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Domestic Windmill Blades Design and Analysis

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ABSTRACT

The optimum twist of a windmill blade is examined on the basis of elementary blade element theory. For a given wind speed and blade angular velocity, it is shown that the maximum power efficiency is achieved when the blade is twisted according to a program that depends upon the variation of the sectional lift and drag coefficients with angle of attack. Results for a typical airfoil cross-section show that the optimum angle of attack decreases from the maximum-lift-coefficient angle of attack at the blade root to greater than eighty percent of this value at the blade tip. The materials used were stainless steel, e-glass epoxy and gray cast iron and results were tabulated.
Keywords: Airfoil Cross-Section, Coefficient Angle, E-Glass Epoxy, MNRE, VAWT, NACA

I. INTRODUCTION

In these modern days the population is rapidly increasing and consumption of power in various fields also increased. Hence, it is very essential to find for an alternative power generation techniques on which all the aspects of modern day technology mainly depends. In that we have non conventional power generation techniques such as solar power, wind power, tidal power which are eco-friendly, abundantly available in nature.

Renewable energy has gained importance in the background of the debates and discussions on climate change all over the world. Resources are gaining importance in reducing global warming gas emissions as they do not depend on fossil fuel. In India at present more than 75% of the power generation depends on coal based thermal power plants. In the background of emerging global obligations to bring down emissions of gases responsible for global warming the Government of India has brought out promising legal provisions and policies to promote renewable energy. Here it will not be out of place to mention that India is the first country to have a separate ministry – Ministry for New and Renewable Energy (MNRE) – to promote renewable energy based power generation in the country. The utilization of wind energy for power generation purposes is becoming increasingly attractive and gaining a great share in the electrical power production market world-wide.

Wind turbines were used long time ago, the very first electricity generating windmill operated in the UK was a battery charging machine installed in 1887 by James Blyth in Scotland. The first utility grid-connected wind turbine operated in the UK was built by the John Brown Company in 1954 in the Orkney Islands. Wind turbines are designed to exploit the wind energy that exists at a location. Virtually all modern wind turbines convert wind energy to electricity for energy distribution.

II. WIND TURBINES

A Wind Turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy a process known as wind power. If the mechanical energy is used to produce electricity, the device may be called a Wind turbine or Wind power plant. If the mechanical energy is used to drive machinery, such as for grinding grain or pumping water, the device is called a wind mill or wind pump. Similarly, it may refer to as a Wind charger when used for charging batteries. The modern wind turbine is a system that comprises three integral components with distinct disciplines of engineering science. The rotor component includes the blades for converting wind energy to an intermediate low speed rotational energy. The generator component includes the electrical generator, the control electronics, and most likely a gearbox component for converting the low speed rotational energy to electricity. The structural support component includes the tower for optimally situating the rotor component to the wind energy source.

Figure 1 : Wind Turbine

Figure 2 : Horizontal Axis Wind Turbine (HAWT)

The result of over a millennium of windmill development and modern engineering, today's wind turbines are manufactured in a wide range of vertical and horizontal axis types. The smallest turbines are used for applications such as battery charging or auxiliary power on boats: while large grid connected arrays of turbines are becoming increasingly important sources of wind power produced commercial electricity.

III. TYPES OF WIND MILLS

Wind turbines are classified, in the basis of their axis in which the turbine rotates, into horizontal axis and vertical axis wind turbines. Because of the ability of the horizontal axis turbines to collect the maximum amount of wind energy for the time of day and season and to adjust their blades to avoid high wind storms; they are considered more common than vertical-axis turbines. Turbines that used in wind farms for commercial production of electric power these days are usually three-bladed and pointed into the wind by computer-controlled motors. This type is produced by the most common wind turbines manufacturers.

Horizontal Axis Wind Turbine (HAWT):

Horizontal-axis wind turbines (HAWT) have the main rotor shaft and electrical generator at the top of a tower, and must be pointed into the wind as shown in figure. Small turbines are pointed by a simple wind vane, while large turbines generally use a wind sensor coupled with a servo motor. Most have a gearbox, which turns the slow rotation of the blades into a quicker rotation that is more suitable to drive an electrical generator. Since a tower produces turbulence behind it, the turbine is usually positioned Upwind of its supporting tower.

Turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds. Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted forward into the wind a small amount. Downwind machines have been built, despite the problem of turbulence (mast wake), because they don't need an additional mechanism for keeping them in line with the wind, and because in high winds the blades can be allowed to bend which reduces their swept area and thus their wind resistance. Since cyclical (that is repetitive) turbulence may lead to fatigue failures, most HAWT's are of upwind design. Turbines used in wind farms for commercial production of electric power are usually three-bladed and pointed into the wind by computer-controlled motors. These have high tip speeds of over 320 km/h (200 mph), high efficiency, and low torque ripple, which contribute to good reliability. The blades are usually colored white for daytime visibility by aircraft and range in length from 20 to 40 meters (66 to 131 ft) or more. The tubular steel towers range from 60 to 90 meters (200 to 300 ft) tall. The blades rotate at 10 to 22 revolutions per minute. At 22 rotations per minute the tip speed exceeds 90 meters per second (300 ft/s). A gear box is commonly used for stepping up the speed of the generator, although designs may also use direct drive of an annular generator. Some models operate at constant speed, but more energy can be collected by variable-speed turbines which use a solid-state power converter to interface to the transmission system.

Vertical axis wind turbines (VAWT):

Vertical-axis wind turbines (VAWT) have the main rotor shaft arranged vertically as shown in figure. One of the main advantages of this Vertical axis rotor is that they do not have to be turned into the wind stream as the wind direction changes. Also, the generator and gearbox can be placed near the ground, using a direct drive from the rotor assembly to the ground-based gearbox, improving accessibility for maintenance.

When a turbine is mounted on a rooftop the building generally redirects wind over the roof and this can double the wind speed at the turbine. If the height of a rooftop mounted turbine tower is approximately 50% of the building height it is near the optimum for maximum wind energy and minimum wind turbulence. Wind speeds within the built environment are generally much lower than at exposed rural sites, noise may be a concern and an existing structure may not adequately resist the additional stress.

Figure 3 : Vertical Axis Wind Turbine (VAWT)

IV. COMPOSITES

A composite material can be defined as a combination of two or more materials that results in better properties than those of the individual components, used alone. In contrast to metallic alloys, each material retains its separate chemical, physical and mechanical properties. The two constituents are reinforcement and a matrix. The main advantages of composite materials are their high strength and stiffness, combined with low density, when compared with bulk materials, allowing for a weight reduction in the finished part.

The reinforcing phases provide the strength and stiffness, in most cases, the reinforcement is harder, stronger, and stiffer than the matrix. The reinforcement is usually a fiber or a particulate. Particulate composites have dimensions. They may be spherical, platelets, or any other regular or irregular geometry. Particulate composites tend to be much weaker and less stiff than continuous fiber composites, but they are usually much less expensive. Particulate reinforced composites usually contain less reinforcement (up to 40 to 50 volume percent) due to processing difficulties and brittleness.

A fiber has a length that is much greater than its diameter. The length to diameter (l/d) ration is known as the aspect ratio and can vary greatly. Continuous fibers have long aspect ratios, while discontinuous fibers have short aspect ratio. Continuous fiber composites normally have a preferred orientation, while discontinuous fibers generally have a random orientation. Examples of continuous reinforcements include unidirectional, woven cloth, and helical winding, while examples of discontinuous reinforcements are chopped fibers and random mat. Continuous fiber composites are often made into laminates by stacking single Sheets of continuous fibers in different orientations to obtain the desired strength and stiffness properties with fiber volumes as high as 60 to 70 percent. Fibers produce high strength composites because of their small diameter; they contain far fewer defects (normally surface defects) compared to the material produced in bulk. As a general rule, the smaller the diameter of the fiber, the higher its strength, but often the cost increases as the diameter becomes smaller. In addition, smaller diameter high strength fibers have greater flexibility and are more amenable to fabrication process such as weaving or forming over radii. Typical fibers include glass, and carbon, which may be continuous or discontinuous.

The continuous phase is the matrix, which is a polymer, metal or ceramic, Polymers have low strength and stiffness, and metals have intermediate strength and stiffness but high ductility, and ceramics have high strength and stiffness but are brittle. The matrix continuous phase performs several critical functions, including maintaining the fibers in the proper orientation and spacing and protecting them from abrasion and environment. In polymer and metal matrix composites that form a strong bond between the fiber and the matrix, the matrix transmits loads from the matrix to the fibers through shear loading at the interface. In ceramic matrix composites the objective is often to increase the toughness rather that the strength and stiffness. Therefore, a low interfacial strength bond is desirable.

GLASS FIBER REINFORCED POLYSTER (GFRP)

There are many types of composite materials and several methods of classifying them. One method is based on the matrix materials which include polymers, metals and ceramics. The other method is based on the reinforcement phase which has the shape of fiber, particulate and whisker. Whiskers are like fibers but their length is shorter. The bonding between the particles, fibers or whiskers and the matrix is also very important. In structural composites, polymeric molecules known as coupling agent are used. These molecules form bonds with the dispersed phase and become integrated into the continuous matrix phase as well. The most popular type of composite material is the fiber-reinforced polyester composites, in which continuous thin fibers of one material such as glass, carbon or natural fibers are embedded in a polyester matrix. They are also called glass fiber reinforced polyester (GFRP), carbon fiber reinforced polyester (CFRP) and natural fiber reinforced polyester (NFRP). The objective is usually to enhance strength, stiffness, fatigue, resistance, or strength to weight ratio by incorporating strong and stiff fibers in a softer, more ductile matrix. The usages of fiber reinforced polyesters are in airplanes, electronics components, automotives, rail ways and wagon systems and sporting equipments. Beside their desired mechanical properties, their resistance to corrosion is also a tempting factor to use these composite in different areas. Although they are sensitive to UV light, heat and moisture environments, good maintenance could increase their life time. In this chapter different phases of FRPs, the mechanical relationships between different components of FRPs, the mechanism of degradation and aging of FRPs and application of them is discussing.

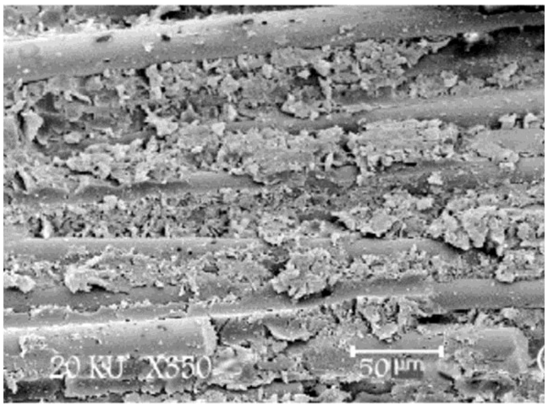


Figure 4 : Microstructure of glass fiber reinforced polyester composite.

The glass fibers are divided into three main classes E-glass, S-glass and C-glass. The E-glass is designated for electrical use and the S-glass for high strength. The C-glass is for high corrosion resistance, and it is uncommon for civil engineering application. Of the three fibers, the E-glass is the most common reinforcement material used in civil and industrial structures. It is produced from lime-alumina-borosilicate which can be easily obtained from abundance of raw materials like sand. The fibers are drawn into very fine filaments with diameters ranging from 2 to 13 X 10 -6 m. The glass fiber strength and modulus can degrade with increasing temperature. Although the glass material creeps under a sustained load, it can be designed to perform satisfactorily. The fiber itself is regarded as an isotropic material and has a lower thermal expansion coefficient than that of steel. There are also the other fiber glasses which are used for FRP reinforcement as well as; - A-glass, soda lime silicate glasses used where the strength, durability, and good electrical resistivity of E-glass are not required. - D-glass, borosilicate glasses with a low dielectric constant for electrical applications. - ECR-glass, calcium alumina silicate glasses with a maximum alkali content of 2 wt. % used where strength, electrical resistivity, and acid corrosion resistance are desired. - AR-glass, alkali resistant glasses composed of alkali zirconium silicates used in cement Substrates and concrete. - R-glass, calcium alumina silicate glasses used for reinforcement where added strength and acid corrosion resistance are required. - S-2-glass, magnesium alumina silicate glasses used for textile substrates or reinforcement in composite structural applications which require high strength, Modulus, and stability under extreme temperature and corrosive environments.

V. BUCKLING LOAD

Thin strictures subject to compression loads that haven't achieved the material strength limits can show failure mode is called buckling. Buckling is characterized by a sudden failure of structural member subjected to high compressive stress, where the actual compressive stress at the point of failure is less than the ultimate stresses that the material is capable of withstanding.

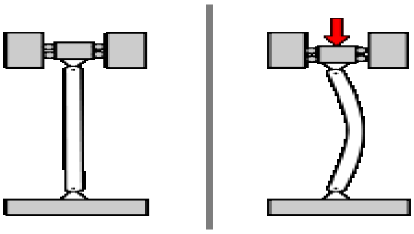


Figure 5 : Buckling Load

When a structure (subjected usually to compression) undergoes visibly large displacements transverse to the load then it is said to buckle. Buckling may be demonstrated by pressing the opposite edges of a flat sheet of cardboard towards one another. For small loads the process is elastic since buckling displacements disappear.

When the load is removed. Local buckling of plates or shells is indicated by the growth of bulges, waves or ripples, and is commonly encountered in the component plates of thin structural members. Buckling proceeds in manner which may be either:

- stable - In which case displacements increase in a controlled fashion as loads are increased, i.e. the structure's ability to sustain loads is maintained, or
- unstable - In which case deformations increase instantaneously, the load carrying capacity nose- dives and the structure collapses catastrophically.

Neutral equilibrium is also a theoretical possibility during buckling - this is characterized by deformation increase without change in load. Buckling and bending are similar in that they both involve bending moments. In bending these moments are substantially independent of the resulting deflections, whereas in buckling the moments and deflections are mutually inter-dependent - so moments, deflections and stresses are not proportional to loads. If buckling deflections become too large then the structure fails - this is a geometric consideration, completely divorced from any material strength consideration. If a component or part thereof is prone to buckling then its design must satisfy both strength and buckling safety constraints - that is why we now examine the subject of buckling.

1) Used Material Properties:

Properties		Carbon Fibre
Young's Modulus (GPa)		388
Poisson's Ratio		0.358
Density (kg/m^3)		1600
Tensile Strength (GPa)		4.1

VI. MODELLING

Introduction to Airfoil

An airfoil-shaped body moved through a fluid produces an aerodynamic force. The component of this force perpendicular to the direction of motion is called lift. The component parallel to the called drag. Subsonic flight airfoils have a characteristic shape with a rounded leading edge, followed by a sharp trailing edge, often with asymmetric direction of motion is curvature of upper and lower surfaces. Foils of similar function designed with water as the working fluid are called hydrofoils

NACA profiles

The NACA airfoils are airfoil shapes for small power wind turbine blade developed by the National Advisory Committee for Aeronautics (NACA). The shape of the NACA airfoils is described using a series of digits following the word "NACA". The parameters in the numerical code can be entered into equations to precisely generate the cross-section of the airfoil.

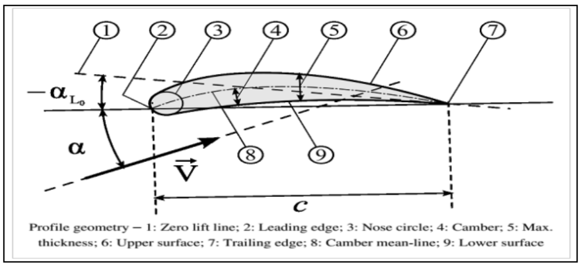


Figure 6 : Profile Geometry

Five-digit series

The NACA five-digit series describes more complex airfoil shapes:

1. The first digit, when multiplied by 0.15, gives the designed coefficient of lift (CL)
2. Second and third digits, when divided by 2, give, the location of maximum camber as a distance from the leading edge (as per cent of chord).
3. Fourth and fifth digits give the maximum thickness of the airfoil (as per cent of the chord).

For example, the NACA 77887 airfoil would give an airfoil with maximum thickness of 8% chord, maximum camber located at 7% chord, with a design lift coefficient of 0.15.

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.

For example, 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. 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.

1-series

A new approach to airfoil design pioneered in the 1930s in which the airfoil shape was mathematically derived from the desired lift characteristics. Prior to this, airfoil shapes were first created and then had their characteristics measured in a wind tunnel. The 1-series airfoils are described by five digits in the following sequence:

1. The number "1" indicating the series
2. One digit describing the distance of the minimum pressure area in tens of percent of chord.
3. A hyphen.

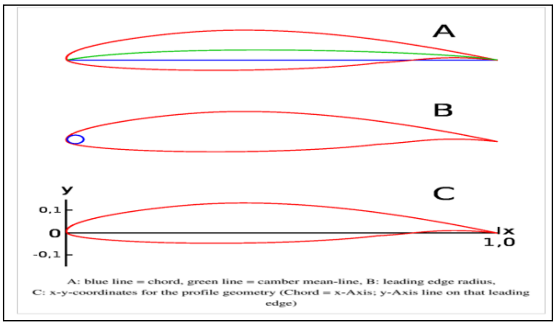


Figure 7: Airfoil profiles

4. One digit describing the lift coefficient in tenths.
5. Two digits describing the maximum thickness in percent of chord.

For example, the NACA 16-123 airfoil has minimum pressure 60% of the chord back with a lift coefficient of 0.1 and maximum thickness of 23% of the chord.

6-series

An improvement over 1-series airfoils with emphasis on maximizing laminar flow. The airfoil is described using six digits in the following sequence:
1. The number "6" indicating the series.
2. One digit describing the distance of the minimum pressure area in tens of percent of chord.
3. The subscript digit gives the range of lift coefficient in tenths above and below the design lift coefficient in which favorable pressure gradients exist on both surfaces
4. A hyphen.
5. One digit describing the design lift coefficient in tenths.
6. Two digits describing the maximum thickness as percent of chord.

For example, the NACA 612-315 a=0.5 has the area of minimum pressure 10% of the chord back, maintains low drag 0.2 above and below the lift coefficient of 0.3, has a maximum thickness of 15% of the chord, and maintains laminar flow over 50% of the chord.

7-series

Further advancement in maximizing laminar flow achieved by separately identifying the low pressure zones on upper and lower surfaces of the airfoil. The airfoil is described by seven digits in the following sequence:

1. The number "7" indicating the series.
2. One digit describing the distance of the minimum pressure area on the upper surface in tens of percent of chord.
3. One digit describing the distance of the minimum pressure area on the lower surface in tens of percent of chord.
4. One letter referring to a standard profile from the earlier NACA series.
5. One digit describing the lift coefficient in tenths.
6. Two digits describing the maximum thickness as percent of chord.
7. "a=" followed by a decimal number describing the fraction of chord over which laminar flow is maintained. a=1 is the default if no value is given.

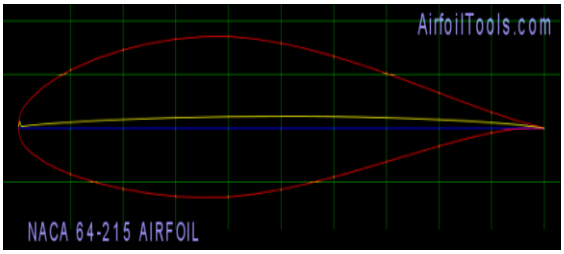
For example, the NACA 712A315 has the area of minimum pressure 10% of the chord back on the upper surface and 20% of the chord back on the lower surface, uses the standard "A" profile, has a lift coefficient of 0.3, and has a maximum thickness of 15% of the chord.

8-series

Supercritical airfoils designed to independently maximize airflow above and below the wing. The numbering is identical to the 7-series airfoils except that the sequence begins with an "8" to identify the series.

NACA 63-215 profile:

Details of aerofoil profile



Max thickness 15% at 34.9%., Max camber 2.2% at 50% chord

Figure 8 : NACA 63-215 airfoil profile

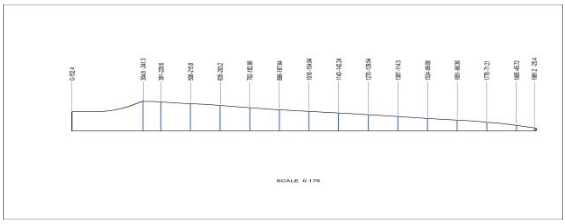


Figure 9: Blade Basic Drawing

Blade Model Developed in Pro/E:

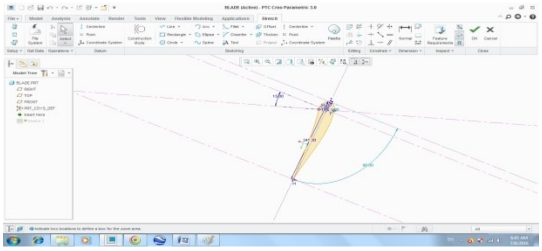


Figure 10: Blade profile

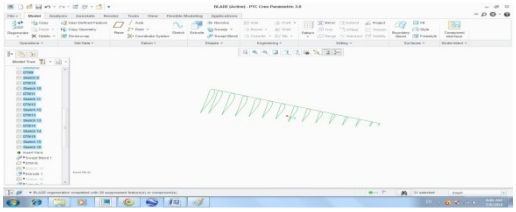


Figure 11: Blade profile way

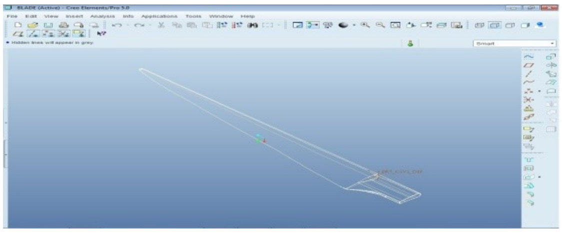


Figure 12: wire frame

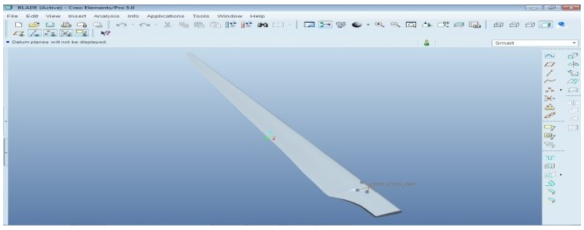
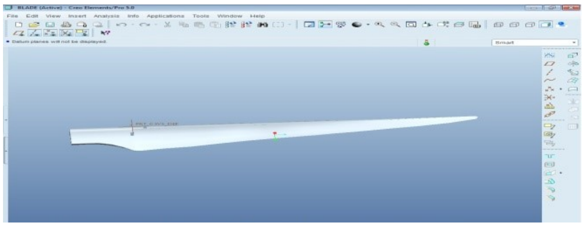


Figure 12: a: pro-E solid model



(b): pro-E solid model

VII. ANALYSIS IN ANSYS

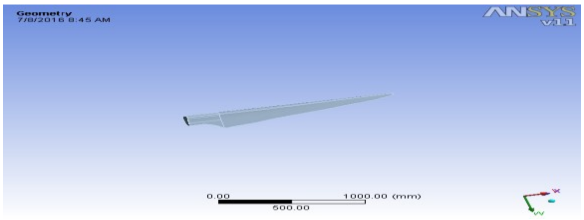


Figure 13: ANSYS- Imported geometry

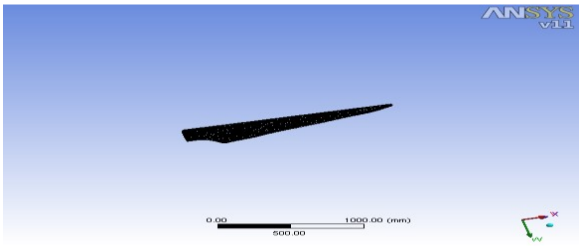


Figure 14: ANSYS- Meshing

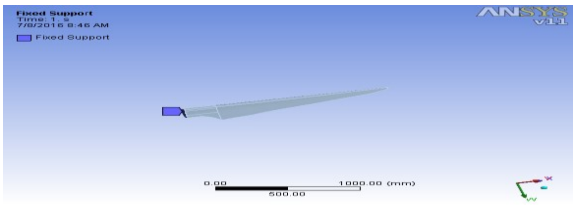


Figure 15: ANSYS- Fixed support

Load 10000N

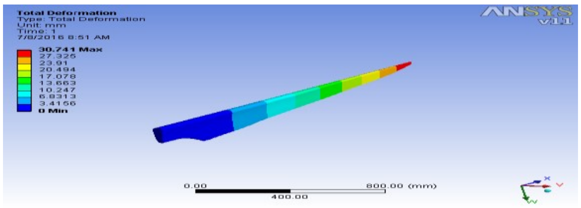


Figure 26 Total Deformation

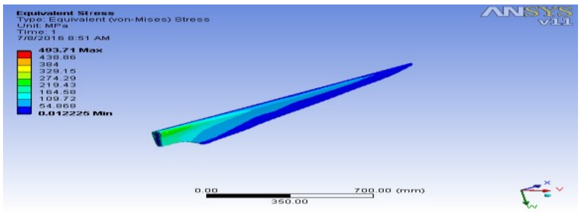


Figure 17: Equivalent stress

Load 6000N

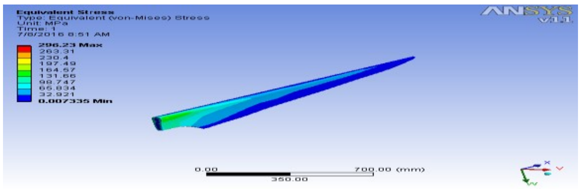


Figure 18: Equivalent stress

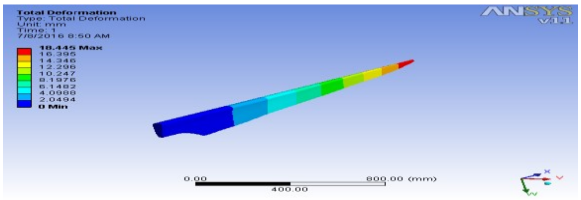


Figure 19: Total Deformation

Load 5000N

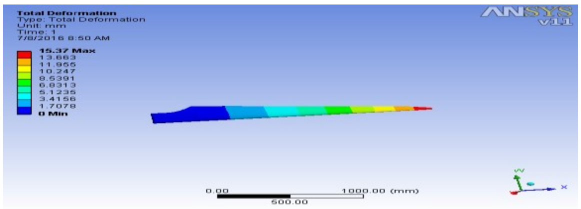


Figure 20: Total Deformation

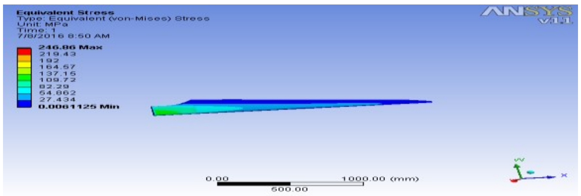


Figure 21: Equivalent stress

Load 4000N

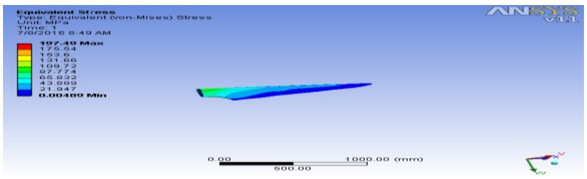


Figure 22: Equivalent stress

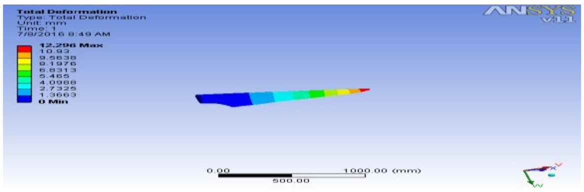


Figure 23: Total Deformation

Load 3000N

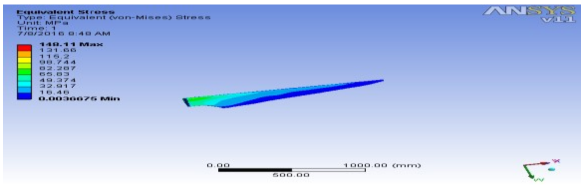


Figure 24 : Equivalent stress

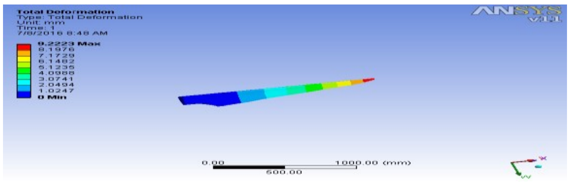


Figure 25: Total Deformation

VIII. RESULTS AND DISCUSSIONS

A Horizontal Axis Wind Turbine Blade has been Analyzed using Carbon Fiber by Static structural and modal analysis Process. The Aerofoil design of NACA-63215 has been considered.

The Model is created using Pro-E with NACA-63215 blade profile of a small Wind Turbine blade and, it is analyzed through ANSYS 11 by applying different loads such as 3000N,4000N,5000N,6000N,10000N in the vertical direction to determine Structure behavior's. Further the Deformation is identified based on the simulation results through ANSYS 11.

Table : Load Vs Deformation

S.no	Applied load(N)	Equivalent stress(MPA)	Total Deformation (MM)
1	3000	148.11	9.2223
2	4000	197.49	12.296
3	5000	246.86	15.37
4	6000	296.23	18.445
5	10000	493.71	30.741

IX. CONCLUSION

The work aims at Fabrication of Horizontal Axis Wind Turbine Blade, Buckling Effect Analysis of a Wind Turbine Blade which is main potential element in the Wind Turbines. The Wind Turbine Blades are subjected to high torque and Buckling Load which are the factors for the failures of the Blade. On this work we analyzed the Buckling Load failures and described along the Blade, and found that it can sustain up to 6700N of Load, Hence it can be helpful for the determination of various failures of Wind Turbine Blades.

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