STATIC AND DYNAMIC ANALYSIS OF STRAIGHT BLADED VERTICAL AXIS WIND TURBINE BLADE

[1]AGNIHOTHRAM MADHULATHA, [2] CHITTURI VENKATESWARA RAO, [3] T.N.CHARYULU
1,2,3 Dept. of Mechanical Engg., Sree Vahini Institute of Science and Technology., Tiruvuru, AP, India

ABSTRACT: Power consumption is increasing day by day but supply is not catching up with the demand. Also depletion of conventional fuels puts the world in a critical position. Hence, unconventional fuels such as air, wind, tidal, geo-thermal, bio-fuels, hydropower plants etc. should take over the conventional resources. wind as one of the sources of energy is being used since long time. It has gained more significance in the current age of energy crisis, as it is non- polluting, abundant, freely available and low maintenance. Design and usage of horizontal axis wind turbines are well defined over the past couple of decades, but vertical axis wind turbines did not get much attention. Recent research is centered on vertical axis wind turbines due to its inherent advantage of simplicity in control over horizontal axis wind turbine. the durability and high life time of wind turbine can be ensured, among others, if the wind blade materials have very high stiffness, strength, corrosion, fatigue damage, environmental loading resistance as well as low weight. for this, composite should be utilized for wind turbines in place of conventional alloys.

Modelling of staring symmetrical blade for a small scale vertical axis wind turbine is done using commercial software package CATIA. Using beam theories, approximate values of stresses and deflections for the alloy and composite materials are calculated and the values are validated by analyzing the above modeled blade by using numerical analysis results with the help of FEM package, ANSYS. The vibration parameters for vertical axis wind turbine such as natural frequencies and mode shapes blade were done with the help of Block Lanczos method. From the modal analysis composite straight bladed vertical axis wind turbine blade has low natural frequency compared to the blade made up of Aluminum material, from the static analysis, the minimum stresses and maximum deformations are developed in composite vertical axis wind turbine blade material when compared with the Aluminum blade material VAWT blade.

Key words: Vertical Axis Wind Turbine, Finite Element Method, coriolis, airfoil, Neat matrix, E – Glass composite.

1. Introduction

The wind turbine first came into being as a horizontal axis windmill for mechanical power generation, used since 1000 AD in Persia. Today wind turbines are considered to be the most developed form of renewable energy technology, with industrial giants such as Siemens and GE amongst the leading manufacturers. In a macro-meteorological sense, winds are movements of air masses in the atmosphere mainly originated by temperature differences. The energy that can be extracted from the wind is directly proportional to the cube of the wind speed. The temperature gradients are due to uneven solar heating. In fact, the equatorial region is more irradiated than the polar ones. Consequently, the warmer and lighter air of the equatorial region rises to the outer layers of the atmosphere and moves towards the poles, being replaced at the lower layers by a return flow of cooler air coming from the Polar Regions. This air circulation is also affected by the coriolis forces associated with the rotation of the earth. In fact, these forces deflect the upper flow towards the east and the lower flow towards the west. Actually, the effects of differential heating dwindle for latitudes greater than 30^0n and 30^os, where westerly winds predominate due to the rotation of the earth. These large-scale air flows that take place in the entire atmosphere constitute the geotropic winds. A wind turbine is a rotating machine which converts the wind kinetic energy into mechanical energy. If the mechanical energy is then converted to electricity, the machine is called a wind generator, wind turbine.

The wind imposes two driving forces on the blades of a turbine; lift and drag. A force is produced when the wind on the leeward side of the airfoil must travel a greater distance than that on the windward side. The wind traveling on the windward side must travel at a greater speed than the wind traveling along the leeward side. This difference in velocity creates a pressure differential. On the leeward side, a low-pressure area is created, pulling the airfoil in that direction. This is known as the Bernoulli's principle.

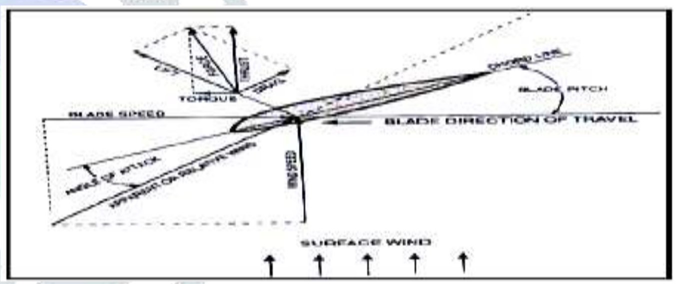


Fig1: force vectors on airfoil cross section

The wind turbines can be divided into two groups of turbines depending on the orientation of their axis of rotation, namely the most common horizontal axis wind turbines (HAWTS) and vertical axis wind turbines (VAWTS).

The experimental studies of VAWTS which can work under an average velocity of wind that is very low, as is the case of most places in Romania. There are many types of VAWTS, which is categorized by the shape of the blades. Basically there are two different shapes of blades; straight blades and curved blades. Curved-bladed VAWTS is rarely applied due to its difficulties in manufacturing. For a small scale wind power generation, straight-bladed VAWTS is more popular because of its design simplicity, low manufacturing cost and also good maintenance. This is why among VAWTS the straight-bladed type is often called as the conventional type.

Anatomy of a wing or airfoil

The airfoil or blade is the predominant moving part on any wind machine. It is the part that captures the kinetic energy of the wind and converts it to useful mechanical motion. Lift producing windmill airfoils or blades predate heavier than air flight by 800 years .However, modern aerodynamics and computations have greatly accelerated the development and refinement of wind turbine airfoils. The cross section of a modem wind blade is similar to an aircraft wing. Figure 2 shows a cross section of a typical modem aircraft wing.

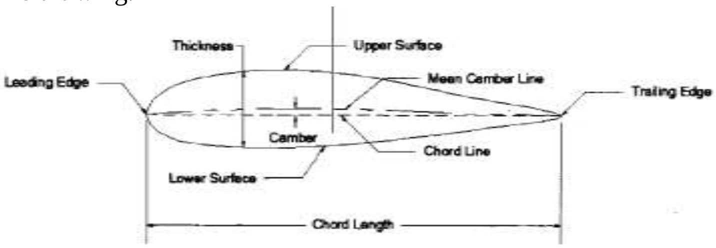


Fig2: Cross section of a wing

Applications of wind turbine are pumping water, desalinating saline or brackish water, aerating water, reservoirs and aquaculture ponds farm, circulating potable wastewater, heating water by fluid turbulence. Because of its sensitivity to moisture and processing costs modern materials such as glass fiber reinforced plastic (GFRP), carbon fiber reinforced plastic (CFRP), steel and aluminum are replacing the traditional wooden units.

2.LITERATURE REVIEW

M. SaqibHameed e.tal [1] Blade is the most important component of a wind turbine which controls the performance of a wind turbine and design of other components attached to it. A concept for the design of a straight symmetrical blade for a small scale vertical axis wind turbine using beam theories for analytical modeling and a commercial software ANSYS 11.0 for numerical modeling is used.

Nitin Tenguria [2] has developed an optimization method for a VAWT blade of VESTAS 1.65 KW horizontal axis wind turbine according to Indian wind condition. BEM theory was used for developing the optimization method.

Dayton A Griffin, [3] performed a study concerning blades for wind turbines using commercial blade designs and manufacturing methods, and innovations in composite materials, manufacturing process and structural configurations were assessed. In the structural designs are developed for hybrid carbon fiber / fiber glass blades.

Dale Retallack [4] designed 25kW wind turbine blade produced from engineered wood at reduced manufacturing cost. In this testing on existing fiber glass and carbon fiber blades and this information was used to design the wood blade. FEA was used in reference testing. Operational testing was conducted and found the results produced are very close to carbon fiber blades.

Bulent Eker [5] investigated the importance of composite materials in wind turbine blades. Their research was based on the theories of material science and wind technology. Some practical results shown that the composites can decrease the danger factor, can control the structural vibration and produce high magnitude of power..

Andrew Corbyn [6] have developed practical guide which is designed to show the process of producing a wind turbine blade from fibre-glass. This guide stemmed from work trying to produce a 1.8m blade for a 1kW version of Hugh's design.

N.M. El Chazly [7] analyzed the lift and the drag forces created in a steady wind conditions by using consistent mass matrix in finite element analysis. NACA 0015 airfoil series was used to test the constant chord, tapered blades for the survival at rated wind speeds. Results showed that maximum stresses occurred at the root of the blades for all configurations and the twisting of the blade lead to the increase of the stiffness and the decrease of the stresses.

Gunner C. Larsen [8] has determined the natural frequencies, damping characteristics and mode shapes of the wind turbine blades by using modal analysis. The experimental results of LM19 m blade has been compared with results from a FE-Modeling and the modal analysis respectively.

Scott Michael Larwood [9] carried out a dynamic analysis for swept wind turbine blades. Adams TM dynamic software was used to develop the codes. The outputs obtained from the codes are validated with field test data. The designs showed a 5% increase in annual energy production and a decrease in flap-bending over the straight blade designs.

Ashwani Kumar [10] The main part of this research is to identify natural frequencies and natural vibration modes of the Al 2024 wind turbine blade. For the design of wind turbine blade Solid Edge software is used and the model is imported in ANSYS 14.0 for modal analysis. For the suitability analysis of Al 2024 we have done structural and Modal analysis. The results of the analysis are used to verify a structure's fitness for use.

3.ANALYTICAL ANALYSIS

RELATION BETWEEN ANGLE OF ATTACK (α) AND PITCHING ANGLE (θ)

The following equation was used to determine the values of angle of attack with the variation in pitching angle. $\alpha = \tan^{-1}\frac{\sin\theta}{TSR+\cos\theta}$

Maximum velocity of the blade in tangential direction, R_W

Relation of tip speed ratio issued here to determine the maxi-mum velocity of blade tip at maximum wind speed viz. 8 m/s in current design. $TSR = \frac{R_W}{V} = 4.1$

Relative velocity, w:

In the case of vertical axis wind turbine, it is not just the simple wind velocity that basically produces the lift on the blade but relative velocity viz. a vector solution of maximum blade tip velocity R_w and wind velocity V, shown in Fig. 3. The variation in β and γ with α was determined and therefore the value of W at different angles of attack was evaluated using sine and cosine laws.

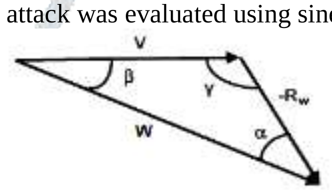


Fig3:Velocity triangle for darrieus VAWT with internal angles

$$\frac{V}{\sin\alpha} = \frac{R_W}{\sin\beta} => \beta = \sin^{-1}(\left(\frac{R_W}{V}\right)\sin\alpha)$$

$$\gamma = 180 - (\alpha + \beta)$$

$$W^2 = V^2 + R_W^2 - 2VR_W\cos\gamma$$

Calculations for normal and axial forces

The values of lift (perpendicular to wind velocity V) and Drag (parallel to V) are calculated in complete360^{o} rotation of the blade using the following relations.

$$L = q_\infty C_L S \text{ , } D = q_\infty C_D\text{,Where } q_\infty = \frac{1}{2}\rho W^2$$

$$N = L\cos\alpha + D\sin\alpha\text{,}A = L\sin\alpha - D\cos\alpha$$

Location of strut attachments and cross sectional properties of the optimized blade model.

For blades with high aspect ratios (low value of c) and higher value of solidity which increases the torque and bending stresses on the blade, a two point support is recommended, shown in Fig4. The location of supporting struts attachment with the blade was chosen in such a manner to achieve minimum deflection and bending stresses at both the regions i.e. cantilever region each of 0.56 m and fixed region of 1.46m. The blade model was optimized from solid to a hollow cross section with different values of wall thickness to reduce the weight and centrifugal forces on the blade. The cross sectional properties using the following relations were calculated and cross checked with the beam section properties facility of ANSYS14.5 for all the design cases at different values of wall thickness.

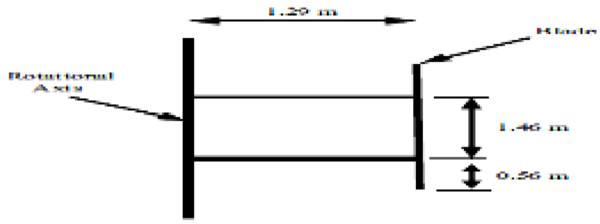


Fig4: Location of Strut attachment with the designed blade front view of designed VAWT.

1).Thickness to chord ratio for NACA001 airfoil (Emami, 2007)

$$\pm\frac{z}{c}=\frac{t}{0.2}\left[0.2969\sqrt{\frac{x}{c}}-0.126\left(\frac{x}{c}\right)-0.3516\left(\frac{x}{c}\right)^2-0.2834\left(\frac{x}{c}\right)^3-0.2834\left(\frac{x}{c}\right)^4\right]$$

2) Area of the airfoil.

$$A=\int_0^{0.206}\left[\left(+\frac{z}{c}\right)-\left(-\frac{z}{c}\right)\right]dx$$

(3) Moment of inertia.

$$I=\int_0^{0.206}\frac{1}{3}\left[\left(+\frac{z}{c}\right)-\left(-\frac{z}{c}\right)\right]dx$$

The bladeis designed with aluminium with E=70 GPa ρ=2700kg/m^3 and ν=.3. The high aspect ratio straight blades of H-darrieus rotor are subjected to high values of centrifugal forces, these values are determined for all designed values of wall thickness (with mass m) at the maximum tip speed velocity(R_w) of 32.8m/s, using the following relationship $F_C=\frac{2mR_W^2}{D}$

Evaluating the values of maximum deflections and stresses

As the blade is divided into two beams, cantilever and fixed at both ends therefore, both the regions were analyzed separately and max.deflection and Max.stress were evaluated using relations taken from beam theories for uniformly distributed loading Max.moments (M_{max}) and max.deflection at beam with both ends fixed and uniformly distributed loading w.

M_{max} (at ends)= $\frac{wl^2}{12}$

Max.deflection (at center) = $\frac{wl^4}{384EI_{xx}}$

Max.moments(M_{max}) and max.deflection at Cantilever beam with uniformly distributed loading.

M_{max}(at fixed end)= $\frac{wl^2}{2}$

Max.deflection (at free end)= $\frac{wl^4}{8EI_{xx}}$

4. MODELING OF WIND TURBINE BLADE CATIA

CATIA (Computer Aided Three-dimensional Interactive Application) is a multi-platform CAD/CAM/CAE commercial software suite developed by the French company assault. Written in the C++ programming language, CATIA is the cornerstone of the Dassault Systems product lifecycle management software suite.

Procedure for modeling of wind turbine blade:

The modeling of straight wind turbine blade of varying wall thickness (i.e. from Solid to 1 mm) models are created by using the CATIA V5 R18.

Fig5: Airfoil spline

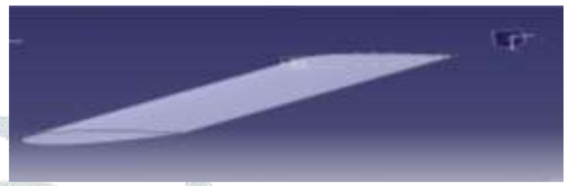


Fig6: Extruded geometry

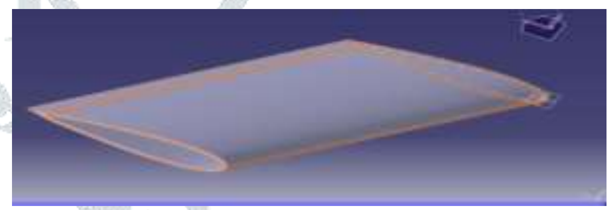
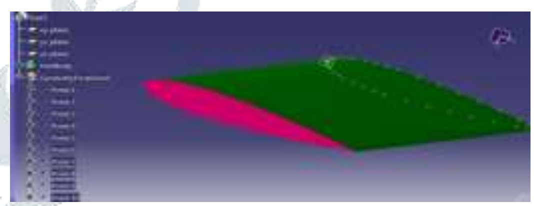
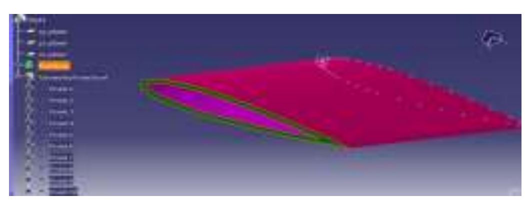


Fig7: Extruded 5mm thickness blade

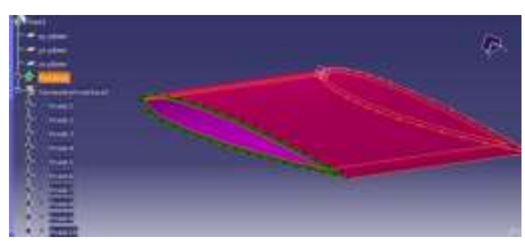
All the blades with different cross sections (with varying values of wall thickness) were modeled as shown in below Fig8: From (a-e)



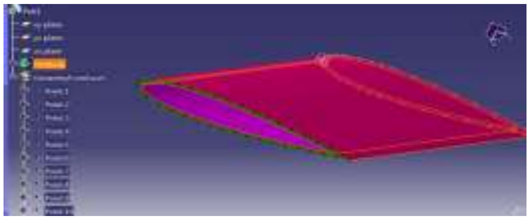
(a) Solid profile blade



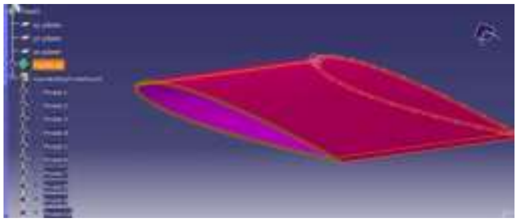
(b) 5mm wall thickness blade



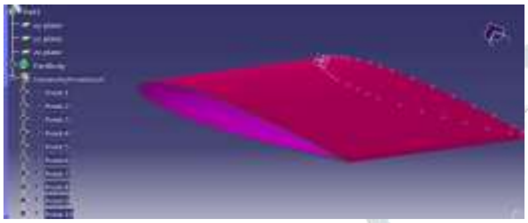
(c) 4mm wall thickness blade



(d) 3mm wall thickness blade



(e) 2mm wall thickness blade



(f) 1mm wall thickness blade

Fig8: (a-e) Cross Sections of designed models of the blade with different values of thickness

Table 1: Mechanical properties of the given materials

Material Type	Young's Modulus E(G Pa)	Poisson's Ratio(υ)	Density (kg/m3)
Aluminum	70	.33	2700
1%carbon fiber	21	0.2	1810
Neat matrix	20	0.2	1800
E-Glass Composite	9.572	0.25	1800

Fig9: Meshed straight solid wind turbine blade

Table2: Number of elements and nodes

Blade model	Elements	Nodes
Solid	450	42356

Therefore all the degrees of freedom of the blade are constraints at the distance of the 0.56 m from both ends giving the cantilever regions of length 0.56 m and fixed region of length 1.46 m viz. The location of struts attached to the blade. Different constraints used in this analysis are as shown below for straight wind turbine blade. Constraints (Ux,y and z and Rx,y and z) : (i) Symmetric mid cross-sectional area (Same for other shell geometry). While taking boundary conditions, all translational (Ux,y and z) and rotational(Rx,y and z) degrees of freedom are constrained. The area to be constrained for straight wind turbine blade is shown as in the fig 10

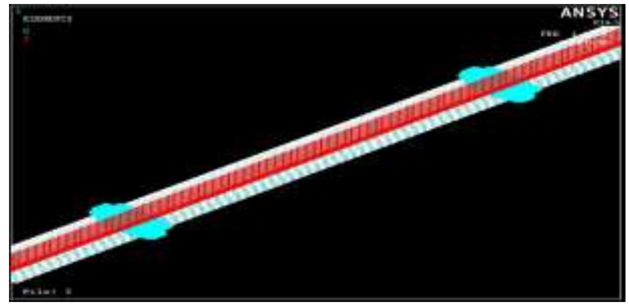


Fig10: Applying Uniformly Distributed load

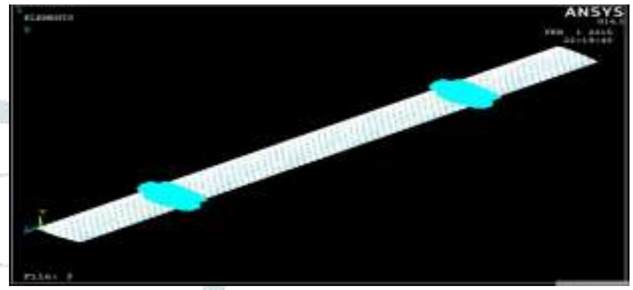


Fig 11: Applying constraints on lines

5.STATIC AND MODAL ANALYSIS

Static analysis is done using "ANSYS SOFTWARE" for the present design of straight (VAWT) vertical axis wind turbine blade. In the analysis we had compared various responses such as von-misses stress, and deformation from the simulation solutions are to be validated against corresponding previous observations. Further dynamic analysis (i.e. Modal analysis) for the current design is carried out in this work. Modal analysis is performed to determine the natural frequencies and mode shapes of a structure or a machine component while it is being designed. Later, application of composite material properties is done. Models made of two composite materials viz. Carbon Fiber and E- Glass reinforced composites have been analyzed. Fatigue analysis is also carried out for the current design. The fatigue analysis is performed to determine fatigue stresses and fatigue life of the component

Static load analysis for aluminum

The Designed models were analyzed by applying various uniformly distributed loads (sum of aerodynamic load and centrifugal load), stress and deformation on the straight wind turbine blade at each loading condition were found. The stresses which are experienced by the straight wind turbine blade and the deformation occurred due to stress on the material and are compared with the existing design values. It is noted that the stress value is well below the yield stress.

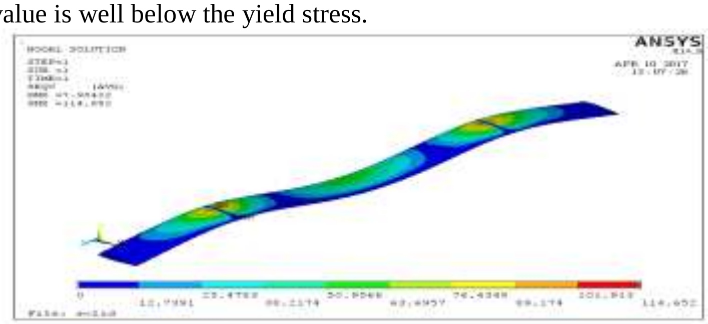


Fig12: Contour of stress distribution over the solid cross section blade (solid element)

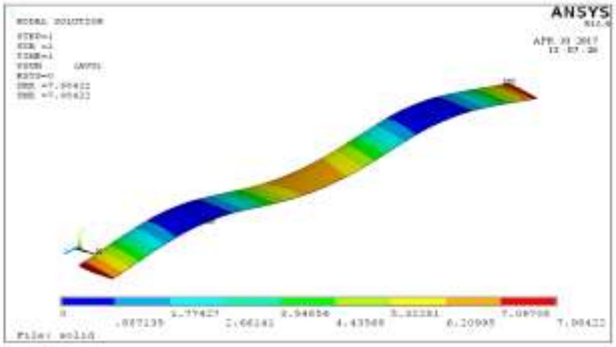


Fig13: Contour of Deformation distribution over the solid cross section blade (solid element)

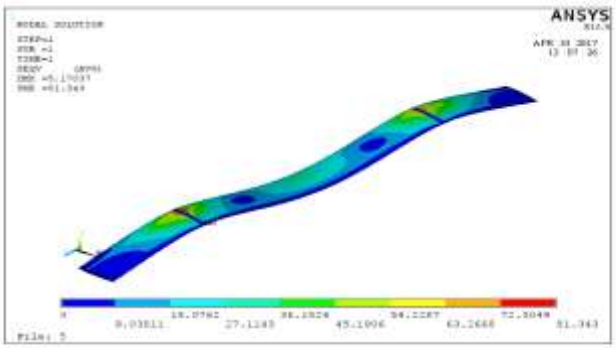


Fig14: Contour of stress distribution over the 5mm thick hallow cross section blade (solid element)

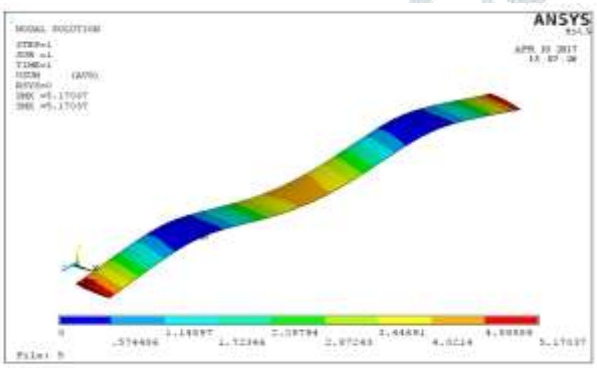


Fig15: Contour of deformation distribution over the 5mm thick hallow cross section blade (solid element)

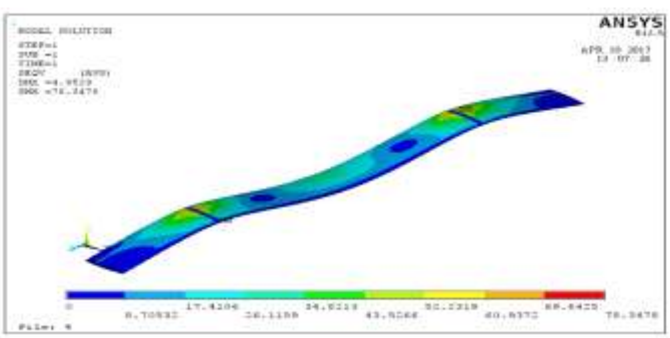


Fig16: Contour of stress distribution over 4 thick hallow cross section blade (solid element)

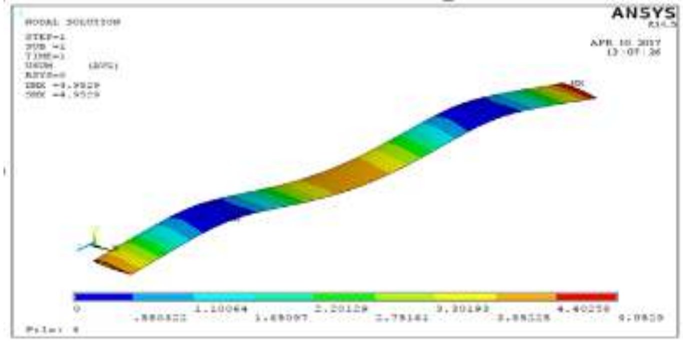


Fig17: Contour of deformation distribution over 4 mm thick hallow cross section blade (solid element)

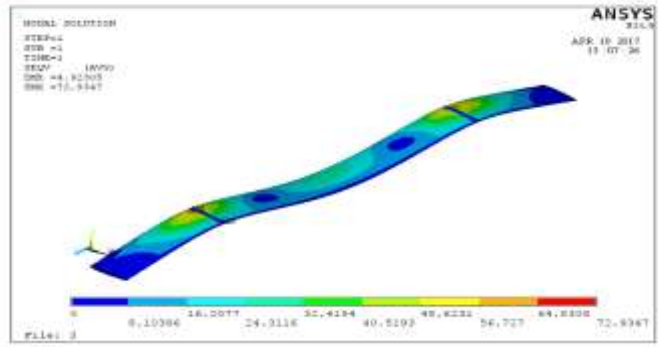


Fig18: Contour of stress distribution over 3 mm thick hallow cross section blade (solid element)

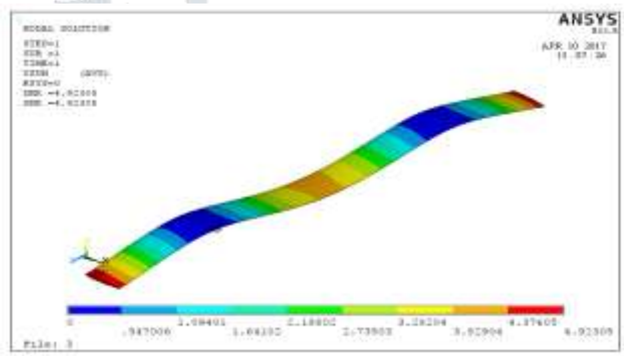


Fig19: Contour of deformation distribution over 3 mm thick hallow cross section blade (solid element)

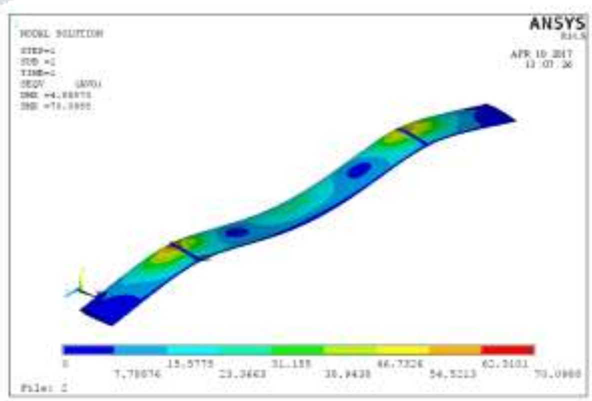


Fig 20: Contour of stress distribution over 2 mm thick hallow cross section blade(solid element)

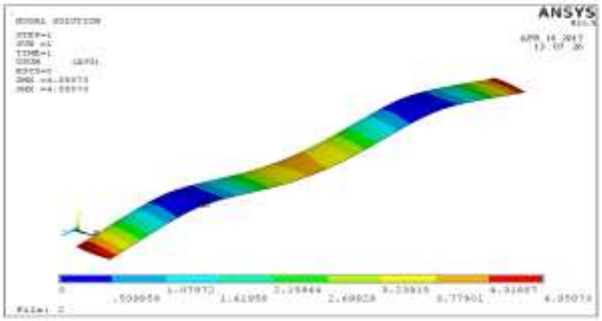


Fig21:Contour of deformation distribution over 2 mm thick hallow cross section blade (solid element)

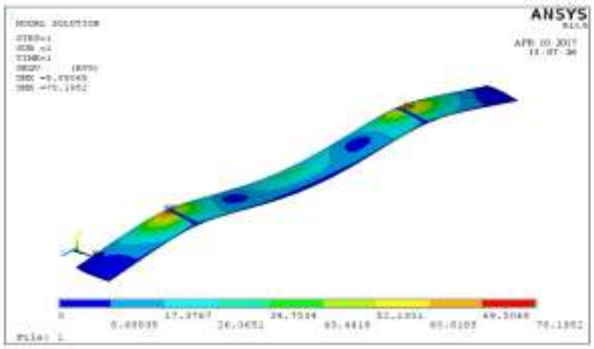


Fig22: Contour of stress distribution over 1 mm thick hallow cross section blade (solid element)

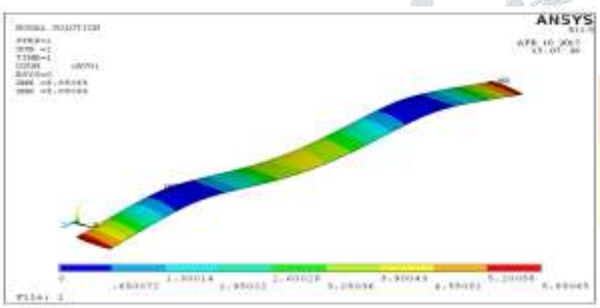


Fig23: Contour of deformation distribution over 1 mm thick hallow cross section blade (solid element)

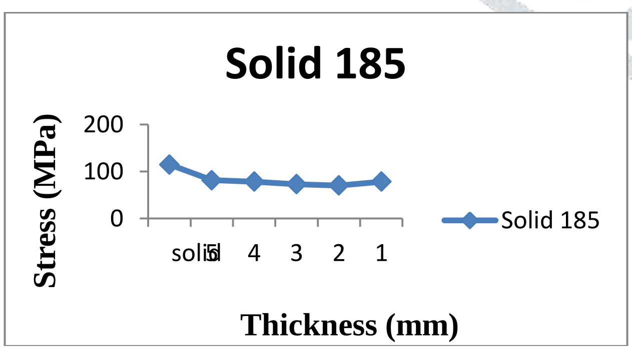


Fig24: Comparison of max.stresses (MPa) at different values of wall thickness

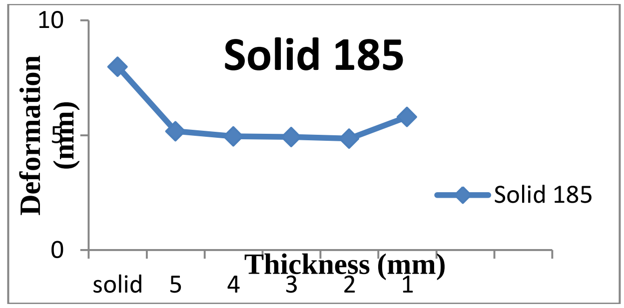
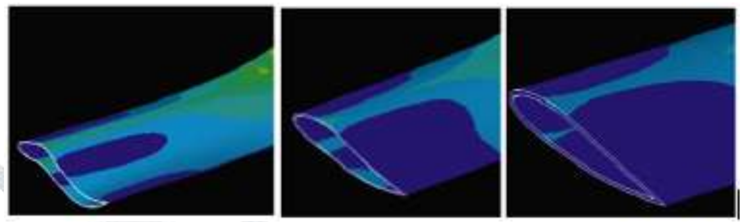
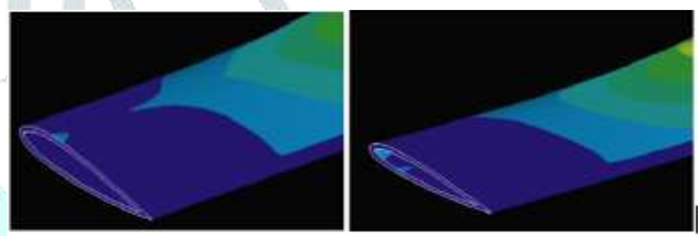


Fig25: Comparison of max.deformation (mm), at different values of wall thickness.



1mm to 3mm (left to right)



4mm to 5mm (left to right)

Fig26: Deformation

DISCUSSION ON STATIC RESULTS FOR DIFFERENT CROSS SEACTION BLADE MODELS

The values of maximum stress and maximum deflections start decreasing from solid cross section to hollow cross section at approximately 2 mm wall thickness but starts increasing by reducing the value of wall thickness further. When the cross sections of these blades were modeled and analyzed it was observed that the distortion in the blade shape occurs at the regions of maximum deflections as shown in Fig25 The values of maximum deflection and stresses are suddenly increased from 2 mm to 1 mm wall thickness. This is due to the large distortion in the shape of the blade as the wall thickness is reduced from 2 mm to further 1 mm. The solid185 element type better approximates the large distortion in the shape of the blade. The distortion in shape reduces with increase in wall thickness of the blade. For the optimal wall thickness of 4 mm, the maximum deflection of 4.27 mm and maximum stress of 66.81 MPa is found. The optimal thickness is found between 3 mm and 4 mm with no distortion in shape of the blade.

STATIC ANALYSIS ON COMPOSITE STRAIGHT WIND TURBINE BLADE.

STATIC LOAD ANALYSIS FOR 1% CARBON FIBER.

The maximum values for stresses and maximum deformation for optimized cross section blade (4mm thickness blade) and the performed static analysis for remaining cross sections blades. The maximum stress occurs at the two fixed supports was identified with help of red color with the values of 53.2 MPa for solid element. The succeeding higher stress levels plotted with different colors representing the corresponding stress levels at a various locations.

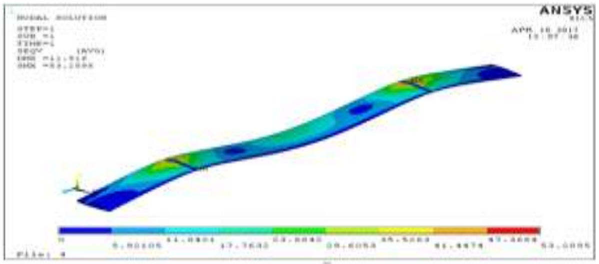


Fig27: Contour of stress distribution over 4mm thick hallow blade (solid element)

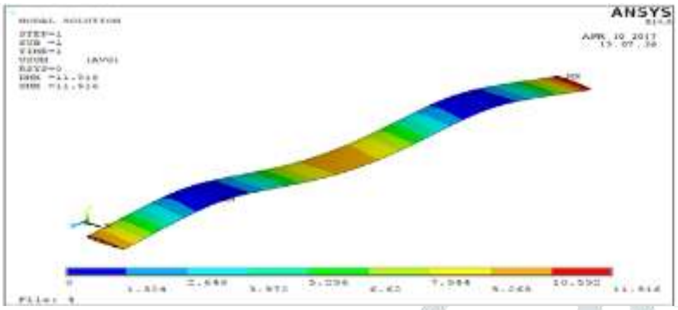


Fig28: Contour of deformation distribution over 4mm thick hallow blade (solid element)

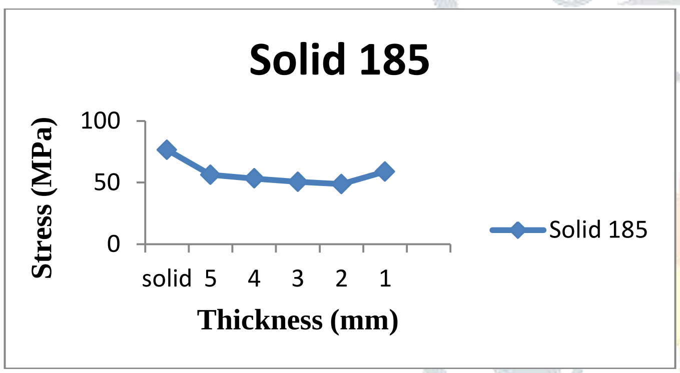


Fig29: Comparison of max.stresses (MPa), at different values of wall thickness.

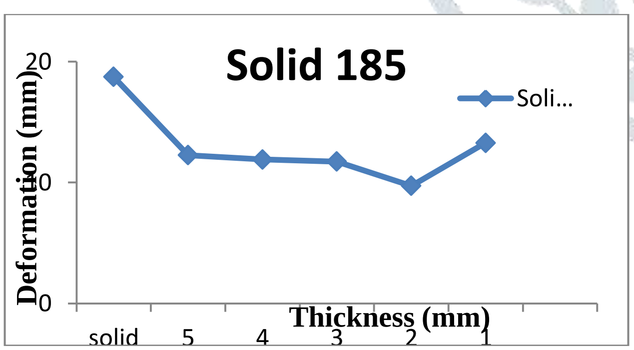


Fig30: Comparison of max.deformation (mm), at different values of wall thickness.

STATIC LOAD ANALYSIS FOR NEAT MATRIX.

The contour plots for 4mm thickness blade (i.e. optimized thickness blade model) model under uniformly distributed loads of 3.807 KN over the fixed region and 2.92 KN over the two cantilever regions by these implication von-mises stresses and deformations were observed in the figs [31, 32, 33 & 34].It can found that maximum stress occurs at the two fixed supports the obtained values are 53.63 MPa for solid element. The maximum deformation occurs at the free ends of the blade are noted as 12.46 mm for solid element.

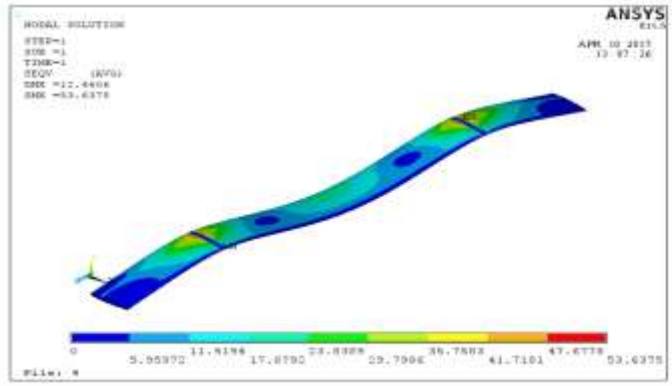


Fig31: Contour of stress distribution over 4mm thick hallow blade (solid element)

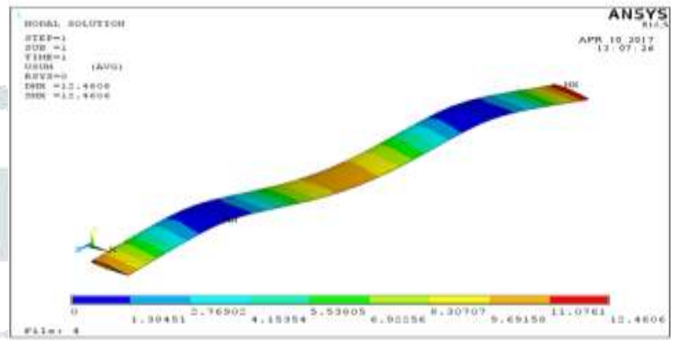


Fig32: Contour of deformation distribution over 4mm thick hallow blade (solid element)

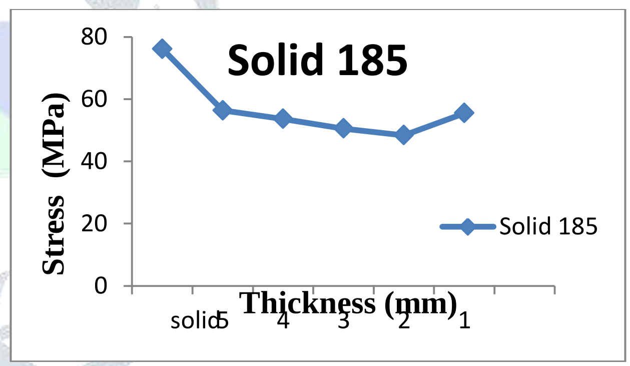


Fig33: Comparison of max.stress(MPa) at different values of wall thickness.

The stress exhibits a decreasing trend with respect to the wall thickness of the blade up to 2mm and further on increases for 1mm thickness. The maximum deformation for 4mm optimized thickness blade is 19.58.

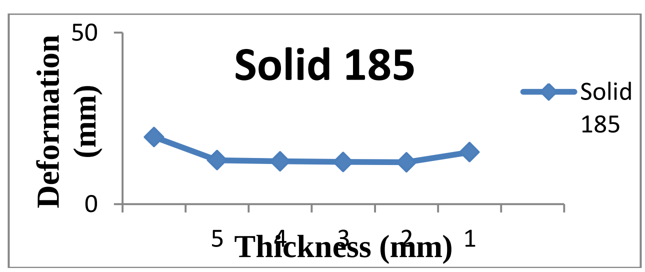


Fig34: Comparison of max.deformation (mm), at different values of wall thickness.

STATIC LOAD ANALYSIS E-GLASS COMPOSITE:

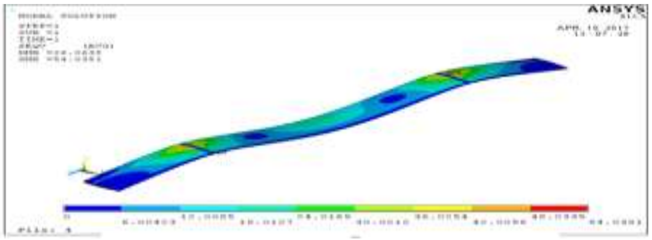


Fig35: Contour of stress distribution over 4mm thick hallow blade (solid element)

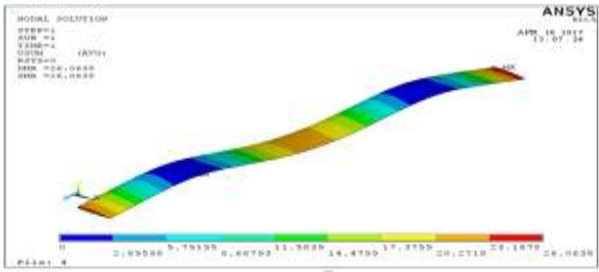


Fig36: Contour of deformation distribution over 4mm thick hallow blade (solid element)

The maximum von-mises stresses of the blade for 4mm thickness for both solid element occurred at fixed region given in the figs (35&36). The maximum deformations obtained at cantilever region shown in the figs (37&38). Maximum von-stresses for solid element blade model is 54.03MPa. For solid models Maximum deformations is 26.06 mm .

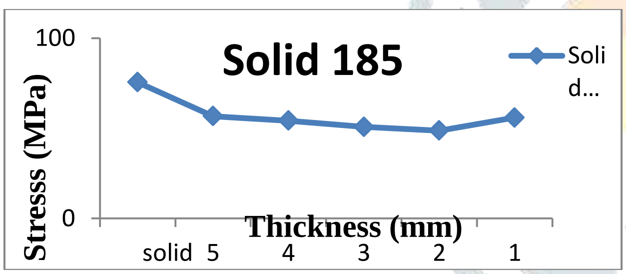


Fig37: Comparison of max.stress (MPa) at different values of wall thickness.

For E-glass the stresses are decreasing from solid cross section to hollow cross section for up to 2 mm wall thickness, and start's increasing by reducing the wall thickness further.It can be observed that the decreasing trend of solid element is some different from the remaining beam element and analytical values.

The masses of different blades decreases with the reduction of wall thickness effects in the decrement of deformations up to 2mm .After 2mm thickness further reduction shows an increment of deformations.

Fig38: Comparison of max.deformation (mm), at different values of wall thickness.

STATIC ANALYSIS RESULTS OF ALUMINUM AND COMPOSITES.

Von-mises stresses and deformation of the 4 mm thickness optimized blade for aluminum, 1%carbon fiber, Neat matrix and E – Glass composite. It can be observed that composite materials have lower von-mises stress and lower masses compared with aluminum material. But the deformations of the composite materials higher than the aluminum material.

MODAL ANALYSIS.

MODE SHAPES.

Deformation patterns (bending, twisting.) at these resonant frequencies take on a variety of different shapes depending on the excitation force frequency. These deformation patterns are referred to as the structure's mode shapes. Mode shapes are normalized to the maximum displacement of the structure. Only the first few (5-6) eigenvalues of the model are interesting and physically meaningful. Since the finite element model is an approximation of the structure, than the higher eigenvalues and vectors are inaccurate.

MODAL ANALYSIS ON STRAIGHT WIND TURBINE BLADE FOR ALUMINUM

The first three mode shapes are characterized by flap wise bending while the another three mode shapes exhibits torsional deformation. The corresponding mode shapes for the first six modes.The modal analysis to the remaining cross sections (i.e. solid, 5mm, 3mm, 2mm & 1mm models) and the corresponding frequency's to that models. It can be observed that the frequencies are decreasing for solid model from 5mm to 4mm thickness. Later, the frequency increases (i.e.3mm to 1mm) because of reduction of the thickness of blade models. For the performed modal analysis on solid element blade model and beam element blade model have resulted in flap wise bending and torisonal bending.

Different frequencies were obtained for first 3modes in effect with flap wise bending. For the next 3 modes resulted in various frequencies with regards to the torsional bending. For the first mode, which are displaced in y-direction the frequency obtained is 2.25Hz for solid element, 1.989Hz for beam element that tends to a displacements of 0.64mm and 0.62mm .The frequencies observed for the 2mode corresponding to the solid element and beam element blade models are 2.47Hz and 2.126Hz.And the recorded displacements for the observed frequencies are 1.25mm and 1.247mm.In 3mode the excited frequencies with the action of flap wise bending are 2.668 Hz and 2.661 Hz have resulted a displacement of 1.25mm and 1.247mm.The 4mode undergoes a torsional bending along the length of the blade having a frequencies 6.14Hz and 6.003Hz with the corresponding displacements are 0.63mm and 0.588mm.The frequencies for 5mode are 10.13Hz and 10.28Hz with respect to solid element blade and beam element blade and their relevant displacements are 0.98mm and 0.48mm.The solid element blade and beam element having a frequencies in effect with torsional bending for 6mode are 11.1819Hz and 11.1809Hz.The equivalent displacements for the noted frequencies are 1.10mm and 0.344mm.

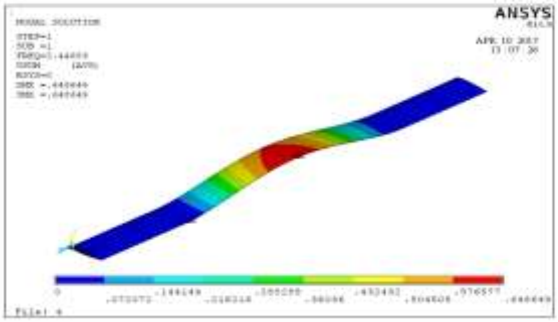


Fig39: 1st flap wise bending (solid element)

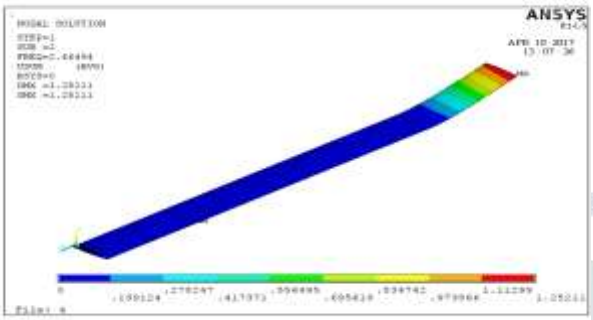


Fig40: 2nd flap wise bending (solid element)

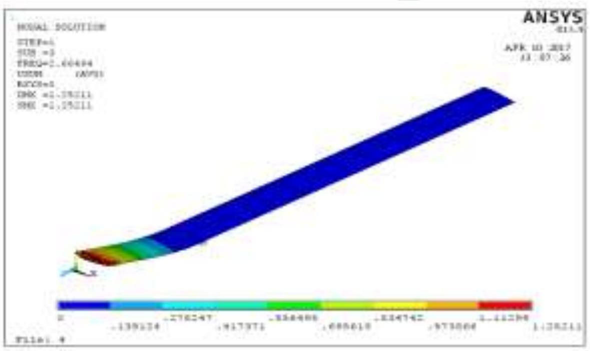


Fig41: 3rd flap wise bending (solid element)

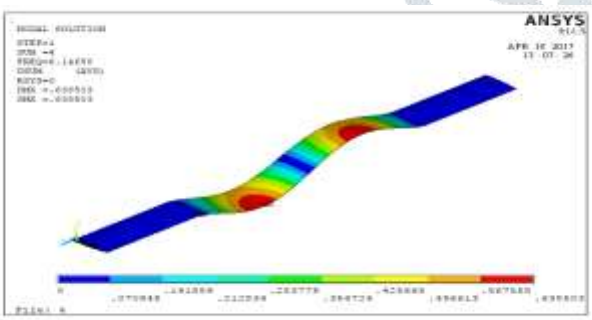


Fig42: 1st torsional bending (solid element)

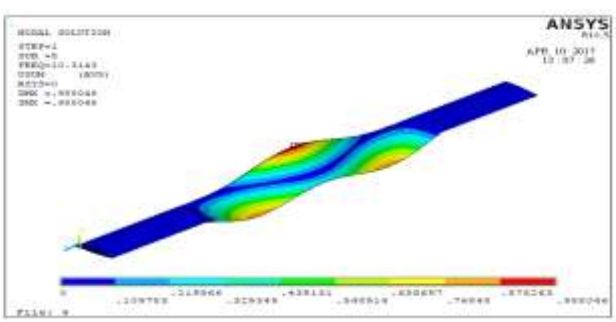


Fig43: 2nd torsional bending (solid element)

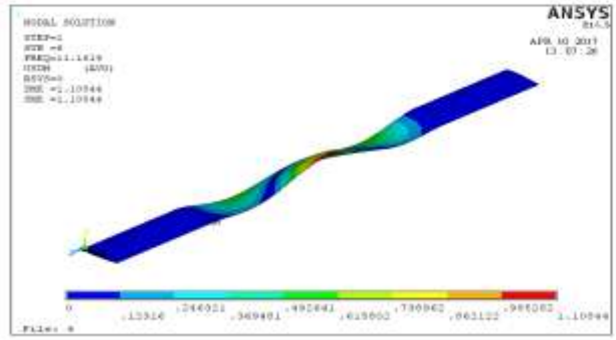


Fig44: 3rd torsional bending (solid element)

The extracted 6modes for various cross section blades get effected by the flap wise bending (1to3modes) and torsional bending (4th to 6th mode) are tabulated. The frequency of the blade decreases up to 4mm thickness and there on slightly increases with respect to the wall thickness.

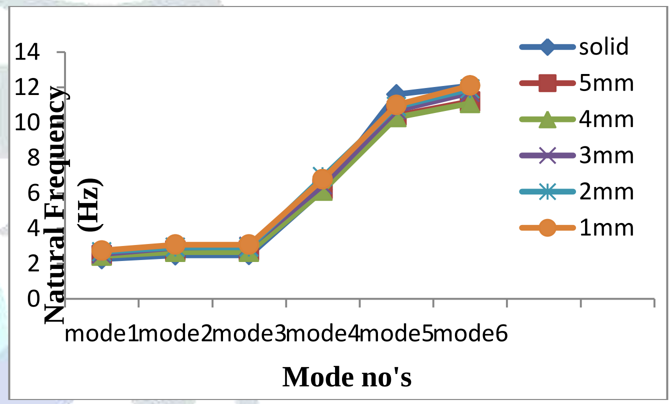


Fig45: Representation of the variation in frequency's at different modes.

For different cross sectional blade the changing values of frequency with regards to the modes (1to6). Out of all the wall thickness presented the solid blade model has the least frequency.

MODAL ANALYSIS ON COMPOSITE STRAIGHT WIND TURBINE BLADE. (a) Modal analysis for 1%carbon fiber.

Modal analysis is carried out with a blade made of 1%carbon fiber composite for the thicknesses (i.e.solid,5 mm, 4 mm, 3 mm, 2 mm,1 mm) optimized straight wind turbine blade and the modal analysis results .The model frequencies for 1%carbon fiber got less values when compared with aluminum. Because, 1%carbon fiber has more strain energy than aluminum. Different cross sectional blades there exhibits same frequency values corresponding to the modes 1 and 2.

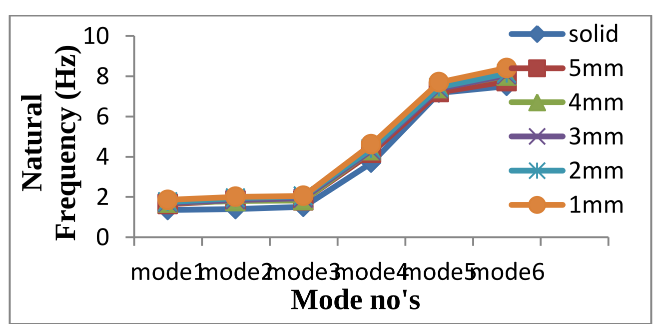


Fig46: Representation of the variation in frequency's at different modes

The extracted modes for various cross sections have different varying frequencies are represented. The change in frequencies is due to the effect of flap wise bending (1to3modes) and torsional bending (4to6modes). Irrespective to the type of bending the 1mm thickness blade models shows higher frequency values among all the other cross sectional blades.

Modal analysis for neat matrix.

The frequencies for various cross section blades made with neat matrix for both solid element blade model. Compare with aluminum and 1%carbon fiber the neat has lower frequencies with respect to wall thickness for different blade models. As the thickness decreases the frequencies of the blades diminish up to 4mm and there on the frequency shows a increasing trend.

The different wall thicknesses blade models show varying frequencies corresponding the modes (1 to 6) is illustrated. The frequencies for the blade model made of neat matrix starts with lower frequencies and ends with high frequency values from 1st mode to 6th mode

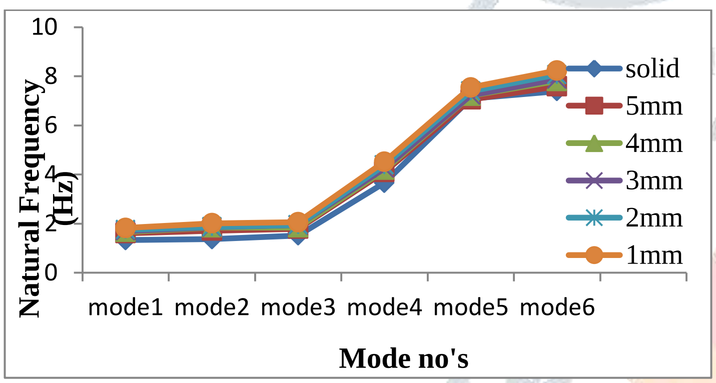


Fig47: Representation of the variation in frequency's at different modes

The different wall thicknesses blade models show varying frequencies corresponding the modes (1 to 6) is illustrated. The frequencies for the blade model made of neat matrix starts with lower frequencies and ends with high frequency values from mode 1 to mode 6.

Modal analysis for E-glass composite.

.For the E -glass composites the model frequencies are relatively low in compared with aluminum, 1%caron fiber and neat matrix.

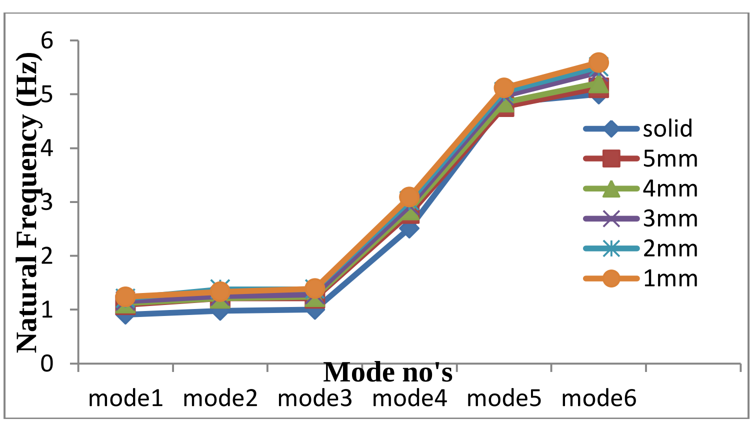


Fig48: Representation of the variation in frequency's at different modes

It can be observed that the frequencies increase from first mode to sixth mode. The frequency values for remaining modes are inappropriate so it is not mentioned in the plot. Solid blade model frequencies are lower compared with reaming blade model frequencies it can be observed that frequencies plots of first three blade models solid blade model, 4mm thickness, 3mm thickness blade model are in lower level compared with remaining three blade models.

MODAL ANALYSIS RESULTS FOR ALUMINUM AND COMPOSITES.

Composite materials put forward some low frequency values in disparity with aluminum for 4mm optimized wall thickness blade model.

The frequencies graph for Neat matrix follows close path with the frequencies graph of 1%carbon fiber, because the material properties are very close. E – Glass material has lower frequencies over the other three materials (i.e.1%carbon fiber, neat matrix and aluminum).

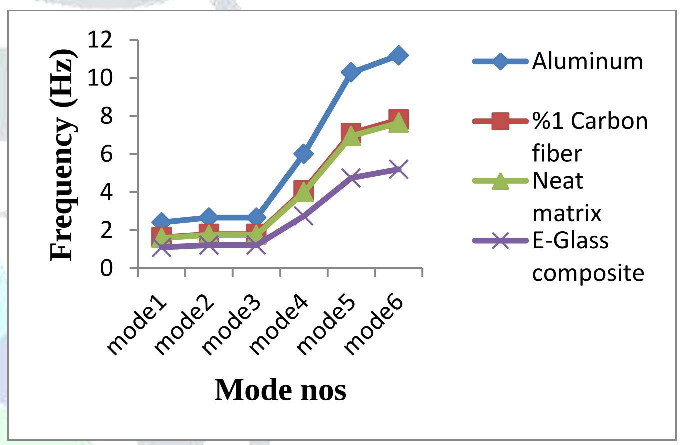


Fig49: Representation of the variation in frequency's at different modes for aluminum and composite.

6.CONCLUSIONS

The Von-Mises stress and total deformation induced due to static loads are compared against the values that are obtained in the previous work [1], where an error 3% in Von-Mises stresses and 0.61% in total deformation is obtained. Hence, the model developed in our present work is validated. When the cross sections of these blades were modeled and analyzed it was observed that the distortion in the blade shape occurs at the regions of maximum deflections as shown in Fig6.27 and it is suggested that choosing 4mm thickness blade is optimized by reducing weight of the blade, maximum stress and maximum deflection were in acceptable range. Masses of the 4mm thickness optimized straight hallow cross section blade (VAWT) for aluminum, 1%carbon fiber, neat matrix, E- Glass composite are 10.89, 7.27, 7.23, 7.23.(i.e. replacing of aluminum with composite masses of blade reducing 30% of its weight). The Von-Misses stresses developed in 4mm thickness optimized straight hallow cross section blade (VAWT) during static analysis for, aluminum, 1%CF, neat matrix and E-glass material respectively as 65.1, 45.09, 45, and 44.9, MPa. These stresses are below yield stress of their respective materials i.e. 250, 185, 201.37, 165.6, and 154 MPa. Thus it is safe. And Von - mises stresses for composites are less compared with aluminum (so, therefore aluminum is replaced with composite von mises stresses which reduced to 30 %.of Von-mises stress). The total deformations induced during static analysis were 4.23, 11.08, 11.91 and 24.99 mm for aluminum, 1%CF, neat matrix and E-glass material respectively. And Deformations induced in the composites are more compared to aluminm.

Frequencies of composite materials less compared with aluminum. So, replacing of aluminum with 1% carbon fiber and neat matrix reduces the frequencies to 33% of its natural frequency, or replacing aluminum with E- glass composite decrease its frequency to 54% of its natural frequency.

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Agnihothram Madhulatha
Studying M.Tech (Machine Design) in SREE VAHINI INSTITUTE OF SCIENCE & TECHNOLOGY , TIRUVURU .

CHITTURI VENKATESWARARAO STUDIED M.Tech in NOVA COLLEGE OF ENGG & TECHNOLOGY, Janga Reddy Gudem, West Godawari (Dist) . Working as a Asst. Professor in SREE VAHINI INSTITUTE OF SCIENCE & TECHNOLOGY, TIRUVURU, KRISHNA (Dist), A.P.

T.N.CHARYULU Pursuing Ph.D from BHARATH UNIVERSITY. Working as a Associate Professor in SREE VAHINI INSTITUTE OF SCIENCE & TECHNOLOGY , TIRUVURU .Published 18 International Journals .