FEM software can be created through a 3D-CAD system. Some of them (e.g. Siemens's NX, formerly Unigraphics) have already a built-in FEM solver. Modelling a wind turbine blade implies wide variety of lay-ups, layer thicknesses and fibres' orientations.

Setting up a parameterization of these characteristics is long time consuming, and it requires an external code or several macros. Drawing the model with CAD software, exporting it to the FE software, and defining layers and materials once everything is imported can be even worse. Other 3D-CAD software as Solid Works has been evaluated, but it does not include a FEM solver, and the student version available does not allow exporting “IGES” files either.

This export-import issue adds extra difficulties about the combination CADFEM, thus other solutions have been looked for. NREL’s PreComp is a freeware able to extract mass, edgewise and flap wise stiffness distribution of the modelled blade. PreComp usually computes the structural characteristics for aero-elastic codes. Structural properties are often problematic to extract from 3-D FEM software, as they need to post process the results. Zwang has extensively employed PreComp in his study, and through it he first discovered inconsistency between the FAST’s mass distribution and the Upwind material lay-up.

PreComp does not create a model for a FEM solver; hence, it does not allow either spotting stress concentrations or performing buckling analysis. Furthermore, it has some limitation regarding the external shape of the airfoil and in order to parameterise the layer thicknesses and automatically modify the input file, an extra code has to be written. Directly writing a new simple code that performs the integrations and extracts mass distribution and stiffness is a more favourable choice.

5.1 MESHING

Meshing is probably the most important part in any of the computer simulations because it can show drastic changes in results you get (have a first-hand experience of this). Meshing means you create a mesh of some grid points called ‘node’. It is done with a variety of tools and options available in the software. The results are calculated by solving the relevant governing equations numerically at each of the nodes of the mesh.

The governing equations are almost always partial differential equations, and finite element method is used to find solutions to find such equations. The pattern and relative positioning of the node also affect the solutions, the computational efficiency & time. This is why good meshing is very essential for a sound computer simulation to give good results.

5.2 MESH VIEW OF BLADE

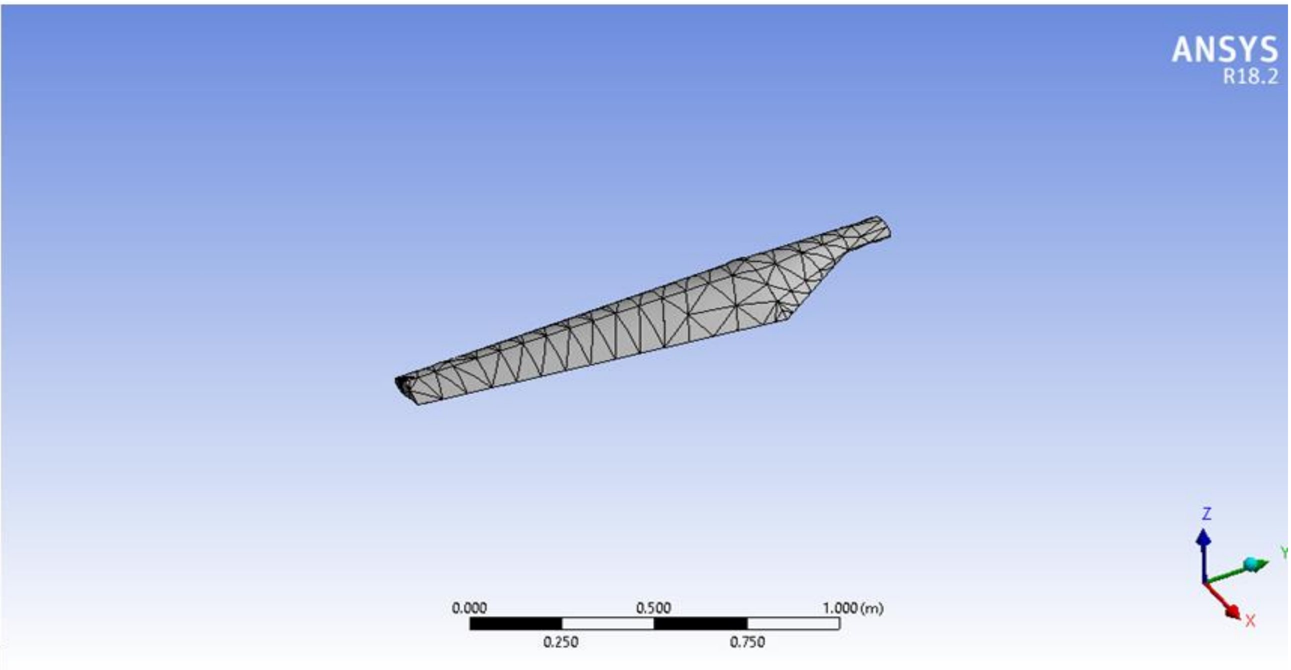


Fig.5.1 Mesh view of blade

5.3 DESIGN CALCULATION

- Design of Rotor Diameter
- $P=1/2\ C_P \times \rho\ AV^3$
- $500*10^3 = 1/2*0.593*1.225*\pi/4*D^2*10^3$
- $D^2 = 1014.321$
- $D = 32m$
- $R = 16m$

5.4 STRESS ANALYSIS

5.4.1 STRESS ANALYSIS FOR 0.05 THICKNESS

CARBON FIBER

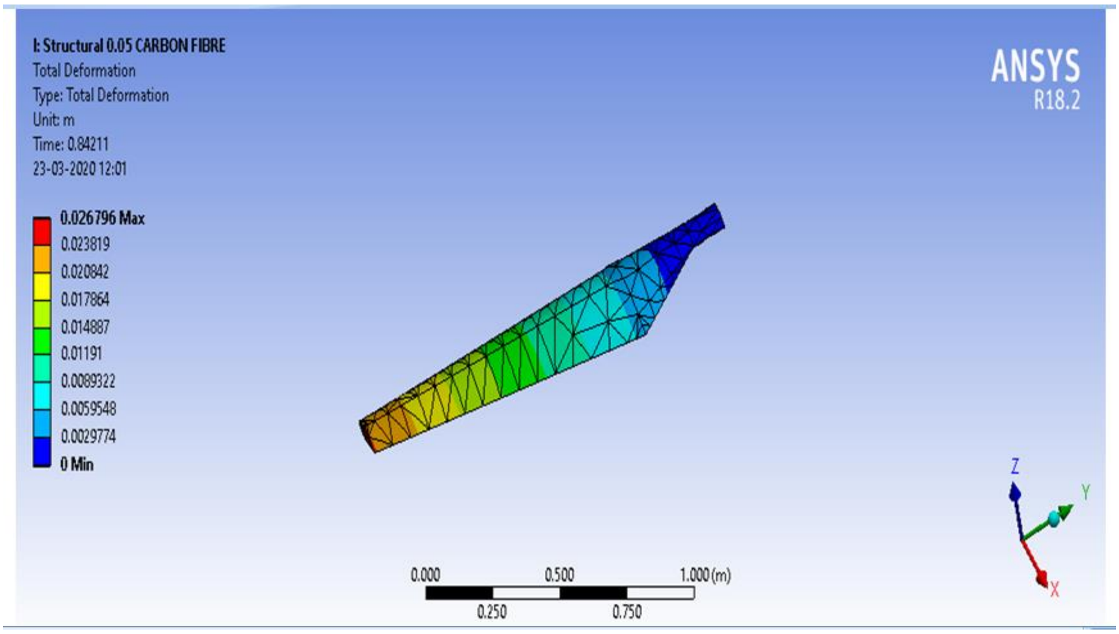


Fig. 5.2 Stress analysis of carbon fiber

GLASS FIBER

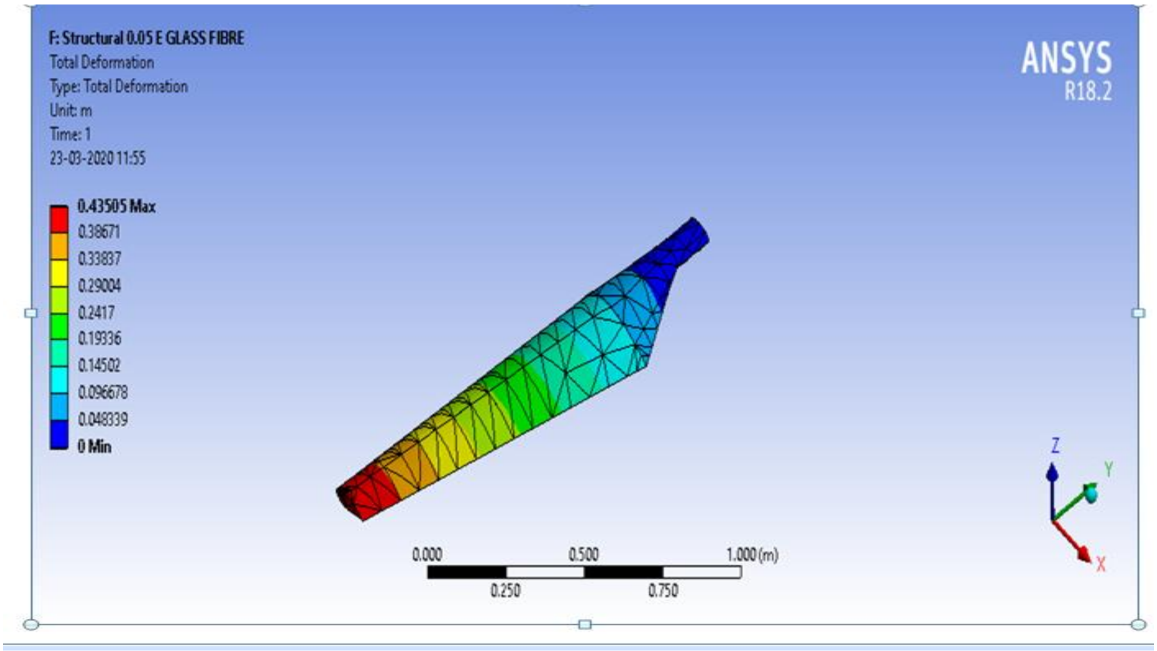


Fig. 5.3 Stress analysis of carbon fiber

5.4.2 STRESS ANALYSIS FOR 0.06 THICKNESS

CARBON FIBER

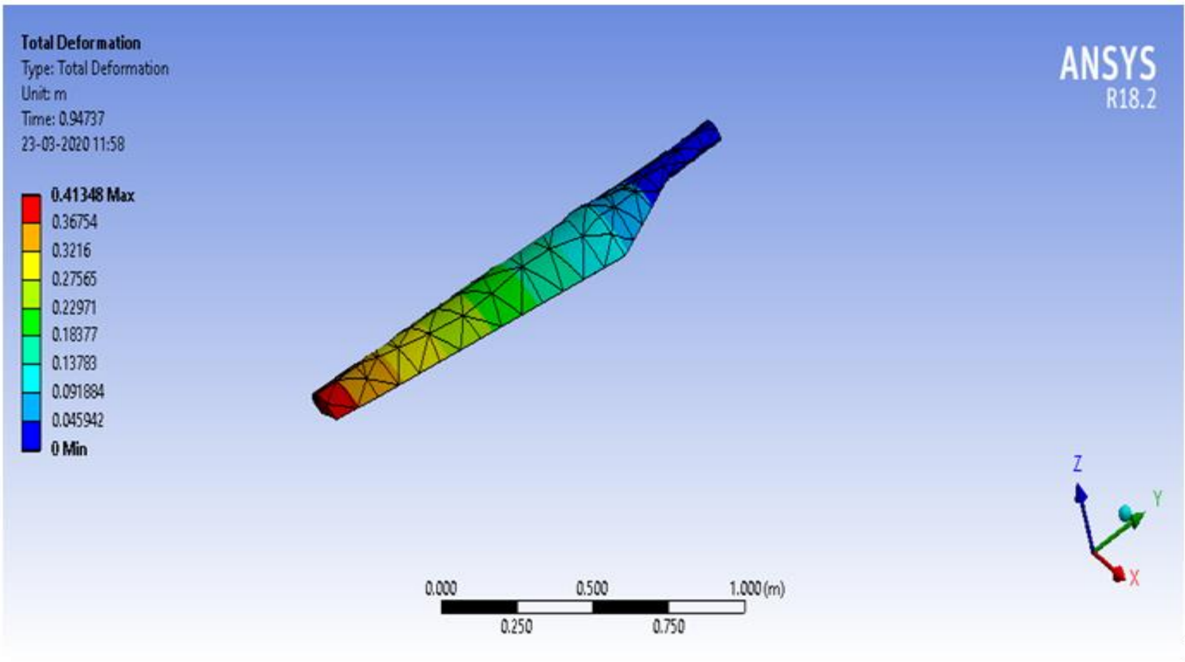


Fig. 5.4 Stress analysis of carbon fiber

GLASS FIBER

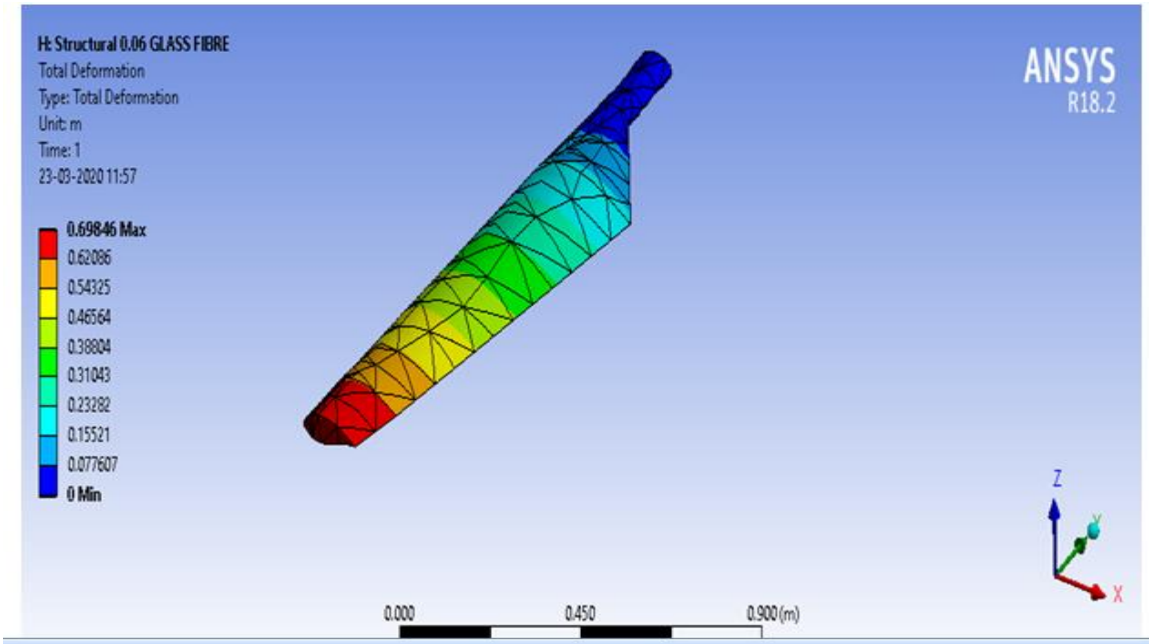
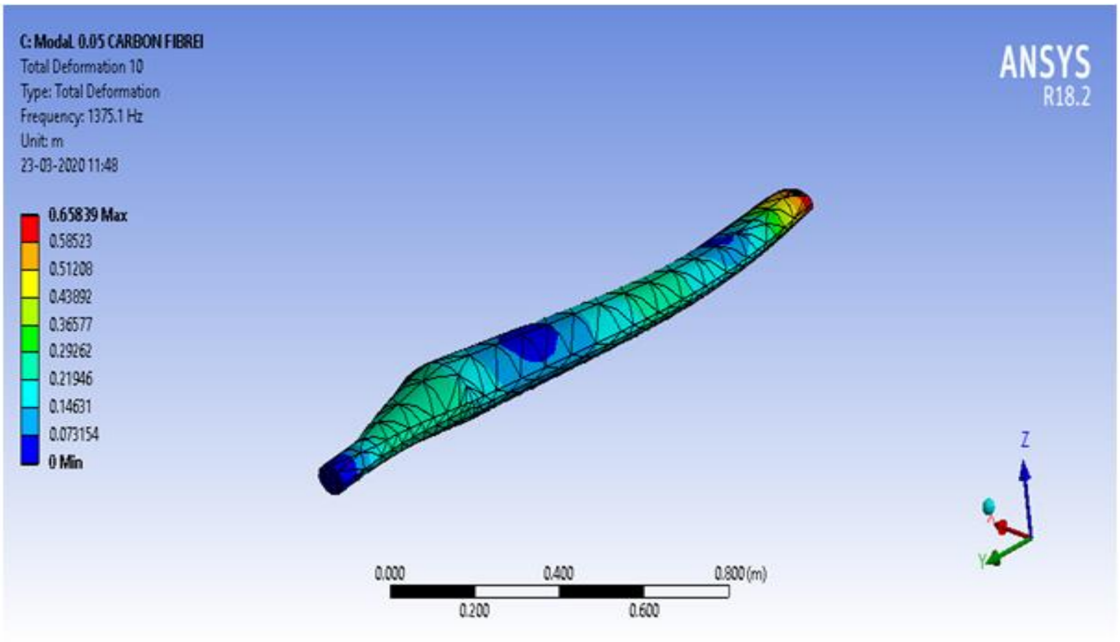


Fig. 5.5 Stress analysis of carbon fiber

5.5 MODEL ANALYSIS

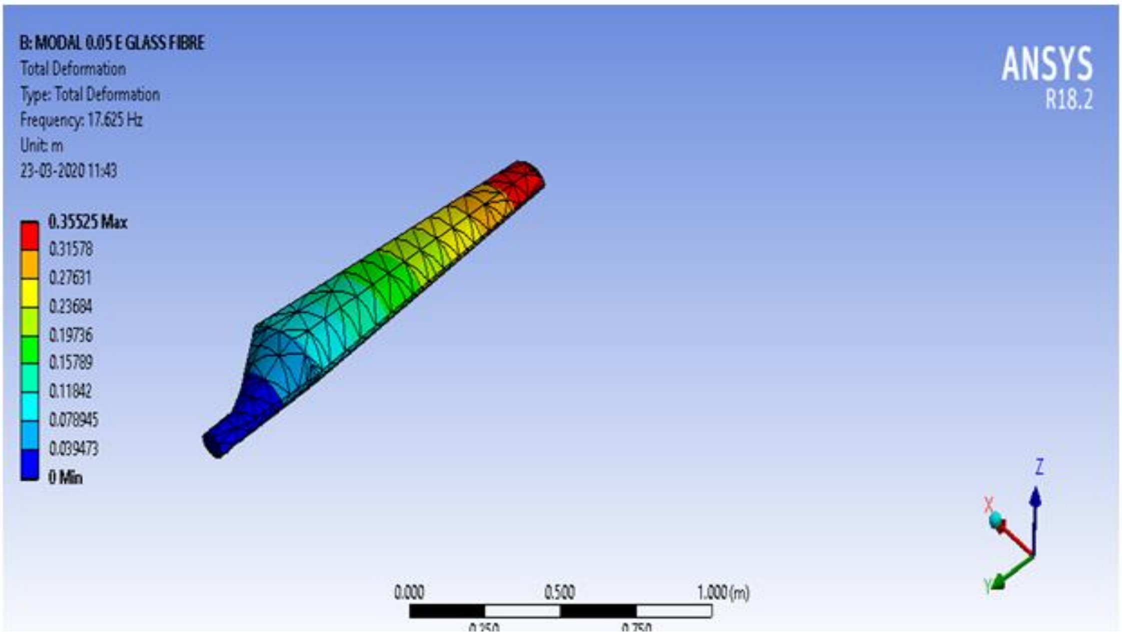
Model analysis has been used to identify natural frequencies, damping characteristics and mode shapes of wind turbine blades.

5.5.1 MODEL ANALYSIS FOR 0.05 THICKNESS CARBON FIBER



Fig,5.6 model analysis for 0.05 thickness carbon fiber

5.5.2 **MODEL ANALYSIS FOR 0.05 THICKNESS GLASS FIBER**



Fig, 5.7 model analysis for 0.05 thickness glass fiber

MODAL ANALYSIS FOR 0.06 THICKNESS CARBON FIBER

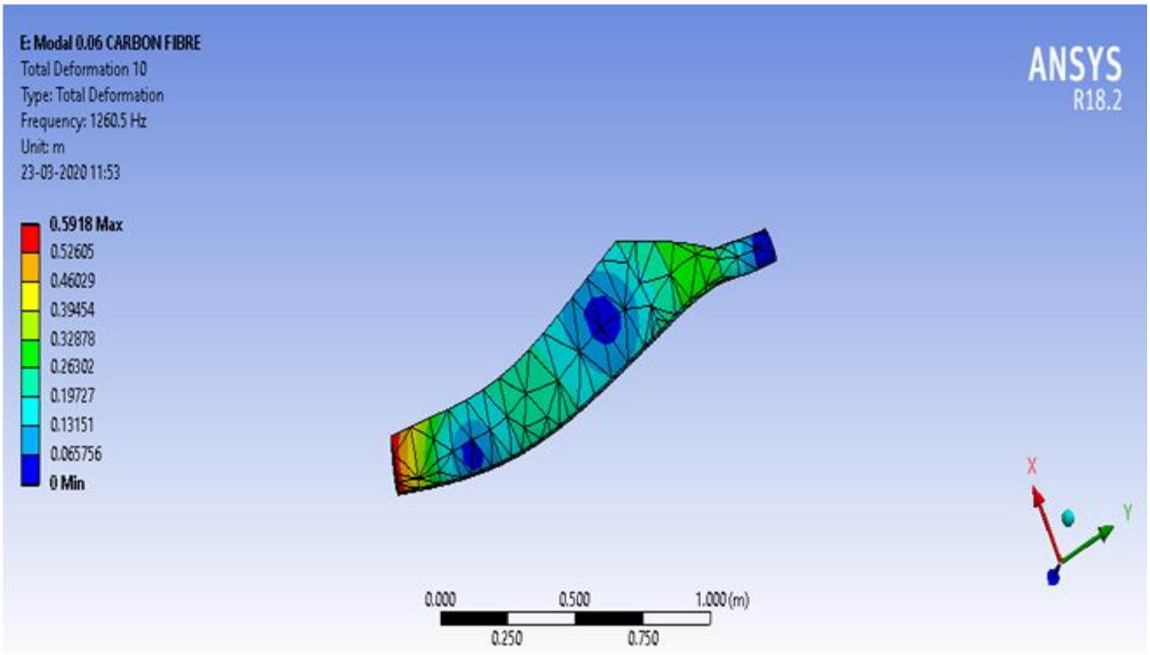


Fig. 5.8 model analysis for 0.06 thickness carbon fiber

5.5.2 MODEL ANALYSIS FOR 0.06 THICKNESS GLASS FIBER

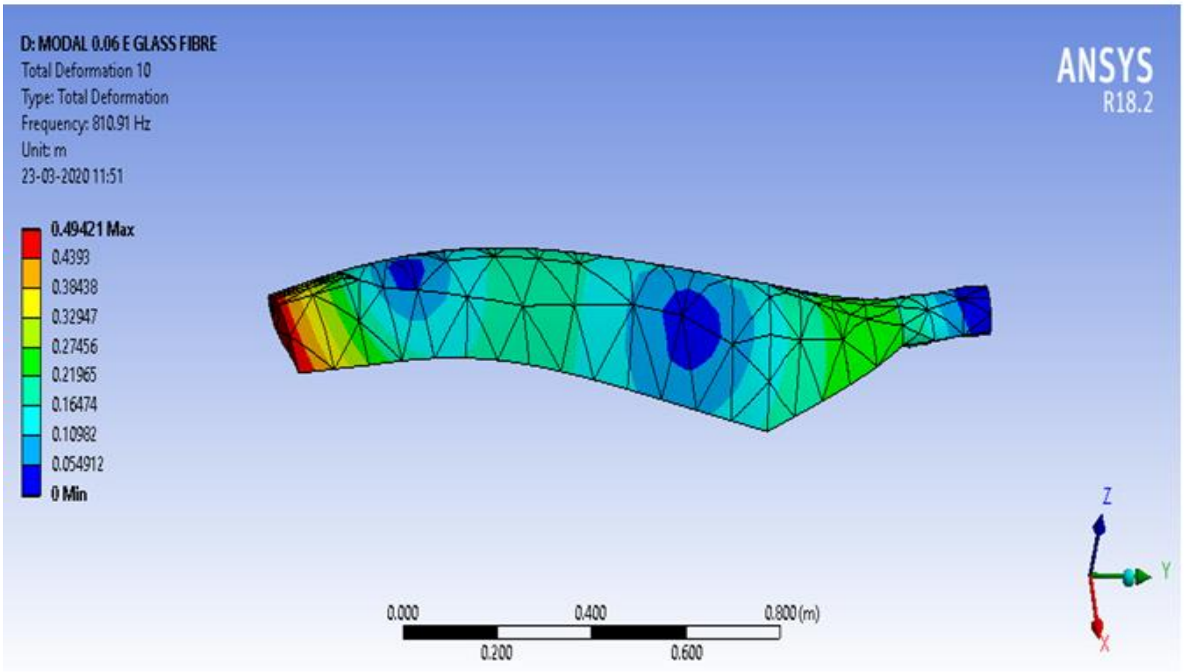


Fig. 5.9 model analysis for 0.06 thickness glass fiber

CHAPTER 6

RESULT AND DISCUSSION

6.1 CARBON & GLASS FIBER

Thickness (m)	Glass Fiber		Carbon Fiber	
	MAXIMUM DEFORMATION (m)	**Max Stress (N/m²)**	**MAXIMUM DEFORMATION (m)**	**Max Stress N/m²**
0.05	0.4305	0.212e10	0.026796	0.355e10
0.06	0.6984	0.206e10	0.41348	0.346e10

Table 6.1 carbon & glass fiber comparison

6.2 GEOMETRICAL PROPERTY

THICKNESS [m]	DENSITY [kg/m3]	GLASS FIBER MASS [kg]	GLASS FIBER VOLUME (m³)	DENSITY [kg/m3]	CARBON FIBER MASS[kg]	CARBON FIBER VOLUME (m³)
0.05	2540	6540	3.14520	1700	4905	3.14520
0.06	2540	7860	3.77424	1700	5895	3.77424

Table 6.2 geometrical property

CHAPTER 7

CONCLUSION

- The wind turbine blade with a length of 16 m was designed in Pro-E for a power output of 500 KW and wind velocity 12 m/sec.
- The types of airfoil used for structural analysis were NREL airfoil and S828.
- By varying the blade thickness from 0.04 m to 0.09 m, the static and dynamic analysis was done by using Ansys software.
- In static analysis the maximum stress and deformation is analyzed. In this analysis the material used are carbon fiber and glass fiber.
- It also showed that the deformation of glass is more compared to carbon fiber.
- The modal analysis was carried out. The results showed carbon fiber has more natural frequency compared to glass fiber. So, carbon fiber is best compared to glass fiber.

CHAPTER 8

REFERENCES

- Arvind Singh Rathore, Siraj Ahmed ,“ Aerodynamic Analyses of Horizontal Axis Wind tunnel By Different Blade Airfoil Using Computer Program”, IOSR Journal of Engineering
- Eng. Ali H. Almukhtar, “Effect of drag on the performance for an efficient wind tunnel blade design”, Energy Procedia
- Eke G.B., Onyewudiala J.I. “Optimization of Wind Tunnel Blades Using Genetic Algorithm”Global Journal of Researches in Engineering
- Michael S. Selig and Bryan D. McGranahan ” Wind Tunnel Aerodynamic Tests of Six Airfoils for Use on Small Wind tunnels” .
- Monir Chandrala, Abhishek Choubey, Bharat Gupta “CFD analysis of horizontal axis wind tunnel blade for optimum value of power”, International Journal Of Energy And Environment.
- Xiongwei Liu, Lin Wang, Xinzi Tang “Optimized linearization of chord and twist angle profiles for fixed-pitch fixed-speed wind tunnel blades”, Renewable Energy.