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Finite Element Analysis of Wind Turbine Blade

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Abstract—In the wake of drastic depletion of conventional energy sources, there is a high demand for the non- conventional alternatives. Wind turbines provide an alternative way of generating energy from the power of wind. At windy places where the wind speeds are so high, sufficient amount of energy can be harnessed by making use of wind turbines. The blades of such turbines are so designed that they generate lift from wind and thus rotate. This work explores the finite element analysis of a Wind Turbine Blade using ANSYS software. Finite Element Analysis is a numerical method of deconstructing a complex system into very small pieces (of designated size) called elements. In this work, the wind turbine blade is modelled in CATIA V5 and analysed for five different blade materials viz., Structural steel, Stainless steel, Titanium Alloy, Aluminium Alloy, T-Graphite Epoxy. The aim of the analysis is to validate the strength of the blade and compare the above materials to select the best material for the wind turbine blade.
Keywords— Blade Design; CATIA V5; NACA 2412; finite element analysis, ANSYS, CATIA, Wind Turbine.

I. INTRODUCTION

Blade is the key component to harness wind energy. In this paper, finite element analysis is conducted on a wind turbine blade with NACA 2412 aerofoil design. The paper studies the analysis of an existing wind turbine blade. [1]The blade optimization is carried out by considering parameter like shapes of aerofoil profile, stresses and deformation on blade. When designing a wind turbine, the aim is to attain the highest possible power output under particular atmospheric conditions and this depends on the shape of the blade as well as on its material. The dynamic and mechanical properties of a wind turbine can be modified by changing the composite material of the blade. Hence emphasis is given on the material of the blade. The results of analysis of different material are compared to evaluate the best possible one suited for practical application.

II. LITERATURE REVIEW

A detailed work on the Structural Analysis and Numerical Simulation of composite wind turbine blade using Glass- Epoxy as the material is shown in [2]. The author, by means of full scale test, has observed the ovalization of the load carrying box girder. A FE-model of the entire blade was prepared; the boundaries to a more detailed model were extracted and calibrated based on full-scale test measurements.

A probabilistic model for analysis of the safety of a wind turbine blade against failure in ultimate loading is presented by Patricio Andres Lillo Gallardo. In his work, he considered only the failure in flap wise bending during the normal operation condition of the wind turbine. The model is based on an extreme analysis of the load response process in conjunction with a representation of the governing tensile strength of the blade material. The probability of failure in flap wise bending of the blade is calculated by means of a first order reliability method, and contributions to this probability from all local maxima of the load response process over the operational life are integrated. Author [3] took the problem of the multi-criteria optimum design of wind turbine blades.

III. NUMERICAL ANALYSIS

All the airfoils in the NACA four-digit airfoil family [4] are defined by a series of four numerical digits, i.e. 2412. The first digit is the maximum value of the mean line in hundredths of the chord and is represented in the following equations with the letter m. The second number represents the position on the chord of the maximum mean line in tenths of the chord and is represented with the letter p. The last two numbers designate the maximum thickness of the airfoil in hundredths of the chord and are represented by t. Therefore, the airfoil 2412 tells us that the airfoil has a maximum mean line value of two hundredths of the chord length at a position four tenths the chord from the front of the airfoil and a maximum thickness of twelve hundredths the chord length. The NACA four-digit wing sections are based upon a set of geometric equations which makes this family of airfoils easy to derive by finding a set of coordinates that define the upper and lower surfaces of the airfoil. These equations will define the coordinates of the 8 surfaces for a given airfoil as percentages of the chord. When an analysis is to be conducted on an airfoil with a chord lengths not equal to one, the coordinates for the airfoil must first be found for a chord length of one and then multiply the coordinates, both x

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and y, by the desired chord length. The coordinates for the upper surface can be found with the following equations:

$$x_u = x - y_t sin\theta$$
$$y_u = y_t + cos\theta \tag{1}$$

Likewise the lower surface coordinates can be found be equation:

$$x_t = x + y_t sin\theta$$
$$y_t = y_c - cos\theta \tag{2}$$

where x is the position along the chord, yt is the corresponding thickness distribution and θ is the angle between the previous point and the current point. When NACA first began trying to determine the best geometry for wings, they looked at the Clark Y and Gottingen 398 which were two of the most successful wing designs at the time. They found that when the chamber was removed, that the effective thickness distribution of the two wings was nearly the same. Therefore, the thickness distribution for the four-digit wing sections was defined off the geometry of those current wing sections and is defined by the equation:

$$\pm y_t = \frac{t}{0.20}\left(0.29690\sqrt{x} - 0.1260\,x - 0.35160x^2 + 0.28430x^3 - 0.10150x^4\right) \tag{3}$$

The leading edge radius of the four-digit aerofoils is defined by the equation:

$$r_t = 1.1019t^2 \tag{4}$$

where the centre of the circle this radius defines is located at 0.05 percentage of the chord on the mean line. The chamber of an air foil is defined by the amount of curve in the mean line. The mean line is defined by two parabolic arcs tangent to the position of the maximum mean-line ordinate. The equations that define the mean line are:

$$y_c = \frac{m}{p^2}(2px - x^2) forward\ of\ maximum\ ordinate \tag{5}$$

$$y_c = \frac{m}{1-p^2}[(1-2p) + 2px - x^2]\ after\ of\ maximum\ ordinate \tag{6}$$

Through the use of equations 1-6 any number of four-digit aerofoil coordinates for the upper and lower surfaces can be defined.

IV. COMPUTATIONAL METHODS

The finite element method (FEM) is very useful and has mostly been used in the development of wind turbine blades. The FE simulation usually predicts the global stresses with high quality accuracy. Local deformations and stresses are often difficult to predict. And hence only a little detailing has been included in this work. Because the highly localised deformations and stresses can be nonlinear, while the global response appears linear for relatively small deflections.[4] Another reason is that the global behaviour can be represented by a relatively simple model, while a computationally expensive 3D solid model may be necessary to predict this localised behaviour.[5] A 3D solid model even it is highly detailed it would rarely be possible to predict deformations or stresses accurately without calibration of the FE model.

V. WIND TURBINE BLADE PROPERTIES

The TABLE I below shows the material properties of blade which are used during the analysis. Five different materials are used in the analysis of the wind turbine blade and by changing their properties the analysis is done. The prime aim was to compare the final results such as different Stress Distribution values and the deformation that may happen to the turbine blade when it is subjected to the wind forces.

TABLE I

Material	Properties		
	Density, ρ [kg/m³]	Modulus of Elasticity, E [N/mm²]	Poisson's ratio, υ
Structural Steel	7850	2e5	0.3
Stainless steel	7750	7.93e5	0.31
Titanium Alloy	4620	9.6e5	0.36
Aluminum Alloy	2770	7.7e5	0.33
T-Graphite Epoxy	1600	1.85e5	0.28

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In general, ideal materials should meet the following criteria:

Wide availability and easy processing to reduce cost low weight or density to reduce gravitational forces.

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

High fatigue resistance to withstand cyclic loading.

High stiffness to ensure stability of the optimal shape and orientation of the blade and clearance with the tower.

High fracture toughness.

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

VI. MODELLING OF THE BLADE

An aerofoil is the required cross section of a turbine blade. The peculiar shape of an aerofoil has got much to do with the operation of the blade. An aerofoil has upper and lower surfaces. As wind blows over the section, high pressure is created on the underside and low pressure is created on the upper side. These pressure gradient results in a net push in the upward direction, which moves the aerofoil upwards. Aerofoil cross sections have got certain standards. Here, chosen standard is NACA 2412.Fig1shows a NACA 2412 Aero foil design.

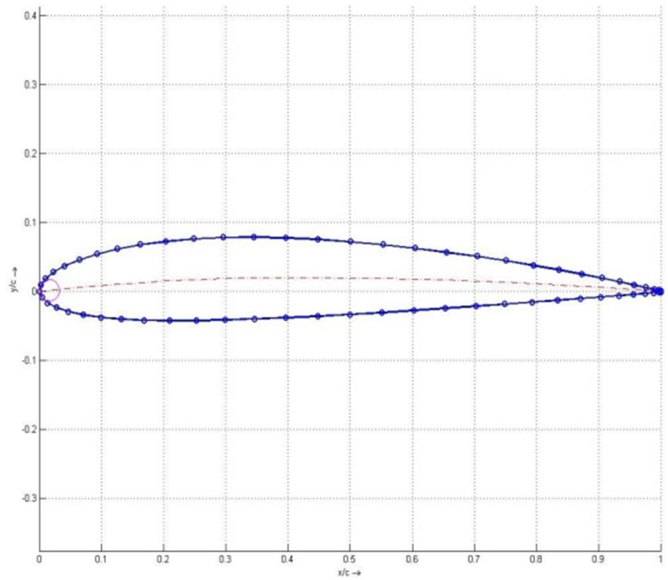

Fig. 1: NACA 2412 Aero foil Design

The Aero foil Design is transformed into a CATIA model in CATIA V5. The points were plotted in the software and joined the points using spline. Then using multisession tool the spline is developed into a wind turbine blade. The final 3D model is developed and the CATIA part file is created.

VII. FINITE ELEMENT ANALYSIS OF BLADE

The CATIA Part file is saved as a step file for analysis. Later from the step file an ANSYS Neutral File (.anf) is generated and directly imported to the ANSYS Mechanical APDL as shown in Fig. 2. The imported CATIA file is defined using Preferences and the element type is given. The material of the turbine blade is selected from different materials and the material properties are given in material modeling as in Fig. 3. The corresponding values of Young’s Modulus & Poison’s ratio of Structural steel have given. This will allow ANSYS to more accurately model the plastic deformation of the material. Next step is meshing the turbine blade. ANSYS Meshing helps in ignoring the individual faces and edges. It ensures the uniformity of the surface and it is an important procedure in the analysis using ANSYS. The meshing is illustrated in Fig. 4. After meshing the loads are defined. As the ends of the turbine blade is fixed, firstly the displacement along the end nodes are arrested by giving zero displacement as in Fig. 5. After arresting the end nodes of the turbine blade, the next stage of loading is applying pressure along the blade surfaces. The total area of the surface is calculated and the pressure is given as force per total area. The force applied is 1 & 10 KN on either side.After the load definition, the blade is analysed using ANSYS software on the basics of the values of Von-Mises Stress and Deflection occurred when it is subjected to the pressure forces.

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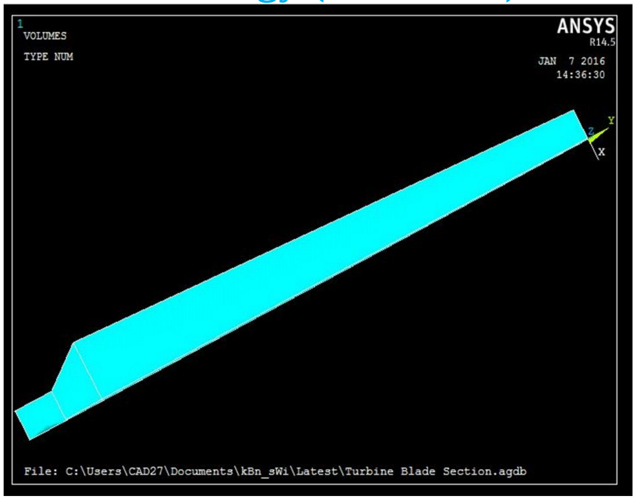

Fig. 2: Importing the CATIA file

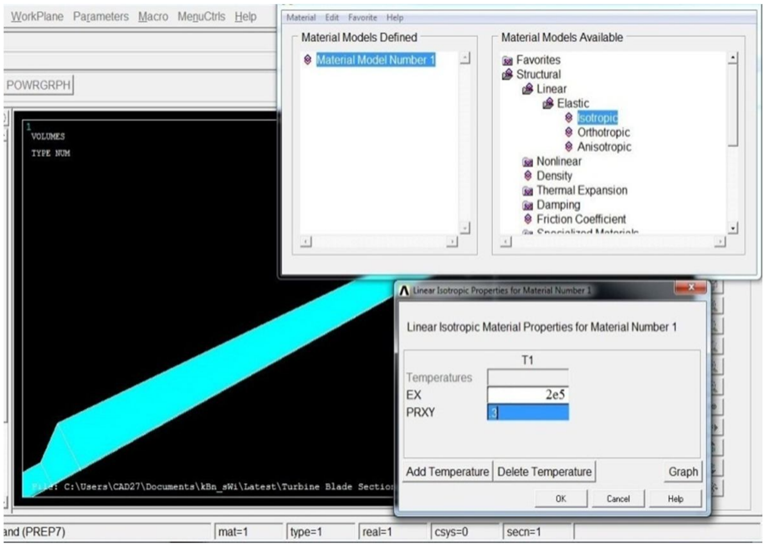

Fig. 3: Material Modelling

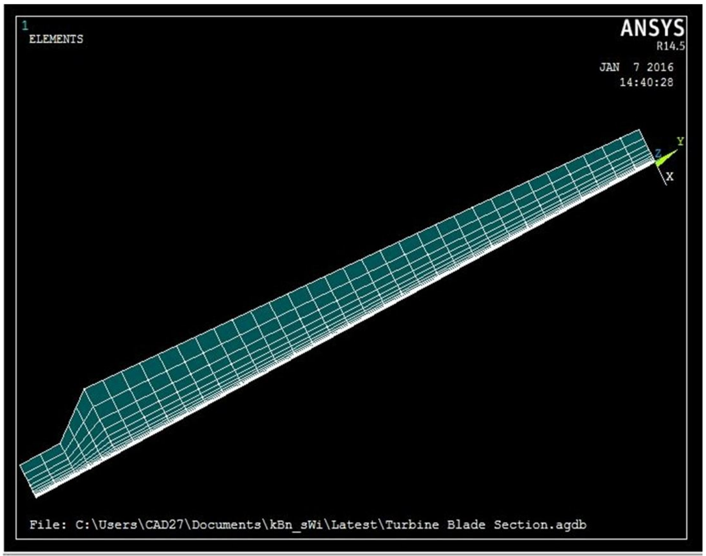

Fig. 4: Meshing

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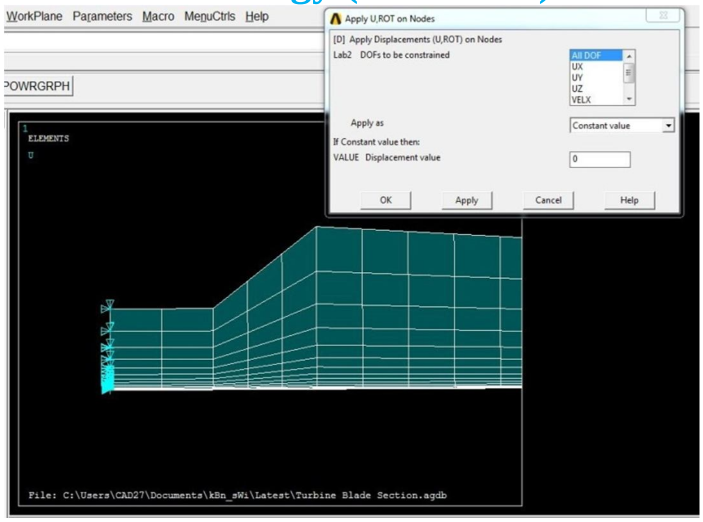

Fig. 5: Defining loads

VIII. RESULT

Based on the analysis done, results are obtained as follows for each material. The resultant value for the Von-Mises stress, Deflection and Elastic strain are listed below.

A. Analysis Using Structural Steel as Blade Material

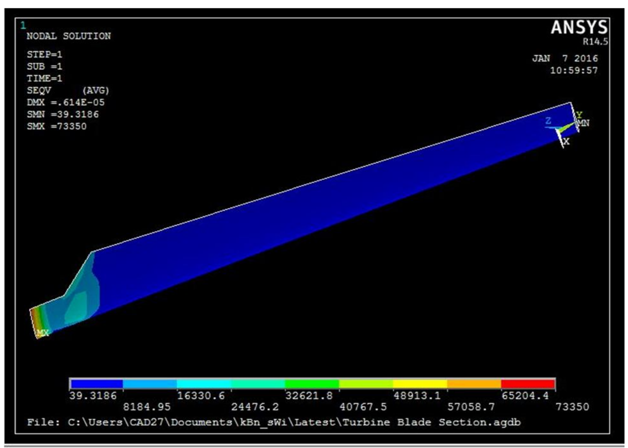

Fig. 6: Von-Mises Stress Distribution of Structural Steel

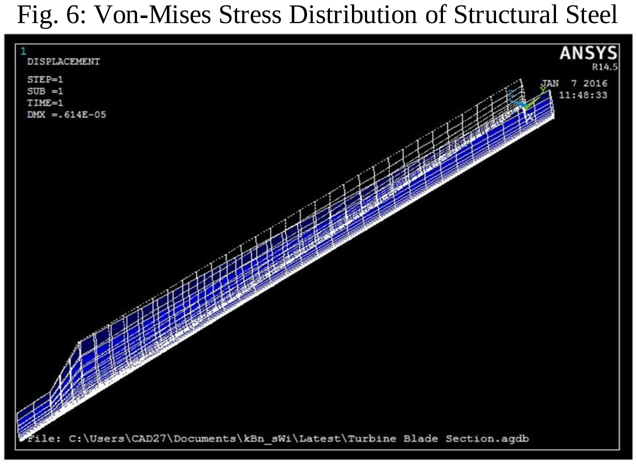

Fig. 7: Deformation / Deflection Distribution of Structural Steel

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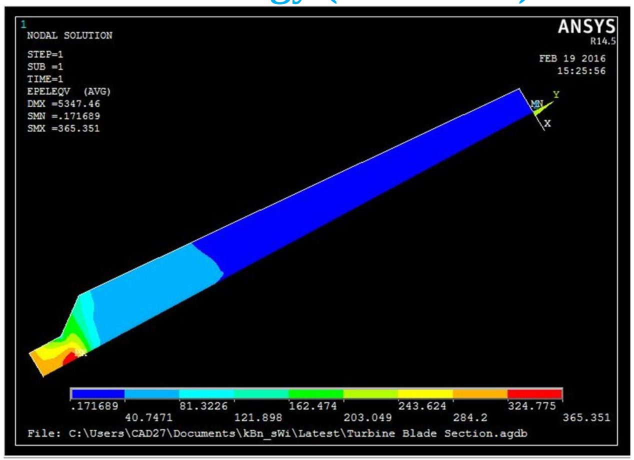

Fig. 8: Elastic Strain Distribution of Structural Steel

B. Analysis Using Stainless Steel as Blade Material

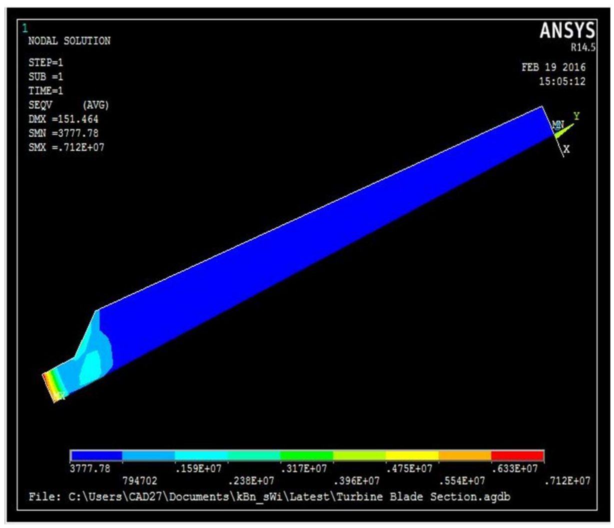

Fig. 9: Von-Mises Stress Distribution of Stainless Steel

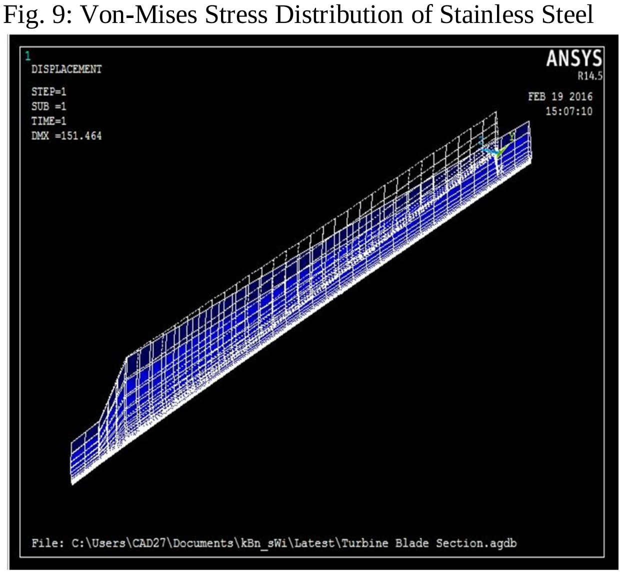

Fig. 10: Deformation / Deflection Distribution of Stainless Steel

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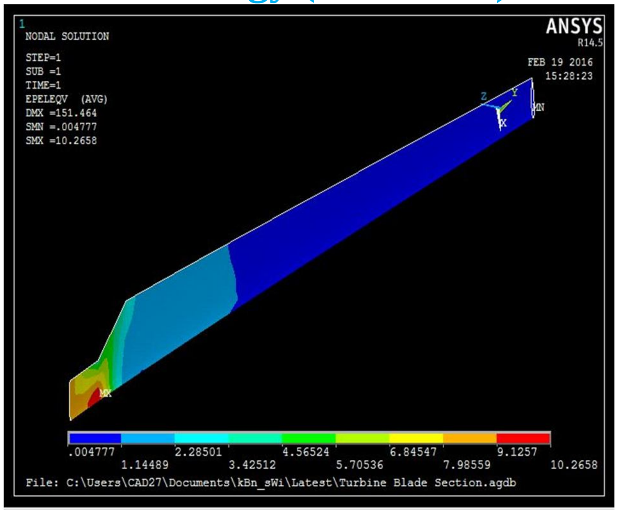

Fig. 11: Elastic Strain Distribution of Stainless Steel

C. Analysis Using Titanium Alloy as Blade Material

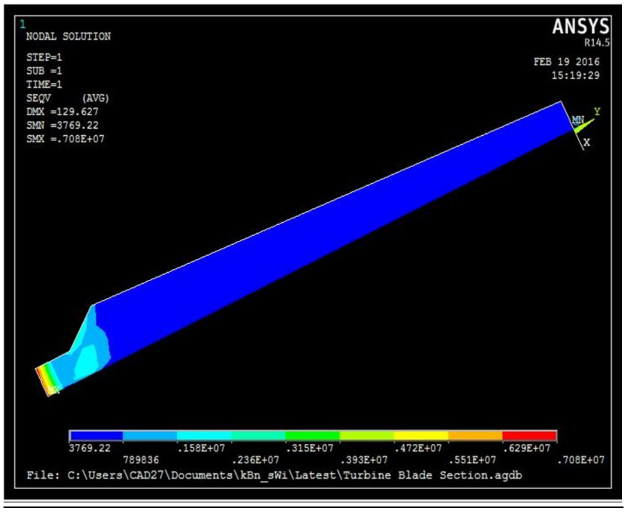

Fig. 12: Von-Mises Stress Distribution of Titanium Alloy

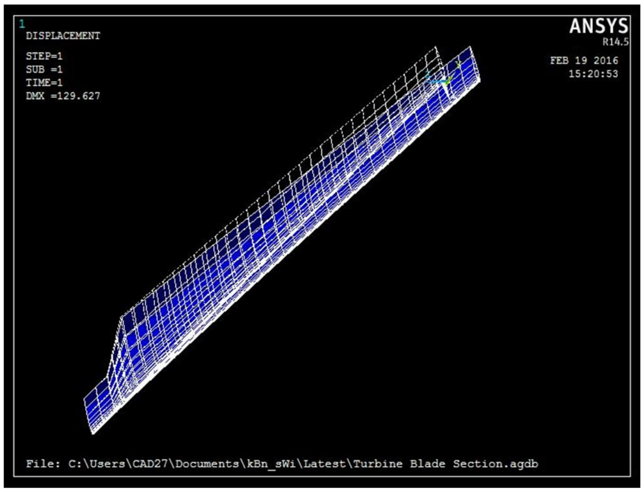

Fig. 13: Deformation / Deflection Distribution of Titanium Alloy

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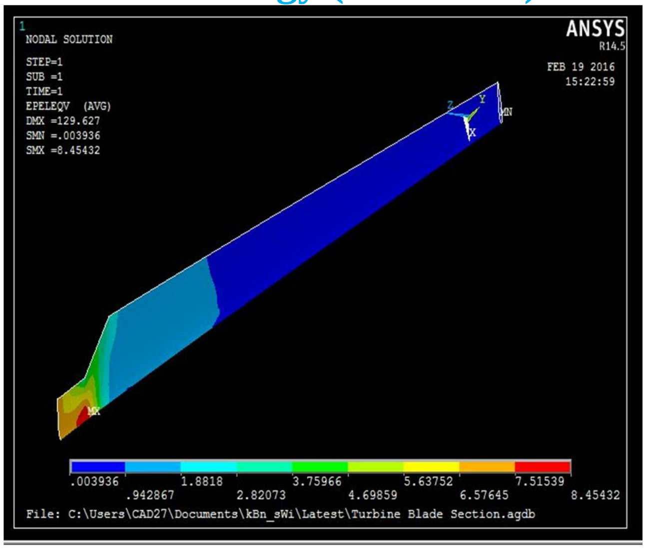

Fig. 14: Elastic Strain Distribution of Titanium Alloy

D. Analysis Using Aluminum Alloy As Blade Material

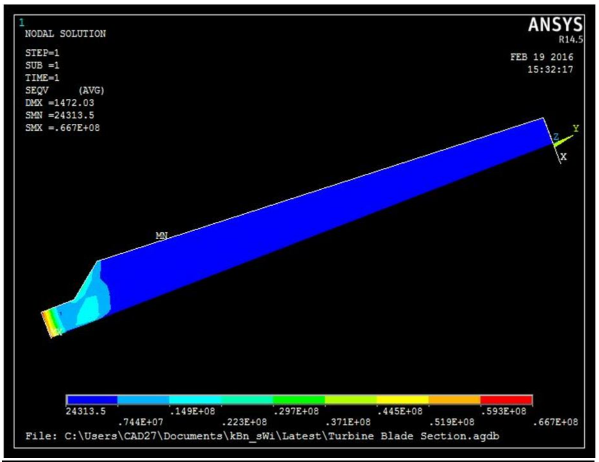

Fig. 15: Von-Mises Stress Distribution of Aluminium Alloy

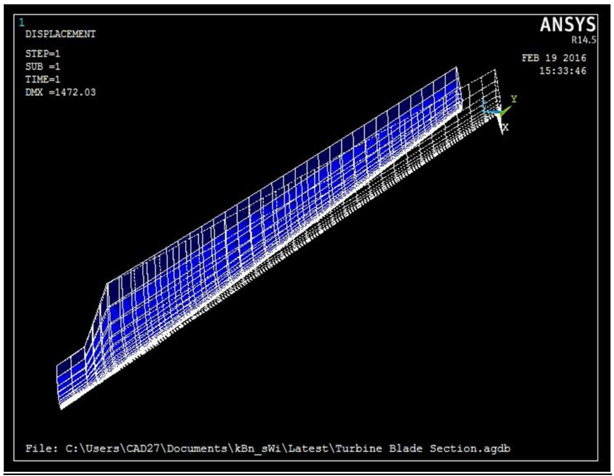

Fig. 16: Deformation / Deflection Distribution of Aluminium Alloy

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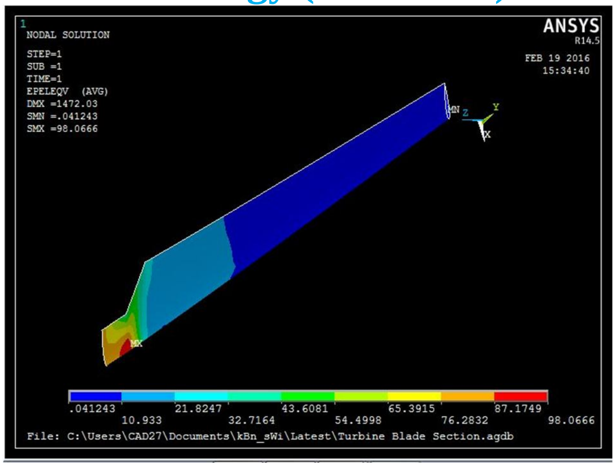

Fig. 17: Elastic Strain Distribution of Aluminium Alloy

E. Analysis Using T-Graphite Epoxy As Blade Material

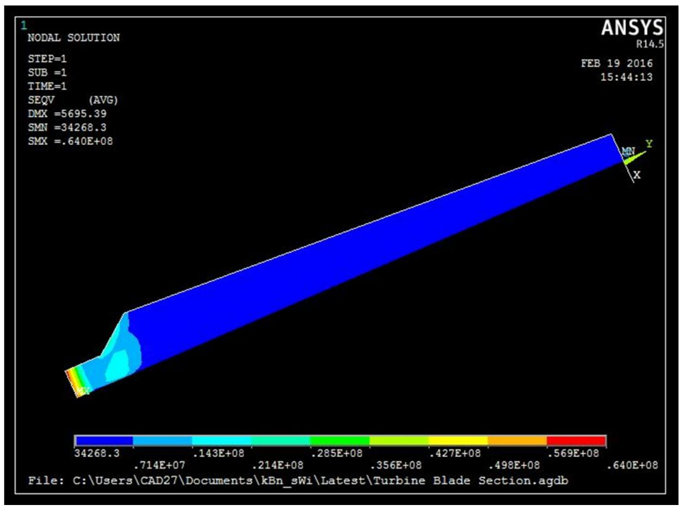

Fig. 18: Von-Mises Stress Distribution of T-Graphite Epoxy

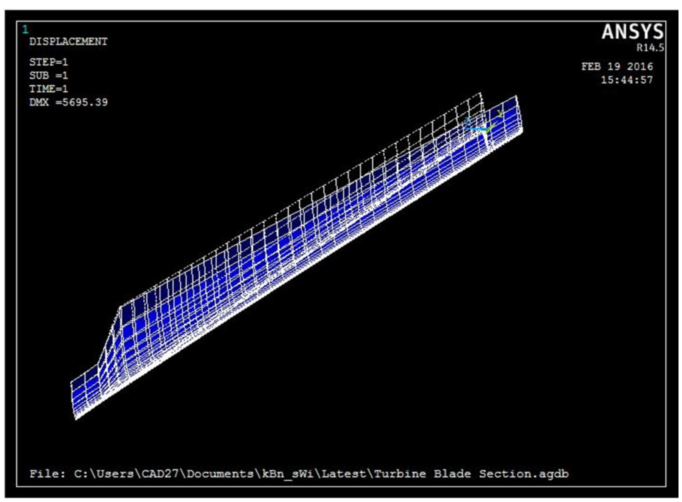

Fig. 19: Deformation / Deflection Distribution of T-Graphite Epoxy

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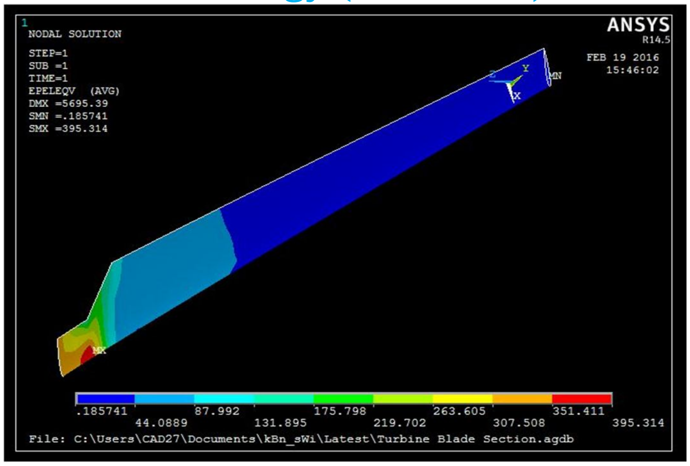

Fig.20: Elastic Strain Distribution of T-Graphite Epoxy

TABLE II shows the results obtained from the finite element analysis done in ANSYS software. The value of Von-Mises stress, Von-Mises strain and Deflection are tabulated. Based on the results, the best material for wind turbine blade is selected.

TABLE II

Material	Properties		
	Von-Mises Stress [kN/mm²]	Von-Mises Strain	Deflection[mm]
Structural Steel	39.3186	17.16e-2	0.614
Stainless steel	3.777	4.77e-2	0.151
Titanium Alloy	3.769	3.936e-2	0.129
Aluminum Alloy	24.313	4.124e-2	1.472
T-Graphite Epoxy	34.268	1.857e-2	5.695

IX. CONCLUSION

This approach showed a way to numerically and experimentally evaluate the existing wind turbine blade. In this paper the obtained values of Von-Mises stress and Deflection determines the suitable material for a wind turbine blade. As the value of Von-Mises stress and Deflection decreases the material will become better for the blade. As per our F E Analysis, the material with less Von-Mises stress and least Deflection is Stainless Steel. So among these materials the Structural Steel is the most suitable material for making wind turbine blades as per our analysis.

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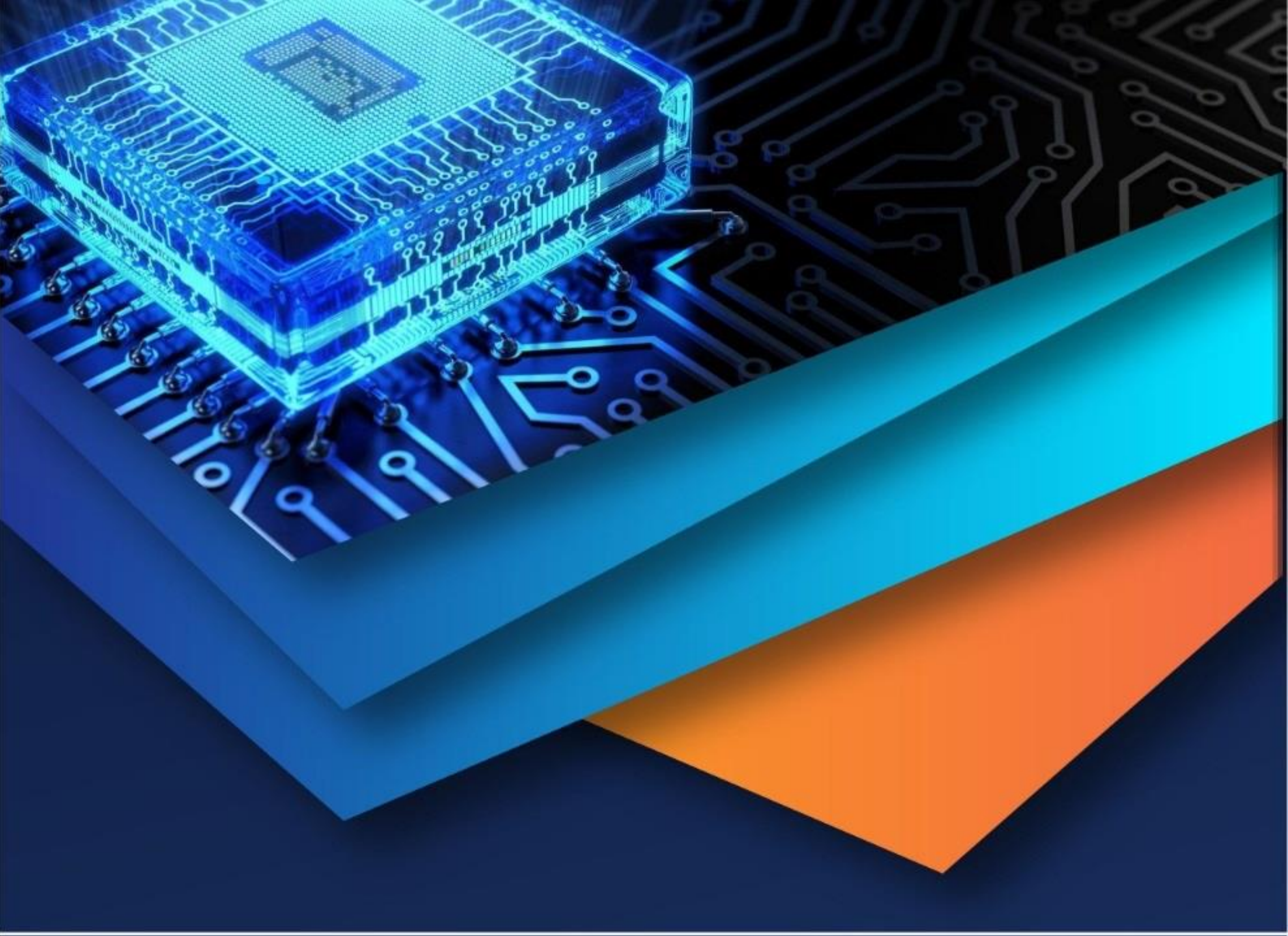

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