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Analysis of Wind Turbine Blade Prototype using ANSYS

Mr. Aditya Arvind Yadav[1], Ms. Ketki Suryakant Deshmane[2], Mr. Niranjan Nitin Oturkar[3], Mr. Shreyash Shashikant Wadekar[4]

[1]*Student, M. Tech (Energy Technology), Department of Technology Shivaji University, Kolhapur, Maharashtra, India.*
[2]*Student, M. Tech (Energy Technology), School of Energy Studies, SPPU, Pune, Maharashtra, India.*
[3]*Student, M. Tech (Energy Technology), School of Energy Studies, SPPU, Pune, Maharashtra, India.*
[4]*Student, M. Tech (CAD/CAM/CAE Engineering), MIT World Peace University, Pune, Maharashtra, India.*

ABSTRACT:
Wind turbine blade undergoes variable static and dynamic during its actual life cycle. Modern wind turbine blades are designed to withstand various dynamic loading conditions. Wind turbine blades undergoes failure in combination of flap wise and edge wise. For optimum design of wind turbine blades, there should be proper selection of materials for turbine blades. Wind turbine blades are manufactured by using composite materials such as epoxy resin, and various other carbon fiber reinforced plastics. In this paper wind turbine blade prototype is analyzed using finite element analysis (ANSYS) for various loading conditions.

***Key Words*:** Wind Turbine Blade, ANSYS, Variable Loading, Finite Element Analysis.

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I. INTRODUCTION

The structural design of wind turbine blades for horizontal axis wind turbine is a complicated process that requires the keen knowledge of materials, modelling and testing methods. A wind turbine blade must be designed against undesired aero-elastic phenomena and failures for a great variety of aerodynamic load cases and environmental conditions. Thus, the design process involves a number of different areas, such as knowledge of the external loads originating from wind and gravity and knowledge of the performance, the strength and the endurance of the full structure and of the basic materials used. The goal of the design process is to ensure that the wind turbine blade will function safely for its design life. The design lifetime of modern wind turbines is normally for 20 years and number of rotations is of the order 108 to 109, which is approximately two orders of magnitude higher than the load cycles experienced by composite materials used in other highly loaded structural applications such as helicopter blades.

The main trends in the development of wind turbine blades are towards longer and optimized blades; this is particularly the case for offshore wind turbines. The weight of a large wind turbine blade also increases the loads on the rotor input shaft and bearings as well as the wind turbine tower and mechanisms used to control yaw and pitch of the blades. Weight savings is therefore of great importance, and significant efforts are devoted by wind turbine companies in the selection of materials. To ensure that the blades can meet the required design life, the materials must have high stiffness, be fatigue resistant, and be damage tolerant. [1]

The orientation of the shaft and rotational axis determines the first classification of the wind turbine. A turbine with a shaft mounted horizontally parallel to the ground is known as a horizontal axis wind turbine or (HAWT). A vertical axis wind turbine (VAWT) has its shaft normal to the ground as shown in figure below. [2]

- **Loads on wind turbine blade:**

The rotor blade is loaded in a combination of flap wise and edgewise loads. Basically, the blades are exposed to three different load sources. One is the wind load that through the lift and drag on the aerodynamic profile loads the blade primarily in bending flap wise. The second load source is the gravity varying edgewise from tension/compression in leading edge and compression/tension in trailing edge. This is the main reason for the edgewise fatigue bending of the blade. Finally, the blades are exposed to centrifugal forces during the rotation. However, these longitudinal loads are relatively low and often not taken into account in the design.

Furthermore, the design loads are divided into static loads and cyclic loads. However, the blades are subjected to various environmental loadings. [1]

- **Blade Construction:**

Modern wind turbine blades are structurally advanced constructions utilizing composite laminates, sandwich core materials, gelcoat films and adhesive joints. Although there are a variety of wind turbine designs, the functionality of wind turbine blades from a structural viewpoint can be understood by considering the blade as a load-carrying beam (spar) enclosed by a shell.

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The primary purpose of the shell is to give the blade an aerodynamic shape, creating the aerodynamic forces that make the wind turbine blade to rotate and thus extracts energy from the wind to make electrical power. The aerodynamic forces are transmitted to the wind turbine hub through a load-carrying beam within the blade. The load-carrying beam can be made as a box girder, sometimes called the main spar, or as laminates in the aero shell supported by webs. Figure 2 shows a sketch of the cross section of a typical wind turbine blade. [1]

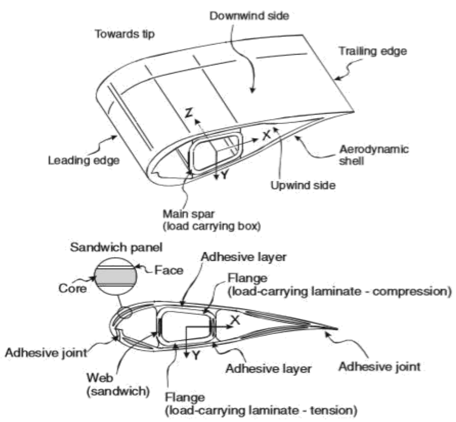

Figure 1. Terminology and Structural parts of wind turbine blade.

- **Materials: -**

Materials used for wind turbine blades must be low density and possess high strength, fatigue resistance and damage tolerance. Large parts of the blades are made of composite materials, i.e. materials that consist of more constituents, e.g. long aligned fibers embedded in a continuous phase called the matrix material. The shells that define the aerodynamic blade profile are typically constructed using polymer matrix composites (PMCs) (e.g. glass fiber reinforced polyester) and sandwich structures consisting of PMC face sheets and lightweight closed-cell polymer foam or end-grain balsa wood cores. The box girder is constructed using glass fiber composites or carbon fiber composites.

Since most wind turbine blades are bonded together, the adhesives used to join blade segments will have a direct influence on the reliability of the blade. The adhesives utilized in blades are primarily epoxy, polyurethane and methacrylate-based adhesives. The quality and mechanical properties (e.g. strength, creep, defect tolerance) of blade adhesives are critical since they are used to bond very large areas of the blade aero shells and box girder and are subjected to complex cyclic loading histories. [1]

II. LITERATURE OUTCOMES: -

1. Failure modes of wind turbine blades

Wind turbine blades can fail by a number of failure and damage modes. Obviously, the details of damage evolution will differ from one blade design to another. However, experience shows that, irrespective of specific blade design, several types of material-related damage modes can develop in a blade. In some instances, these damage modes can lead to blade failure or require blade repair or replacement.

The load-carrying laminates in the blade aero shell and box girder are made of composite materials and adhesive joints that are damage tolerant. Damage tolerant behaviour implies that the first mode of damage does not lead directly to failure, but propagates in a stable manner and gives detectable changes so that the damage can be detected before it reaches a critical size where it leads to failure. Therefore, failure of wind turbine blades does not occur as a direct result of crack initiation along an interface or by progressive damage to the fibres and matrix. Rather, global failure of a wind turbine blade involves the progression of several damage mechanisms that can act in series or in parallel. [1]

2. Materials Properties: -

a. Elastic properties: -

Modern wind turbine blades are three-dimensional structures made by the use of several different materials and the elastic properties and thermal–physical constants, such as thermal expansion coefficient, of materials influence the damage developed in a blade. As a result, the stress field depends on the elastic properties of the materials used. For isotropic materials, the elastic properties are the Young's modulus, E, and the Poisson's ratio. Orthotropic materials, such as composite laminates with aligned continuous fibres, have different elastic properties in different directions. Therefore, the elastic properties must be related to a coordinate system. It is convenient to use a global x – y – z coordinate system and a local coordinate system that follows the direction of the fibres. [1]

Table 1. Classification of various materials used in wind turbine blades.

Isotropic materials	Orthotropic materials
Adhesives	Glass fiber/polyester composites
Steel	Carbon fiber/epoxy composites
Polymer foam	Wood
Gelcoat	Bamboo

b. Strength and fracture toughness properties

Damage and failure modes are described by various parameters that may be stress based, energy-based or length-based (e.g. critical defect length). A damage mode that involves a distributed damage zone is usually described in terms of a critical stress value, i.e. by a maximum stress criterion (tensile or compressive strength). Crack growth along a fracture plane is a localized phenomenon. The onset of crack growth can be described in terms of a maximum stress intensity this can be done by a cohesive law (a traction-separation law). The area under the traction-separation law is the work of separation.

These concepts are applicable to static failure factor (fracture toughness) or a maximum energy release rate (fracture energy). A crack experiencing fiber bridging requires modeling of the bridging fibers. [1]

c. Overview of Blade Damage:

In addition to the various structural loading effects, wind turbine blades can also be subjected to lightning strikes, physical impacts and damaging surface erosion conditions whilst in operation. In certain rare but dramatic cases, a particular event can cause the total failure of a blade almost immediately; a powerful lightning strike or an extreme wind loading that leads to a rotating blade hitting the tower for example. Operators of wind farms take measures to minimize exposure of their structural assets to the full effect of storm conditions when these are forecast. But more commonly, over the course of a normal 25-year service life, it is expected that the composite material in a wind turbine blade will accumulate some signs of damage.

Blades are the most vulnerable parts of a wind turbine with respect to lightning. As every turbine can expect to experience a significant number of strikes during service life, all blades have a lightning protection system to reduce the effect of such strikes when they occur. Despite this it is common to observe scorching damage and cracking around the lightning attraction point of a blade as well as spar rupture, separation and surface tearing in more extreme cases.[3]

III. MATERIALS AND METHODS

The finite element method (FEM) is a mathematical technique for setting up and solving systems of partial differential (or integral) equations. In engineering, the finite element method is used to divide a system whose behavior cannot be predicted using closed form equations into small pieces, or elements, whose solution is known or can be approximated. The finite element method requires the system geometry to be defined by a number of points in space called nodes. Each node has a set of degrees of freedom (temperature, displacements, etc.) that can vary based on the inputs to the system. These nodes are connected by elements that define the mathematical interactions of the degrees of freedom (DOFs). For some elements, such as beams, the closed form solution is known. For other elements, such as continuum elements, the interaction among the degrees of freedom is estimated by a numerical integration over the element. All individual elements in the model are combined to create a set of equations that represent the system to be analyzed. Finally, these equations are solved to reveal useful information about the behavior of the system.[6] – [7]

IV. RESULT AND DISCUSSION

Basic Procedure for Finite Element Analysis:

There are 10 basic steps in any finite element analysis. First, the solid model geometry is created, the element type(s) and material properties are defined, and the solid model geometry is meshed to create the finite element model. In ANSYS, these steps are performed in the Preprocessor (PREP7). Next, loads and constraints are applied, solution options are defined, and the problem is solved. These steps are performed in the Solution processor (SOL). After the solution is ready, the results are plotted, viewed, and exported in one of the postprocessors (POST1 or POST26). Finally, the results are compared to first-order estimates, closed-form solutions, mathematical models, or experimental results to ensure that the output of the program is reasonable and as expected. [4]& [8]

Procedure:
1. Define the Solid Model Geometry
2. Select the Element Types.
3. Define the Material Properties
4. Mesh
5. Define the Boundary Conditions
6. Define the Loads
7. Set the Solution Options
8. Solve
9. Plot, View, and Export the Results
10. Compare and Verify the Results

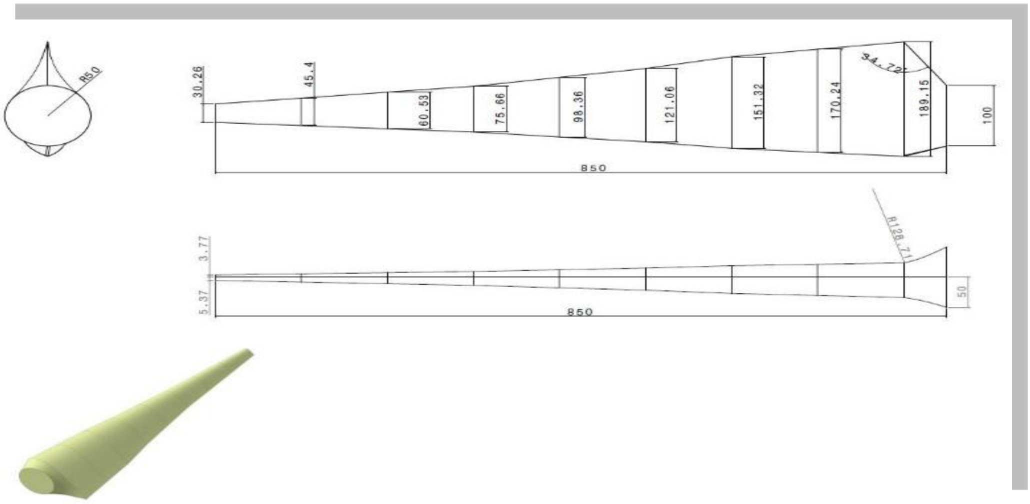

Figure 3. Detail drafting of wind turbine blade

The software approach for 3D modelling was done in SOLIDWORKS and for simulation ANSYS was used.

The actual working of the wind turbine: -
Cut-in speed = 3.5m/s
Rated wind speed = 11.5 m/s
Cut-out speed = 20.0 m/s
Survival wind speed = 59.5 m/s
The detail of loading condition is as per given following standard: -

WINDSPEED TO PRESSURE CONVERSION CHART			
Metres/Second m/s	Kilometres/Hour km/h	Miles/Hour mph	Pascals Pa
6.38	22.97	14.28	25
9.03	32.50	20.19	50
11.06	39.80	24.73	75
12.77	45.96	28.56	100
15.63	56.27	34.97	150
18.06	65.00	40.39	200
20.18	72.66	45.16	250
22.11	79.60	49.46	300
23.88	85.97	53.43	350
25.53	91.91	57.11	400
27.08	97.47	60.58	450
28.54	102.76	63.85	500
31.27	112.56	69.94	600
33.77	121.57	75.54	700
36.11	130.00	80.78	800
38.30	137.88	85.67	900
40.31	145.13	90.18	1000
42.34	152.42	94.71	1100
44.22	159.19	98.92	1200
46.03	165.72	102.97	1300
47.77	171.96	106.85	1400
49.44	178.00	110.60	1500
51.06	183.83	114.23	1600
54.16	194.97	121.15	1800
57.09	205.53	127.71	2000
59.87	215.60	133.94	2200
62.54	225.10	139.90	2400

igure 4. Wind speed to pressure conversion chart [5]

The material properties of the glass fiber is as follows: -

Properties of Outline Row 3: E-Glass Fiber

	A	B	C
1	Property	Value	Unit
2	Density	2.55E-06	kg m^-3
3	Isotropic Elasticity		
4	Derive from	Young's Modulus an...	
5	Young's Modulus	7.2E+10	Pa
6	Poisson's Ratio	0.21	
7	Bulk Modulus	4.1379E+10	Pa
8	Shear Modulus	2.9752E+10	Pa
9	Tensile Yield Strength	1.95E+09	Pa
10	Compressive Yield Strength	4E+09	Pa

Figure 5. Materials properties of wind turbine prototype

The details of the ANSYS report is as follows: -
For
Survival wind speed = 59.5 m/s
Therefore, Pressure applied = 2200 Pa

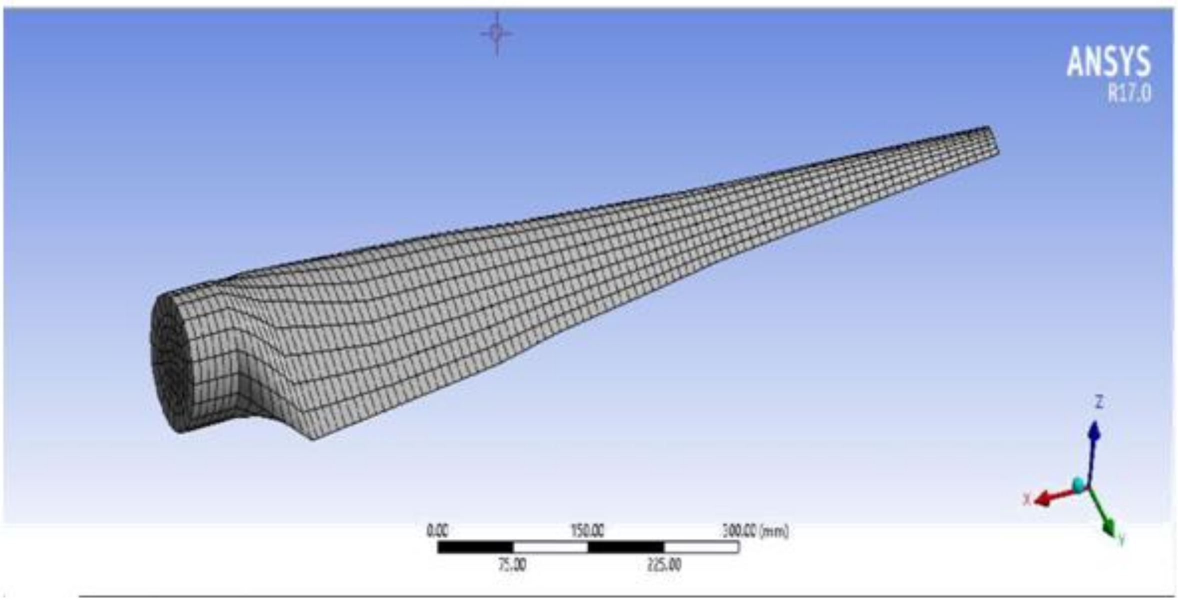

Figure 6. Detail meshing of the wind turbine blade

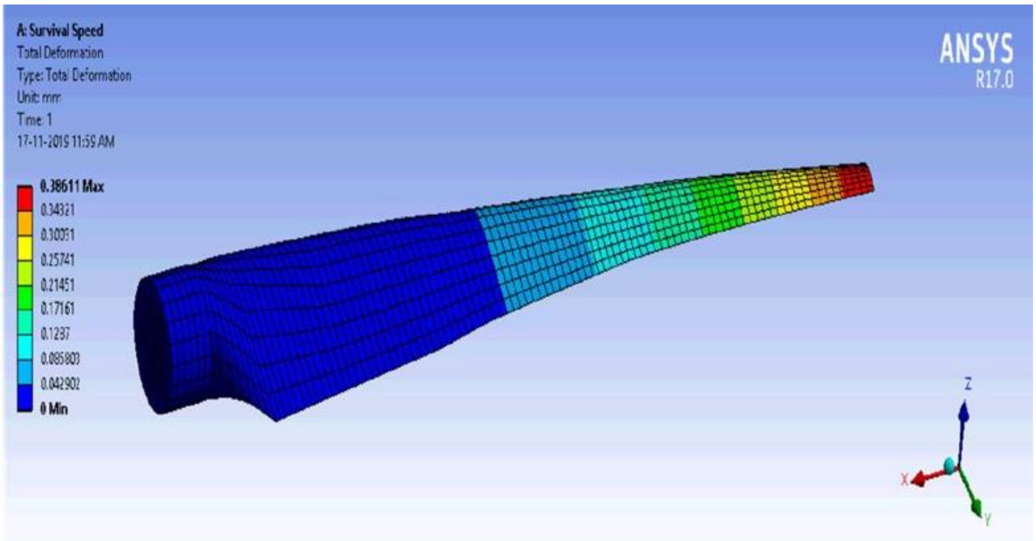

Figure 7. Total Deformation at survival speed.

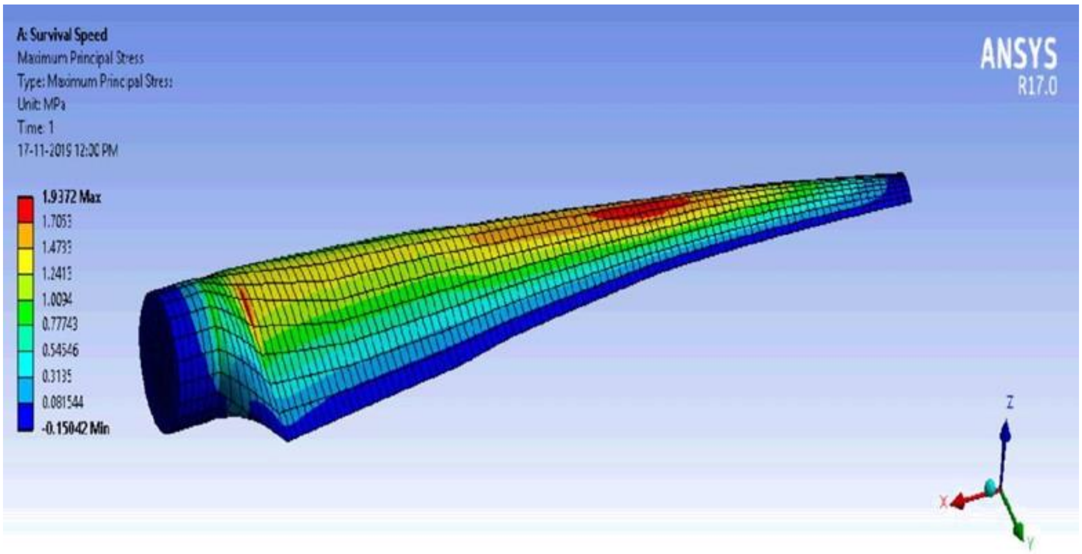

Figure 8. Maximum Principal Stress at survival speed.

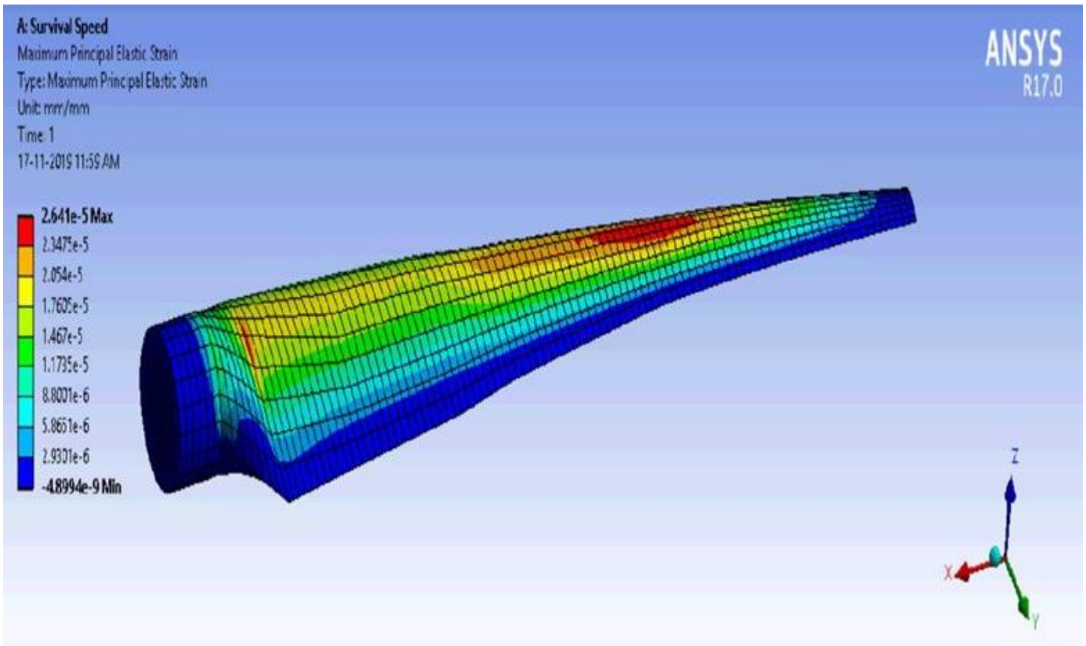

Figure 9. Maximum Principal Elastic Strain at survival speed.

The details of the ANSYS report is as follows: -
For
As cut out wind speed = 20 m/s
Therefore, Pressure applied = 250 Pa

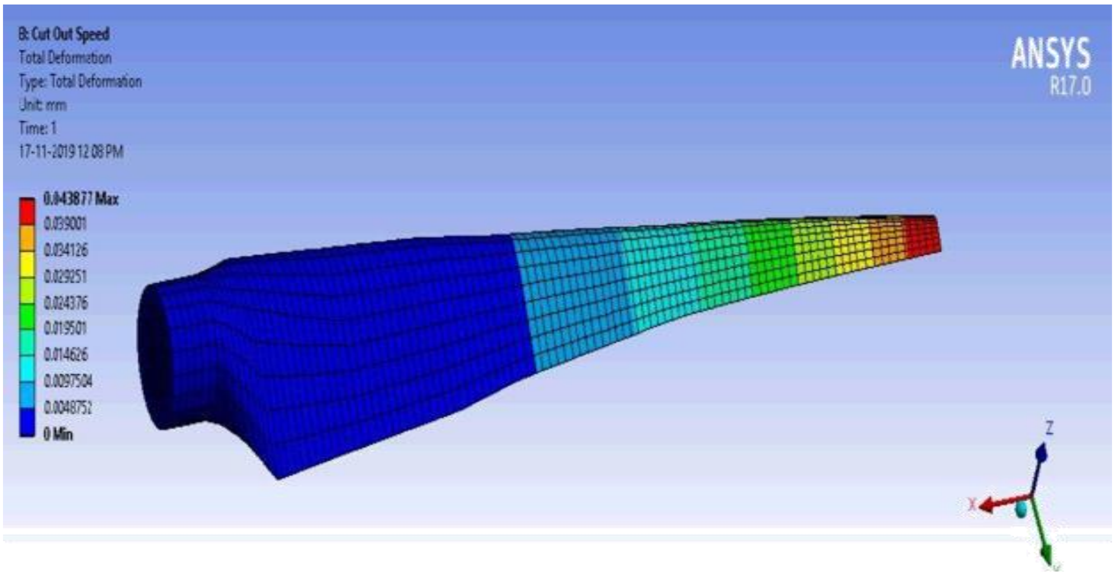

Figure 10. Total Deformation at cut out speed

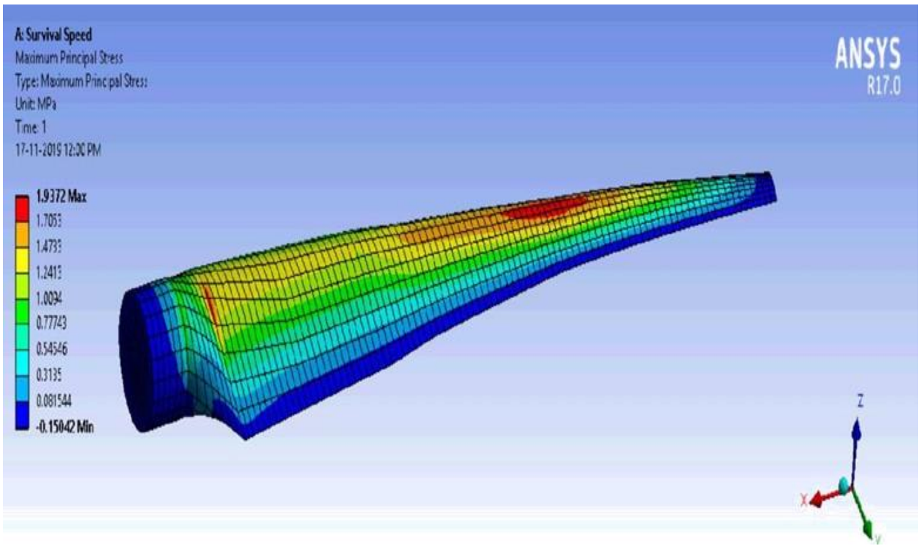

Figure 11. Maximum Principal Stress at Cut out speed

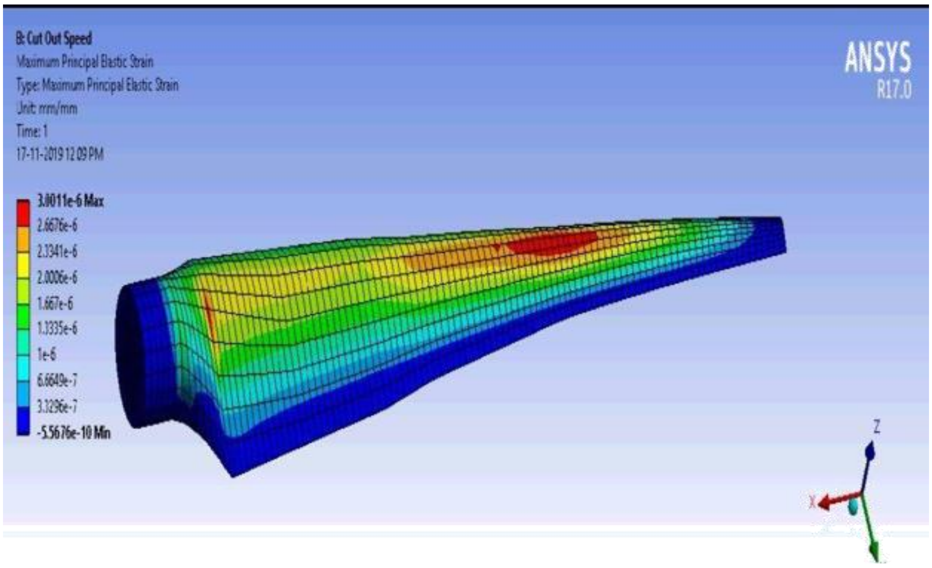

Figure 12. Maximum Principal Elastic Strain at cut out speed.

V. SUMMARY

The detail result of the wind turbine blade is as given below:

Table 3. Detail result of loading conditions for deformation, stress and Strain for Survival Speed

Sr. No	Mechanical properties	Loading Condition	Minimum value	Maximum value
1	Total deformation	2200 Pa	0mm	0.38611
2	Maximum Principal Stress	2200Pa	-0.15042 MPa	1.9372 MPa
3	Maximum Principal Strain	2200 Pa	-4.8×10^{-9}	2.64×10^{-5}

Table 2. Detail result of loading conditions for deformation, stress and Strain for Cut out Speed

Sr. No	Mechanical Properties	Loading Conditions	Minimum value	Maximum value
1	Total deformation	250Pa	0mm	0.0438 mm
2	Maximum Principal Stress	250Pa	-0.0170MPa	0.22014 MPa
3	Maximum Principal Strain	250Pa	-5.5×10^{-10}	3.00×10^{-6}

VI. CONCLUSION

The results obtained from the ANSYS reports states that for maximum loading conditions i.e. 250 Pa and 2200 Pa wind pressures following range was obtained: -

Table 4. Range of data obtained from ANSYS report

Sr. No	Mechanical properties	Range
1.	Total deformation	0.0438 to 0.38611 mm
1.	Maximum Principle Stress	0.22014 to 1.9372 MPa
3.	Minimum Principle Stress	3.00×10^{-6} to 2.64×10^{-5}

Total deformation observed for cutout and survival speed ranges from 0.04381 to 0.38611 mm, for 250 and 2200 Pa loading conditions. The glass fiber material loses its elastic properties at survival speed range i.e. at 2200 Pa, and it begins to behave like a brittle material, thereby increasing the rate of failure of the wind turbine blade. As the value of maximum principal strain decreases for higher loading condition, the material begins to lose its elastic properties, and fails due to fracture. Further dealing with materials the use of composite materials such as glass fiber along with vinyl esters provides more strength and the elastic limit of the material also increases consequently. The major area of concern is to make the material in more elastic limit rather than in plastic limit. For excessive loading conditions the materials show direct deformation to the load respectively.

REFERENCES

[1]. T. Wei. Ecopath with Ecosim: linking fisheries and ecology Why ecosystem modeling in fisheries?," WIT Trans. State Art Sci. Eng: 2009; (34) ; 1755–8336.
[2]. P. S. Premkumar et al.Uncertainty and Risk Assessment in the Design Process for Wind. Journal of Adv. Research Dyn. Control Syst:2015; (9); V07AT30A013.
[3]. L. Mishnaevsky, K. Branner, H. N. Petersen, J. Beauson, M. McGugan, and B. F. Sørensen. Materials for wind turbine blades: An overview. Materials (Basel): 2017; (10); 1–24.
[4]. M. K. Thompson and J. M. Thompson. Introduction to ANSYS and Finite Element Modeling. ANSYS Mech. APDL Finite Elem. Anal: 2017; 1–9.
[5]. Cyclone Glass product rating Now available high-performance Storm Shield 5. 75 kPa to & cost; 1800.
[6]. Ketki M, Deshmane S, Yadav AA, Ingawale SM. Wind data Estimation of Kolhapur district using Improved Hybrid Optimization by Genetic Algorithms (iHOGA) and NASA Prediction of Worldwide Energy Resources (NASA Power). 2020;2530 –2538.
[7]. Sagare PM, Arvind Yadav A, Mahadev Pol A, Deepak Mane P. Recycling Plastics to Automobile Fuel. Int J Res Eng Appl Manag. 2018;
[8]. Sagare PM, Yadav AA, Manglekar S, Mahadev A, et al. Finite Element Analysis of Piston using Aluminum Alloys on ANYSYS. Vol. 4, IJSTE-International Journal of Science Technology & Engineering |. 2018.