Stress Analysis of Helicopter Composite Blade Using Finite Element Analysis

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ABSTRACT

Composite materials are widely used in the aerospace industry because of their high strength-to-weight ratios. Military aircraft, including Navy aircraft, are constructed using considerable amounts of composites. Present paper proposes a methodology to model a propeller with a metal and composite material to analyze its strength and deformation using software. In order to evaluate the effectiveness of composite over metals, stress analysis is performed on both composite and metal propeller using software. Proposed methodology showed substantial improvements in metal propellers. The mean deflection, normal stress and shear stress were found for both metallic and composite propeller by using software. From the results, stress analysis composite propeller is safe resonance phenomenon. In this work effort is made to reduce stress levels so that advantage of weight reduction along with stresses can be obtained. The comparison analysis of metallic and composite propeller was made for the maximum deformation and normal stresses.

Keywords: Composite Propeller, FEA, Stress Analysis

1.INTRODUCTION

Composite materials are used in numerous structural applications. The application of composite materials technology to marine architecture has increased with particular benefits of its light weight, less noise and pressure fluctuation and less fuel consumption. A structural analysis of the propeller blade is difficult because its geometry and loading is complex. The classical curved beam, plate and shell theories were applied in early structural analysis of propellers. These approaches have been demonstrated to be successful, but special assumptions limit their application of the methods. The finite element method is so popular and has been used by many researchers. Traditionally marine propellers are made off manganese-nickel aluminum-bronze and nickel aluminum bronze for their superior corrosion resistance, high yield strength, reliability and affordability. However, it is expensive to machine metallic materials into complex material geometries. Moreover, metallic propellers are subjected to corrosion and cavitation damage, fatigue induced cracking, and have relatively poor acoustic damping properties that can lead to noise due to structural vibration.

The application of composite materials technology to marine architecture has increased with particular benefits of its light weight, less noise and pressure fluctuation and less fuel consumption[1].The finite element method is so popular and has been used by many researchers[2].The technology advances and the costs of composites are becoming cheaper[3]. Moreovercomposites can offer the potential benefits of reduced corrosion and cavitation damage, improved fatigue performance, lower noise, improved material damping properties and reduced life time maintenance costs[4].Changes to the tensile and flexure properties of marine-grade glass –reinforced polyester, vinylsterand resole phenolic composites after exposure to radiant heat are investigated[5].When using the Genetic Algorithm approach, some techniques for parameter setting to provide quick and correct results were discussed along with the influence of these parameters[6].The numerical results are in agreement with experimental data and the general characteristics of the propeller flow seem to be quite well predicted[7].A strong correlation was identified between the divergence ship speed and the change in the tip pitch angle of the blades in brief communication static divergence of self-twisting composite rotors. The methodology used is equally applicable to other structures such as tidal and wind turbines[8].Taylor[9] considered a propeller blade as a cantilever rigid at the boss. Chang Suplee[10] investigated the main sources of propeller blade failure and resolved the problems related to blades symmetrically. G.H.M.Beek[11] examined the interference between the stress conditions in the propeller blade and the hub. GauFenglin[12] carried out stress calculations for fiber reinforced composite thrust blade.[1]

Presently conventional marine propellers remain the standard propulsion mechanism for surface ships and under water vehicles. The propeller blade geometry and its design are complex involving many controlling parameters. The strength analysis of such complex 3D blades with conventional formula will give less accurate values. In such cases finite element

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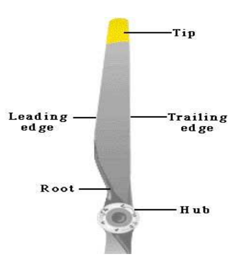
method gives comparable results with experimental values.

The propeller is a vital component for the safe operation of ship at sea. It is therefore important to ensure that ship propeller have adequate strength to with stand the forces that act upon them. Fiber reinforced plastic composite have high strength to weight and these materials have better corrosion resistance, lower maintenance, non-magnetic property and it also have stealth property for naval vessels. The forces that act on a propeller blade arise from thrust and torque of the propeller and the centrifugal force on each blade caused by its revolution around the axis. Owing to somewhat complex shape of propeller blades, the accurate calculations of the stresses resulting from these forces is extremely difficult. The stress analysis of propeller blade with aluminum and composite material is carried out in the present work.

The application of composite technology to marine applications has with particular benefits of its light weight, less noise, pressure fluctuations and fuel consumption [1]. The finite element method is so popular and has been used many researchers [2]. The research and development of propellers using composites are advancing. The back drop to this advancement is the fact that composites can provide a wide variety of special characteristics that metals cannot. In terms of cost, as well as diffusion rates of composites is rapid, technology advances yearly and the costs of composites are becoming cheaper [3]. More over composites can offer the potential benefits corrosion resistance and fatigue performance, improved material damping properties and reduced life time maintenance cost [4]. Taylor [5] considered a propeller blade as a cantilever rigid at the boss. J.E Conolly [6] combined theory and with experimental work for wide blades. Chang suplee [7] investigated the main sources of propeller blade failure and resolved the problems related to blades symmetrically. G.H.M Beet [8] examined the interference between the stress conditions in the propeller blade and the hub. W.J.Colcough [9] studied the advantages of a composite propeller blade with fiber reinforced plastic over that of the propeller blade made from over materials. GauFengLin [10] carried out a stress calculations for fiber reinforced composite thrust blade.

Blade profile



2.Forces and stresses acting on a propeller in flight

The forces acting on a propeller in flight are:

-Thrust is the air force on the propeller which is parallel to the direction of advance and induces bending stress in the propeller.

-Centrifugal force is caused by rotation of the propeller and tends to throw the blade out from the center.

-Torsion or Twisting forces in the blade itself, caused by the resultant of air forces which tend to twist the blades toward a lower blade angle.

The stress acting on a propeller in flight is:

-Bending stresses are induced by the trust forces. These stresses tend to bend the blade forward as the airplane is moved through the air by the propeller.

-Tensile stresses are caused by centrifugal force.

-Torsion stresses are produced in rotating propeller blades by two twisting moments. One of these stresses is caused by the air reaction on the blades and is called the aerodynamic twisting moment. Another stress is caused by centrifugal force and is called the centrifugal twisting moment.

3. CONSTITUTIVE MODELING:

3.1Composite Materials

Most of composite materials are anisotropic and heterogeneous. These two characteristics applied to the composite materials since the material properties are different in all directions and locations in the body. It differs from any common isotropic material, for example, steel which has identical material properties in any direction and location in the body. Hence, the difficulty in analysing the stress-strain relationship of composite materials becomes greater. However, it is still acceptable assuming that the stress-strain relationship of composite material behaves linearly and elastically and follows Hooke's law. The relationship for three dimensional bodies in a 1-2-3 orthogonal Cartesian coordinate system is given as follows (Kaw, 2006)

$$[\sigma] = [C][\varepsilon]$$

$$\begin{bmatrix} \sigma_1 \\ \sigma_2 \\ \sigma_3 \\ \tau_{23} \\ \tau_{31} \\ \tau_{12} \end{bmatrix} = \begin{bmatrix} C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16} \\ C_{21} & C_{22} & C_{23} & C_{24} & C_{25} & C_{26} \\ C_{31} & C_{32} & C_{33} & C_{34} & C_{35} & C_{36} \\ C_{41} & C_{42} & C_{43} & C_{44} & C_{45} & C_{46} \\ C_{51} & C_{52} & C_{53} & C_{54} & C_{55} & C_{56} \\ C_{61} & C_{62} & C_{63} & C_{64} & C_{65} & C_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \gamma_{23} \\ \gamma_{31} \\ \gamma_{12} \end{bmatrix}$$

This 6 x 6 [C] matrix is called stiffness matrix and it has 36 constants. However, due to symmetry of stiffness matrix, the constants can be reduced to 21 constants. It can be shown as follows. The stress-strain relationship can also be formulated as:

$$\sigma_i = \sum_{j=1}^{6} C_{ij}\varepsilon_j, \quad i = 1....6$$

The strain energy in the body per unit volume is taken as:

$$W = \frac{1}{2}\sum_{j=1}^{6}\sigma_i\varepsilon_j, \quad i=1....6$$

$$W = \frac{1}{2}\sum_{i=1}^{6}\sum_{j=1}^{6} C_{ij}\varepsilon_i\varepsilon_j$$

By partial differentiation gives:

$$\frac{\partial W}{\partial\varepsilon_i\partial\varepsilon_j} = C_{ij} \quad \text{and}$$

$$\frac{\partial W}{\partial\varepsilon_j\partial\varepsilon_i} = C_{ji}$$

Since the differentiation is not necessarily to be in either sequent, thus:

$$C_{ij} = C_{ji}$$

Therefore, the stiffness matrix [C] is only left 21 elastic constants instead of 36.

$$\begin{bmatrix}\sigma_1\\\sigma_2\\\sigma_3\\\tau_{23}\\\tau_{31}\\\tau_{12}\end{bmatrix} = \begin{bmatrix}C_{11} & C_{12} & C_{13} & C_{14} & C_{15} & C_{16}\\ & C_{22} & C_{23} & C_{24} & C_{25} & C_{26}\\ & & C_{33} & C_{34} & C_{35} & C_{36}\\ & sym & & C_{44} & C_{45} & C_{46}\\ & & & & C_{55} & C_{56}\\ & & & & & C_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\\varepsilon_2\\\varepsilon_3\\\gamma_{23}\\\gamma_{31}\\\gamma_{12}\end{bmatrix}$$

As mentioned earlier, composite materials is an anisotropic material. Thus, in order to determine its stress-strain relationship, all 21 constants must be obtained. Nonetheless, many composite materials possess material symmetry. Material symmetry is defined as the material and its mirror image about the plane of symmetry are identical. In that case, the elastic properties are similar in directions of symmetry due to symmetry is present in the internal structure of the material. Consequently, this symmetry leads to reducing the number of the independent elastic constants by zeroing out or relating some of the constants within the 6 x 6 stiffness matrix. Thus, the stress-strain relationship will be simplified according to the types of elastic symmetry.

3.2Orthotropic Material

A material is considered as an orthotropic material if there are three mutually perpendicular directions and has only three mutually perpendicular planes of material symmetry (Datoo, 1991[6]). Generally, composite materials are considered as an orthotropic material since there are three mutually perpendicular planes of material property symmetry at a point in the body. The directions orthogonal to the three planes of material symmetry in an orthotropic material define the principal material directions (Grujicic et al., 2006[5]). It has been illustrated in Figure 2.1

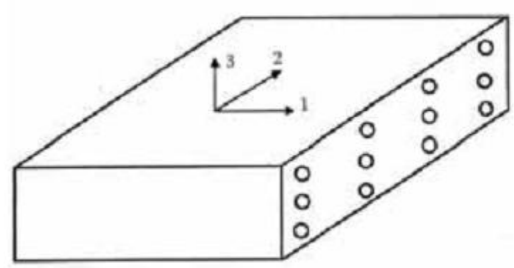


Figure: Principal material directions in an orthotropic material (Kaw, 2006).

As composite materials are considered as orthotropic material, the stiffness matrix is given by (Kaw, 2006)

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$$[C] = \begin{bmatrix}C_{11} & C_{12} & C_{13} & & & \\ C_{21} & C_{22} & C_{23} & & & \\ C_{13} & C_{23} & C_{33} & & & \\ & & & C_{44} & & \\ & & & & C_{55} & \\ & & & & & C_{66}\end{bmatrix}$$

Therefore, it can be shown that only 9 elastic constants need to be solved in order to determine the stress-strain relationship of composite materials. It is expressed as;

$$\begin{bmatrix}\sigma_1\\\sigma_2\\\sigma_3\\\tau_{23}\\\tau_{31}\\\tau_{12}\end{bmatrix} = \begin{bmatrix}C_{11} & C_{12} & C_{13} & & & \\ C_{21} & C_{22} & C_{23} & & & \\ C_{13} & C_{23} & C_{33} & & & \\ & & & C_{44} & & \\ & & & & C_{55} & \\ & & & & & C_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\\varepsilon_2\\\varepsilon_3\\\gamma_{23}\\\gamma_{31}\\\gamma_{12}\end{bmatrix}$$

By substituting the stiffness matrix [C] with engineering constants

$$[C]=\begin{bmatrix} \frac{1-\nu_{23}\nu_{32}}{E_2E_3\Delta} & \frac{\nu_{21}+\nu_{23}\nu_{31}}{E_2E_3\Delta} & \frac{\nu_{31}+\nu_{21}\nu_{32}}{E_2E_3\Delta} & 0 & 0 & 0 \\ \frac{\nu_{21}+\nu_{23}\nu_{31}}{E_2E_3\Delta} & \frac{1-\nu_{23}\nu_{31}}{E_1E_3\Delta} & \frac{\nu_{32}+\nu_{12}\nu_{31}}{E_1E_3\Delta} & 0 & 0 & 0 \\ \frac{\nu_{31}+\nu_{21}\nu_{32}}{E_2E_3\Delta} & \frac{\nu_{32}+\nu_{12}\nu_{31}}{E_1E_3\Delta} & \frac{1-\nu_{12}\nu_{21}}{E_1E_2\Delta} & 0 & 0 & 0 \\ 0 & 0 & 0 & G_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & G_{31} & 0 \\ 0 & 0 & 0 & 0 & 0 & G_{12} \end{bmatrix}$$

$$|\nu_{12}|<\sqrt{\frac{E_1}{E_2}}\ ,\ |\nu_{21}|<\sqrt{\frac{E_2}{E_1}}\ ,\ |\nu_{32}|<\sqrt{\frac{E_3}{E_2}}$$

$$|\nu_{23}|<\sqrt{\frac{E_2}{E_3}}\ ,\ |\nu_{31}|<\sqrt{\frac{E_3}{E_1}}\ ,\ |\nu_{13}|<\sqrt{\frac{E_1}{E_3}} \quad (5.13)$$

4. METHODOLOGY

4.1 Statement of the problem

In this thesis, the problem is to model the tail rotor of helicopter of EC225. Present work proposes a methodology to model a propeller with a metal and composite material to analyze its stress, strength and deformation using Ansys software. In order to evaluate the effectiveness of composite over metals, stress analysis is performed on both composite and metal propeller using Ansys.

Proposed methodology showed substantial improvements in metal propellers. The mean deflection, stress and modal analysis were found for both metallic and composite propeller by using Ansys. From the results, stress analysis composite propeller is safe and sustains more stresses. In this work effort is made to reduce stress levels so that advantage of weight reduction along with stresses can be obtained. The comparison analysis of metallic and composite propeller was made for the maximum deformation and stresses.

4.2DIMENSIONS OF MODEL

Length of the blade =270mm

4.3MATERIAL PROPERTIES OF ALUMINUM

Young's modulus, E = 70e9 GPa

Poisson's ratio, υ=0.3

4.4BOUNDARY CONDITIONS

First modal analysis is done for the blade and found different modes from it.

In the static analysis, the one end of the blade constrained all Degrees of freedom (left side) and other end of the blade is applied pressure of 1Mpa.

Next the material properties of different composite materials are considered like glass fabric/epoxy, carbon/epoxy, and kevlar149. At different orientations like (0,45), (0,90), (-45,+45).

4.5MATERIAL PROPERTIES OF GLASS FABRIC/EPOXY

Young's modulus, Ex = 22925 Mpa
Young's modulus, Ey =22925 Mpa
Young's modulus, Ez =12400Mpa
In-plane shear modulus, Gxy = 4700 MPa
In-plane shear modulus, Gyz = 4200 MPa
In-plane shear modulus, Gyz = 4200 MPa
Poisson's ratio NUxy = 0.12
Poisson's ratio NUyx = 0.2
Poisson's ratio NUzx = 0.2

4.6MATERIAL PROPERTIES OF CARBON EPOXY

Young's modulus, Ex = 120000Mpa
Young's modulus, Ey =10000Mpa
Young's modulus, Ez =10000Mpa
In-plane shear modulus, Gxy = 5200MPa
In-plane shear modulus, Gyz = 3800 MPa
In-plane shear modulus, Gyz = 6000MPa
Poisson's ratio NUxy = 0.16
Poisson's ratio NUyx = 0.16
Poisson's ratio NUzx = 0.16

5. RESULTS & DISCUSSIONS

5.1VALIDATION

For making the validation for the present problem, considering the blade length and modeling in ANSYS in the form of a cantilever beam and applying the load in the form of a uniform distributed load. The derivation of the cantilever beam of uniformly distributed load is taken from the strength of materials by. The derivation as follows:

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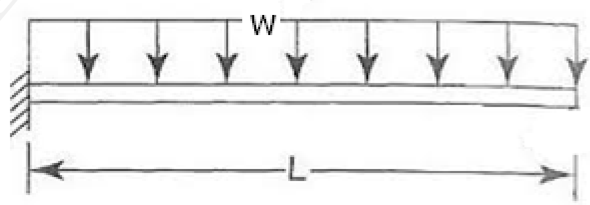

EI $\frac{d^2y}{dx^2}$ = M_x , $C_2=\frac{Wl^4}{24}-\frac{Wl^4}{6}$ $C_2=\frac{Wl^4}{8}$

EI y $=\frac{-Wx^4}{24}+\frac{Wl^3}{6}x+\frac{Wl^4}{8}$

Maximum slope occurs at free end

Maximum deflection occurs at free end

$\delta_{max}=\frac{wl^4}{8\,EI}$

Input data

I_{xx} = (0.02*0.03^3)/12

B= 0.02m

H= 0.03m

E= 7E5 KN/ m^2

L= 0.27m

P= 1 KPa

Calculations

DMX= (1)*(0.27^4) / 3* (7E5)* (4.5*10^{-8})

DMX= 5.31441 * 10^{-3}

DMX= 0.021088 m

6. COMPARISON BETWEEN ALUMINUM AND COMPOSITE MATERIALS

- Aluminum material properties are considered and applied to the blade for modal and static analysis.
- Even for the composite materials like glass fabric/ epoxy, carbon epoxy and is taken and applied for the blade for the modal and static analysis.
- The frequencies are in HZ.

The modal analysis of the aluminum and 5 modes are given below:

MODES	ALUMINUM	GLASS FABRIC	CARBON EPOXY
1	1.73E-03	2.13E-03	2.26E-03
2	1.78E-03	2.21E-03	2.27E-03
3	5.83E-05	2.88E-03	2.88E-03
4	1.39E-03	6.13E-03	6.19E-03
5	2.25E-03	8.04E-02	8.04E-02

Table no.6.1 modal analysis of all the materials

Modal analysis for the aluminum is taken and compared with the computational and analytical values. With that the percentage of error is found between them.

The formula for the natural frequency is given below:

$$Wn = (n - \frac{1}{2})^2 * \frac{\Pi^2}{l^2}\sqrt{EI/m}$$

Where Wn = natural frequencies
N= number of modes
L= length of the beam
E= young's modulus
M= mass of the beam

Below table shows the values compared with the computational and analytical values.

MODES	COMPUTATIONAL	ANALYTICAL	ERROR %
1	1.73E-03	0.0471	0.04537
2	1.78E-03	0.4243	0.42252
3	5.83E-05	1.1786	1.178017
4	1.39E-03	2.31	2.30861
5	2.25E-03	3.8187	3.81645

Table no. 6.2 comparison of the computational & analytical values

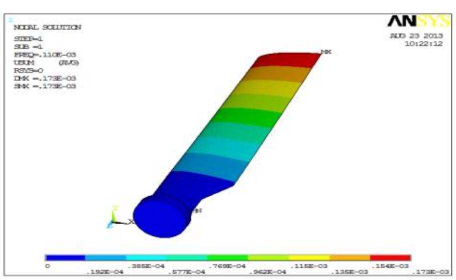

Fig no.6.3 modal analysis of aluminum blade 1 set

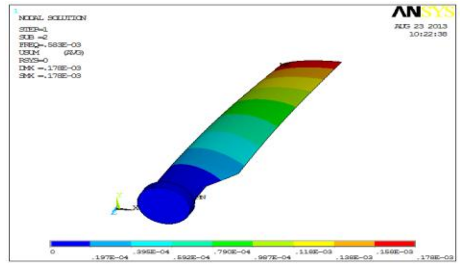

Fig no.6.4 Modal analysis of aluminum blade 2nd set

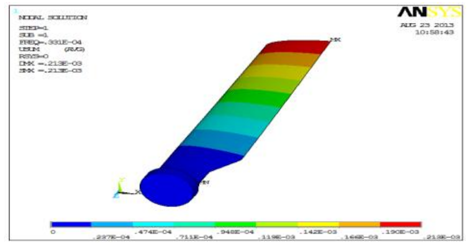

Fig no.6.5 Modal analysis of glass fabric/ epoxy composite 1st set

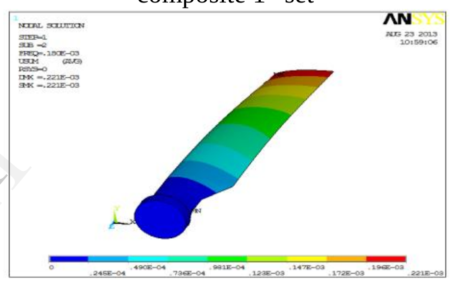

Fig no.6.6Modal analysis of glass fabric/ epoxy composite material 2nd set

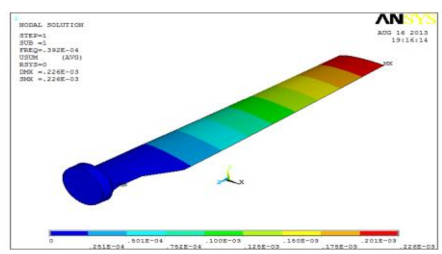

Fig no.6.7Modal analysis of carbon epoxy composite material 1st set

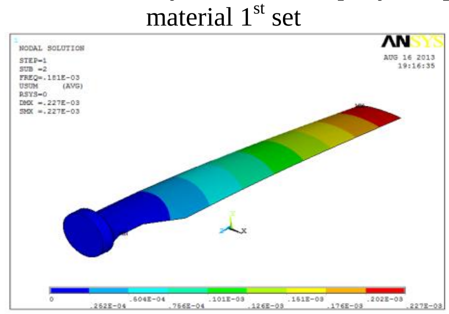

Fig no.6.8Modal analysis of carbon epoxy composite material 2nd set

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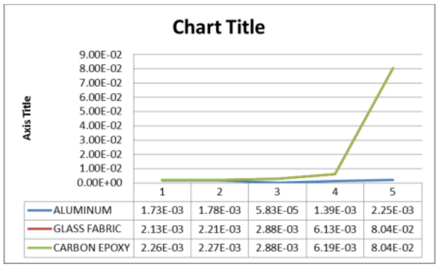

Graph no.6.9 modes. Frequencies of different materials

By seeing the graph between the different metals, we can that carbon epoxy has more frequencies higher and by which we can say that carbon epoxy is a better material compared to other metals

STATIC ANALYSIS

Static analysis of the aluminum one end is constrained and other end is applied pressure of 1Mpa.

The stress of aluminum metal blade is:

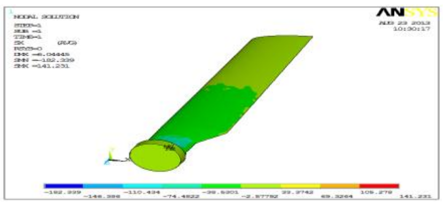

Fig no. 6.10Stress distribution in x direction of aluminum metal

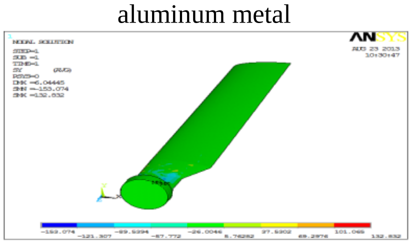

Fig no.6.11Stress distribution in y direction of aluminum metal

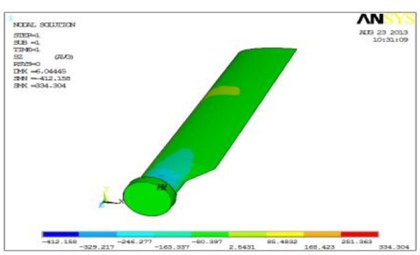

Fig no.6.12Stress distribution in z direction of aluminum metal

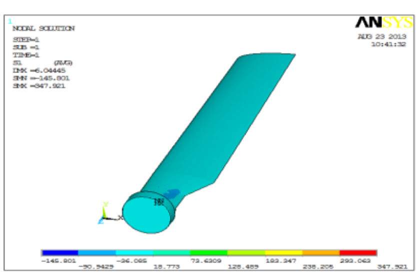

Fig no.6.13 1st principal stresses of aluminum metal

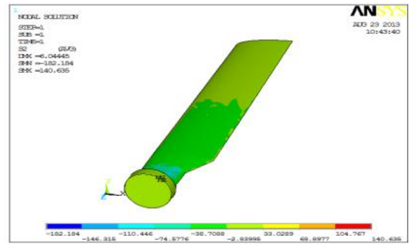

Fig no.6.14 2nd principal stresses of the aluminum metal

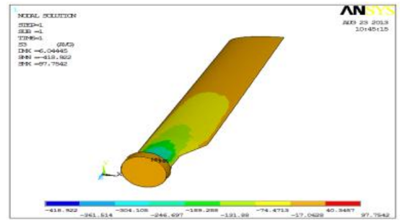

Fig no.6.15 3rd principal stresses of the aluminum metal

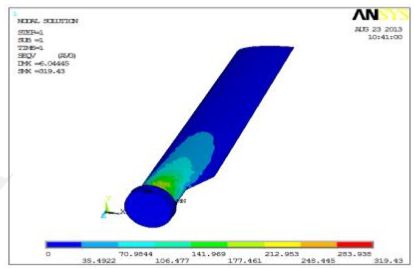

Fig no.6.16 Von misses stresses acting on the aluminum metal

Stresses of Aluminum Metal (SMX)	
X	141.231
Y	132.832
Z	334.304
1st principal	347.921
2nd principal	140.635
3rd principal	97.7542

Table no. 6.17 stresses of aluminum metal

STRESSES OF GLASS FABRIC/ EPOXY ACTING ON THE BLADE

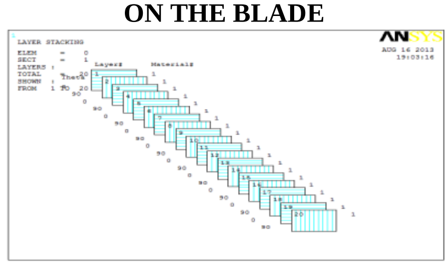

Fig no.6.18 orientation representation of composite layers in ANSYS (0,90)

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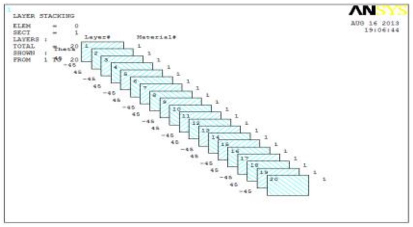

Fig no.6.19 Orientation representation of composite layers in ANSYS (-45,45)

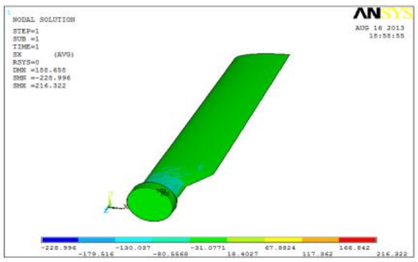

Fig no.6.20 Stress distribution in x direction of glass fabric / epoxy

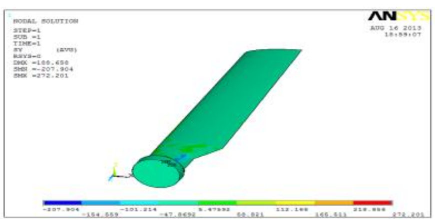

Fig no.6.21 Stress distribution in x direction of glass fabric / epoxy

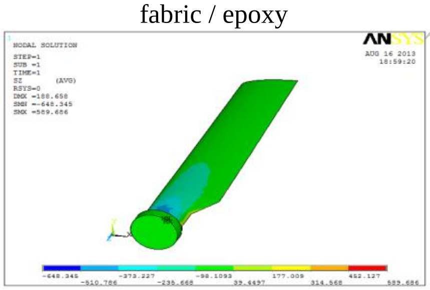

Fig no.6.22Stress distribution in x direction of glass fabric / epoxy

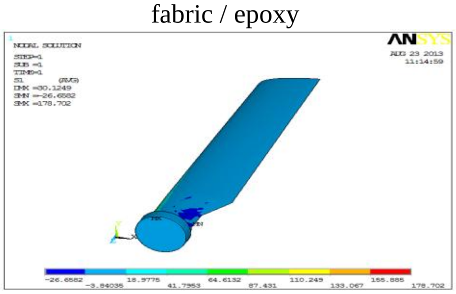

Fig no.6.23 1st principal stresses of glass fabric/epoxy

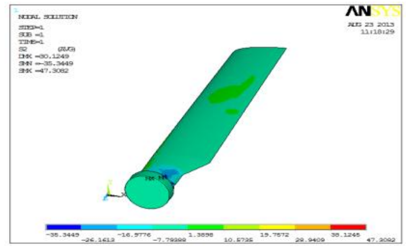

Fig no.6.24 2nd principal stresses of glass fabric/epoxy (0,45)

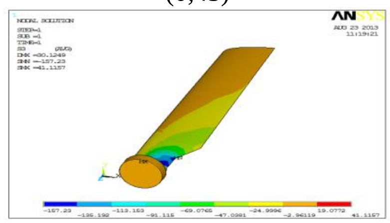

Fig no.6.25 3rd principal stresses of glass fabric/epoxy(0,45)

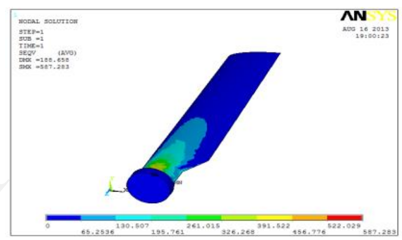

Fig no.6.26 Von misses stresses of glass fabric/epoxy of orientation (0,90)

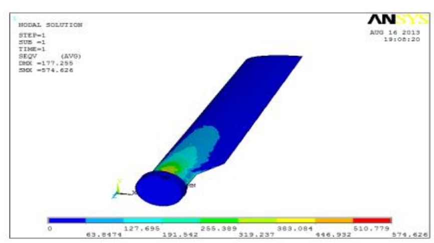

Fig no.6.27 Von misses stresses of glass fabric/epoxy (-45, 45)

Stresses of GLASS FABRIC/EPOXY (SMX)	
X	216.322
Y	272.201
Z	589.686
1st principal	178.702
2nd principal	47.3082
3rd principal	41.1157
Von-misses(0,90)	587.283
Von-misses(-45,45)	574.626

Table no.6.28 Maximum stresses of the glass fabric/epoxy

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-By seeing the stresses obtained when applied of glass fabric/epoxy composite metal on the blade of different orientations like (-45, 45), (0, 90). The von- misses stresses are more in the orientation of (-45, 45) compared with (0, 90).
-(0, 90) orientation the can sustain more loads and is better than (-45, 45) orientation.
-The other stresses like x, y, z of the same orientation is better than other orientations and it can sustain more loads.

STATIC ANALYSIS OF CARBON EPOXY METAL

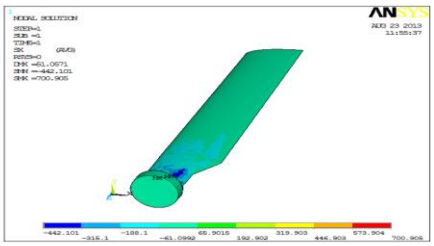

Fig no.6.29 Stress distribution in x direction of carbon epoxy

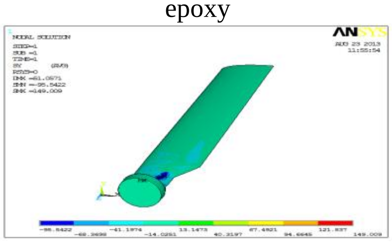

Fig no.6.30Stress distribution in y direction of glass fabric / epoxy

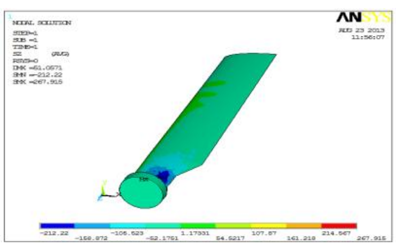

Fig no.6.31 Stress distribution in z direction of glass fabric / epoxy

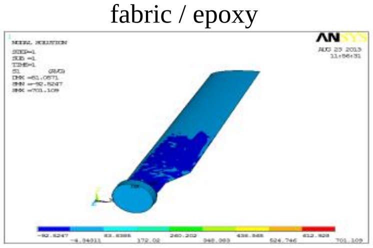

Fig no.6.32 1st principal stresses of carbon epoxy

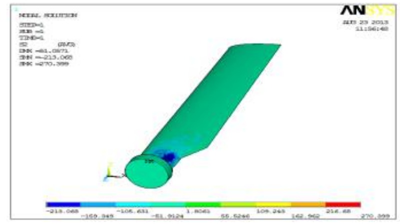

Fig no.6.33 2nd principal stresses of carbon epoxy

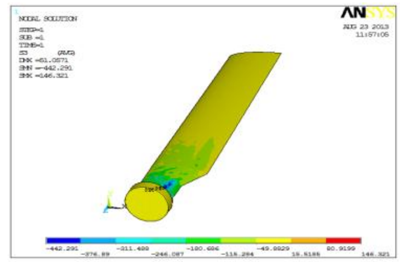

Fig no.6.34 3rd principal stresses of carbon epoxy

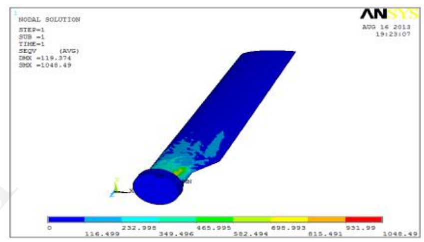

Fig no.6.35 Von- misses stresses of carbon epoxy (0,90)

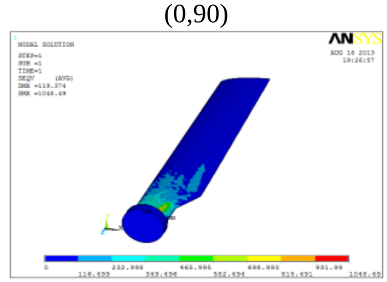

Fig no.6.36 Von misses stresses of carbon epoxy (-45,45)

Stresses of CARBON EPOXY (SMX)	
X	700.905
Y	149.009
Z	267.915
1st principal	701.109
2nd principal	270.399
3rd principal	146.321
Von-misses(0,90)	1048.49
Von-misses(-45,45)	1048.49

Table no.6.37 stresses of carbon epoxy

-Static analysis are obtained of carbon epoxy of different orientations like (-45, 45), (0, 90) and the results are similar.

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-At all an orientation it can sustain loads and compared to glass fabric/epoxy and aluminum carbon epoxy is better to others.

7. CONCULSIONS

Eurocopter 225 helicopter tail rotor blade is considered and comparison of aluminum and composite materials are considered. The blade analysis is done using ANSYS and here we are comparing the modal and static analysis of the aluminum, composite materials like glass fabric/epoxy, carbon epoxy.

In this case, the modal analysis of carbon/epoxy has more range of frequencies compared with other two materials. In the static analysis the stresses of the aluminum are less compared to the carbon/epoxy and for the different orientations like (-45,45), (0,90). The carbon/epoxy can sustain more loads compared to other materials.

In this case, we have taken different orientations and the better orientation is (0,90) for glass fabric/epoxy compared to other orientations. We considered the carbon/epoxy and orientation (0,90), (-45,45) are better to bare the more loads and good to sustain the more stresses.

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