

Optimization Analysis of Helicopter Tail Rotor by Using Metal Matrix Composites



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Abstract:

The helicopter tail rotor spar is designed by modeling software. The spar consists of various parts with different materials. The materials we use here are carbon fiber, matrix composite and stainless steel. The created model in 3D is exported to ANSYS by converting it to IGES format. The imported model is meshed in ANSYS and boundary constraints are defined. With the Boundary constraints, the stresses and strain of the vane can be determined and the values are tabulated. Thus the investigation of stress and strain is carried out using ANSYS. This project will also help to learn Pro E and also ANSYS.

Introduction:

The design of a composite rotor blade in a helicopter is inherently a multidisciplinary problem involving aerodynamics, static and dynamic loads, aeroelasticity, materials, fatigue life, manufacturing aspects, etc. Different stages of a product design and the variation of estimated cost committed, design freedom and knowledge about the design is shown in Figure. It also highlights the current design process and future trend in product design. As indicated in the figure (by dark lines), during the preliminary design stage, the knowledge about the design and the cost committed is the least while the design freedom is the highest. As further progress is made in the design, there is an increase in the cost and knowledge about the design and there is a decrease in the design freedom. At the completion point, we have a complete product. The future trend (indicated by gray lines) would be to shift the "knowledge about the design" curve towards conceptual and preliminary design stage such that there is more design freedom at less cost in the early stages. This strategy will help the designers to make better exploration

of the design variables in the early stages without significant cost. In order to achieve this target, it is desired to obtain "mature" designs in the preliminary design stage by making use of high-fidelity numerical tools for analysis. Thus, during the conceptual design stage, there is a need to balance the fidelity of different models used in the analysis with computational time requirements. Since making design changes in later stages is far more expensive, it is essential to explore the complete design space in the preliminary design stage itself.

For the detailed structural analysis of a rotor blade, a 3D Finite Element (FE) analysis is required in order to capture all the topological details. However, the time-consuming FE analysis is not suitable for conceptual design since a large design space needs to be explored. Instead, due to the geometry of rotor blades, a "dimensional reduction" can be performed that takes the original 3-D body and represents it as a 1D beam along a predefined reference line. This can be done because one dimension (along the length) of a rotor blade is much larger than the other two, and the structure is mostly uniform along the span. For accurate dimensional reduction, following features are required:

- Detailed modeling of the rotor blade cross section which includes isotropic and orthotropic material properties and cross section topology.
 - Accurate representation of 3D blade properties along a reference line.
 - Non-linear aero elastic analysis of the 1D blade.
- The design environment presented here includes these features for rotor blade design through the coupling of the following high-fidelity analysis tools in a design environment:
- IXGEN, the Intelligent Cross Section generator developed by Advatech Pacific, Inc ,

- b) UM/VABS, the University of Michigan / Variational-Asymptotic Beam Sectional analysis
- c) RCAS, the Rotorcraft Comprehensive Analysis System

Design Approach:

The basic approach to the rotor blade design problem, which is adopted in this thesis, is shown in Figure. It is based on the approach used for the design of a rotor blade with active twist in, however, that framework did not include the aeromechanic analysis. In , the failure analysis was done using the worst case loading obtained a priori. In this approach, important sections along the blade span are identified, where geometrical or material properties do not change significantly. For each of these sections, structural topology, layout of composite plies, materials and ply thicknesses are obtained either through a user input or from the optimizer. This information is passed as input for generating cross-sectional mesh and a UM/VABS input file using IXGEN. In the analysis performed in this thesis, IXGEN is used as a mesh generator, though it has more capabilities which are discussed in .

The cross-sectional analysis performed using UM/VABS provides the mass and stiffness matrices which are used as input for 1D nonlinear beam analysis. These matrices can also be used to determine the chordwise location of shear center and center of gravity which act as constraints in the optimization studies. The nonlinear beam finite element analysis of the composite beam is performed in RCAS. It also includes aerodynamic models of different fidelities and various models for determining inflow velocity and for capturing the dynamic stall effects. In a post-processing step, the element loads resulting from the dynamic or aeromechanical analysis are converted to equivalent stress and strain distributions in the individual cross sections.

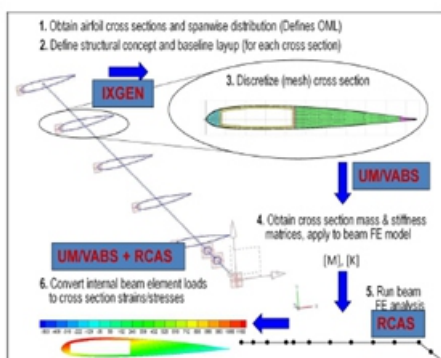
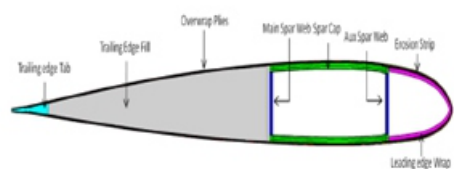
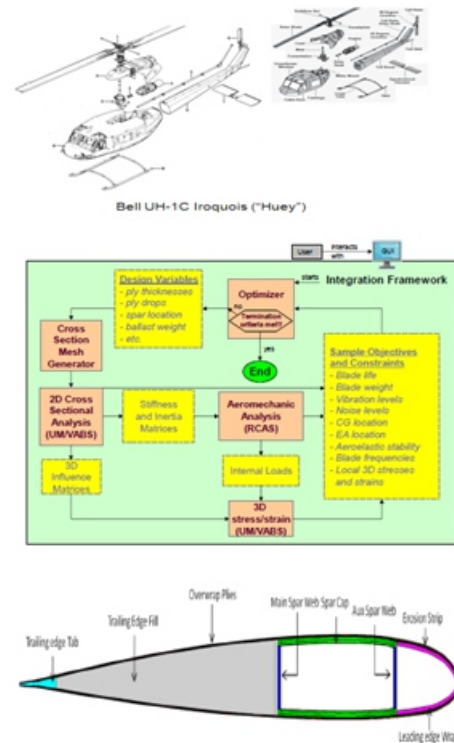


Figure shows the Multidisciplinary Design Optimization (MDO) process that implements the design approach described earlier for the design of a passive composite rotor blade. The main pieces of software/codes used in this analysis are IXGEN, RCAS and UM/VABS.



Terminology of blade

MATERIAL PROPERTIES

3.1 CARBON FIBRE (HIGH MODULUS):

Carbon fiber, alternatively graphite fiber or CF, is a material consisting of fibers about 5–10 μm in diameter and composed mostly of carbon atoms. To produce carbon fiber, the carbon atoms are bonded together in crystals that are more or less aligned parallel to the long axis of the fiber as the crystal alignment gives the fiber high strength-to-volume ratio (making it strong for its size). Several thousand carbon fibers are bundled together to form a tow, which may be used by itself or woven into a fabric.

MECHANICAL PROPERTIES:

Young's modulus	4.0e+5 MPa
Poisson's ratio	0.36
Density	6000 kg/m ³
Shear modulus	1.4706e+5 MPa
Bulk modulus	4.7619e+5 MPa

ADVANTAGES:

The advantages of carbon fibers, such as high stiffness, high tensile strength, low weight, high chemical resistance, high temperature tolerance and low thermal expansion.

3.2 METAL MATRIX COMPOSITE (Ti-6Al-4V+12% TiC):

The addition of titanium with titanium carbide has a positive influence on the modified MMCs. It is noticed that the hardness of the substrate increased from 357.30 HV to 541.30 HV for 88%Ti+12%TiC MMC which have the highest hardness value in the Ti+TiC system. Metal injection moulding (MIM) was used to fabricate Ti-6Al-4V matrix composites reinforced with 12 vol.% TiC particles (referred to as TMCs) at CANMET Materials Technology Laboratory. In this method, a mixture of gas atomized Ti and 60Al40V master alloy powders (both with an average size less than 45 μm) were mixed with TiC particles (irregular in shape and size ranging from 1 to 10 μm) and a wax-based binder in a Tumbler mixer for 30 min followed by hot mixing in a twin-screw extruder at 130 °C to produce the feedstock.

MECHANICAL PROPERTIES:

Density kg m ⁻³	4.43e-006
Young's Modulus MPa	1.14e+008
Poisson's Ratio	0.342
Bulk Modulus MPa	1.2e+008
Shear Modulus MPa	4.2e+007

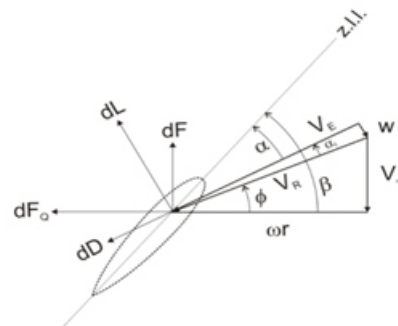
ADVANTAGES:

TiC particulate reinforced Ti6Al4V metal matrix composites (Ti6Al4V+12wt.% TiC) have high strength-to-weight ratio and good high temperature properties. TiC reinforced Ti6Al4V based composites (TiC/Ti6Al4V), and these work has got a remarkable improvement in hardness and tribological properties. Hardness values of TiC/Ti6Al4V composites maintain at about 345HB which is nearly 70HB higher than that of the titanium alloy.

4.5. THEORETICAL CALCULATIONS:

Momentum-Blade Element Theory

- Logically, the next level of analysis would look at a given propeller blade's aerodynamic performance from hub to blade tip
- one can discretize the blade into a finite number of elements, while applying momentum conservation principles



Increment of thrust:

$$dF = dL \cos(\phi + \alpha_i) - dD \sin(\phi + \alpha_i)$$

Resultant velocity:

$$V_R = \sqrt{(\omega r)^2 + V_\infty^2}$$

Increment of torque:

$$dQ = r dF_Q = r [dL \sin(\phi + \alpha_i) + dD \cos(\phi + \alpha_i)]$$

Increment of lift:

$$dL = \frac{1}{2} \rho V_E^2 c C_L dr$$

Increment of drag:

$$dD = \frac{1}{2} \rho V_E^2 c C_d dr$$

Overall resultant velocity:

$$V_E = \sqrt{(w \cos(\phi + \alpha_i) + V_\infty)^2 + (w \sin(\phi + \alpha_i))^2}$$

Induced angle of attack:

$$\alpha_i = \sin^{-1} \left(\frac{w}{V_E} \right)$$

Airfoil lift coefficient:

$$C_l = C_{l_\alpha} (\beta - \alpha_i - \phi) = a_o (\beta - \alpha_i - \phi)$$

Airfoil drag coefficient:

$$C_d = C_{d,min} \quad C_o < C_{o,min}$$

$$C_d = C_{d,min} + k(C_l - C_{l,min})^2 \quad C_{o,min} < C_o < C_{o,max}$$

$$C_d = C_{d,max} + k_l(\alpha - \alpha_{min}) \quad \alpha > \alpha_{max}$$

Via substitutions, increment of thrust:

$$dF \approx dL \cdot \cos \phi = \frac{B}{2} \rho V_E^2 c a_o (\beta - \alpha_i - \phi) dr \cdot \cos \phi$$

Where B is number of blades.

Borrowing from actuator disk theory:

$$dF \approx 2 \rho \cdot dA \cdot (V_o + w)w \approx 2 \rho \cdot dA \cdot (V_\infty + w \cos \phi)w \cos \phi$$

$$\approx 2 \rho (2\pi r dr) \cdot (V_\infty + \alpha_i V_R \cos \phi) \alpha_i V_R \cos \phi$$

Equating the above relations, one arrives at:

$$\alpha_i^2 + \left(\frac{V_\infty}{V_R \cos \phi} + \frac{c a_o B}{8\pi r \cos \phi} \right) \alpha_i - \frac{c a_o B}{8\pi r \cos \phi} (\beta - \phi) = 0$$

Overall propeller solidity:

$$\sigma_{ref} = \frac{\text{blade area}}{\text{disk area}} = \frac{B \cdot c_{ref} R}{\pi R^2} = \frac{B c_{ref}}{\pi R}$$

Local solidity:

$$x = r/R \quad \sigma = \frac{Bc}{\pi R} = x \frac{Bc}{\pi r}$$

Advance ratio:

$$J = \frac{V_\infty}{n d_p} = \frac{V_\infty}{(\omega / (2\pi))(2R)} = \frac{\pi V_\infty}{\omega R}$$

Where n is the prop shaft rotation speed (rps).

Non dimensional velocity ratio:

$$\lambda = \frac{V_\infty}{\omega R} = \frac{J}{\pi}$$

Propeller thrust coefficient:

$$C_T = \frac{F}{\rho n^2 d^4}$$

Propeller power coefficient:

$$C_P = \frac{P_S}{\rho n^3 d^5} \quad P_S = Q\omega$$

Incremental thrust H no. of blades:

$$dF = \frac{1}{2} \rho V_E^2 B c [C_l \cos(\phi + \alpha_i) - C_d \sin(\phi + \alpha_i)] dr$$

Incremental power H no. of blades:

$$dP_S = \omega r \frac{1}{2} \rho V_E^2 B c [C_l \sin(\phi + \alpha_i) + C_d \cos(\phi + \alpha_i)] dr$$

$$V_E^2 \approx V_R^2 = V_\infty^2 + \omega^2 r^2 = \frac{\omega^2 r^2}{\pi^2} (J^2 + \pi^2 x^2)$$

Note:

Thrust coefficient:

$$C_T = \frac{\pi^2}{4 \rho \omega^2 R^4} F$$

$$C_T = \frac{\pi^2}{4 \rho \omega^2 R^4} \int_0^1 dF = \frac{\pi^2}{8} \int_0^1 \sigma (J^2 + \pi^2 x^2) [C_l \cos(\phi + \alpha_i) - C_d \sin(\phi + \alpha_i)] dx$$

Power coefficient:

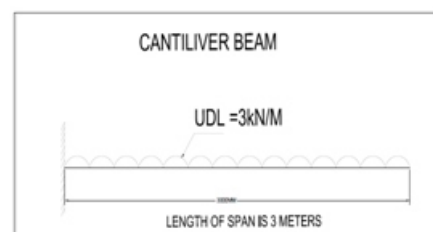
$$C_P = \frac{\pi^3}{4 \rho \omega^3 R^5} P_S$$

$$C_P = \frac{\pi^3}{4 \rho \omega^3 R^5} \int_0^1 dP_S = \frac{\pi^3}{8} \int_0^1 \sigma x (J^2 + \pi^2 x^2) [C_l \sin(\phi + \alpha_i) + C_d \cos(\phi + \alpha_i)] dx$$

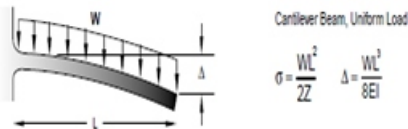
THEORETICAL CALCULATION:

Consider problem as Cantilever Beam, span of 3 Meters and UDL load of 3KN/mm.

CAD image is given below:



σ = maximum stress at outer fiber
 Δ = deflection
 P = force (load)
 W = distributive load
 L = length of beam
 Z = section modulus
 E = flexural modulus
 I = moment of inertia about bending axis



Base Equations:

$$W = 3 \text{ KN/MM}$$

$$L = 3000 \text{ MM}$$

$$Z = \text{(Got from Pro-E model)}$$

$$E = \text{Young's Modules of material.}$$

$$\text{Bending Stress} = M/I = E/R = \sigma / Y$$

$$\text{Deflection } \nabla = WL^3/8EI$$

$$\frac{M}{I} = \frac{\sigma}{y} \text{ or } \sigma = \frac{M}{I} \times y = \left(\frac{M}{I}\right) \times \frac{M}{Z}$$

where Z = Section modulus.

$$\text{Maximum Bending Moment} = W \times X^2/2$$

$$= 3 \times 32/2 = 13.5 \text{ KNM}^2$$

$$\text{Moment of Inertia} = I = 9.45E-4 \text{ m}^4$$

For Material Aluminum:

$$\text{Deflection: } \nabla = WL^3/8EI$$

$$W = 3 \text{ KN}$$

$$E = 69E3 \text{ MPa}$$

$$I = 9.45E-4 \text{ m}^4$$

$$\nabla = 140.3 \text{ mm}$$

Stress:

$$\text{Using the equation: } (M/I) = (E/R) = (\sigma/Y),$$

$$\text{Analytic Stress developed } \sigma = 975.4 \text{ MPa}$$

Stress:

$$\text{Using the equation: } (M/I) = (E/R) = (\sigma/Y),$$

$$\text{Analytic Stress developed } \sigma = 975.4 \text{ MPa}$$

Strain:

$$\text{Using Hooks law : } E = \text{Stress/Strain}$$

$$\text{Strain} = 0.021$$

For Material CARBON FIBRE (HIGH MODULUS):

$$\text{Deflection: } \nabla = WL^3/8EI$$

$$W = 3 \text{ KN}$$

$$E = 4.0e+5 \text{ MPa}$$

$$I = 9.45E-4 \text{ m}^4$$

$$\nabla = 30.5 \text{ mm}$$

Stress:

$$\text{Using the equation: } (M/I) = (E/R) = (\sigma/Y),$$

$$\text{Analytic Stress developed } \sigma = 960.2 \text{ MPa}$$

Strain:

$$\text{Using Hooks law : } E = \text{Stress/Strain}$$

$$\text{Strain} = 0.0015$$

For Material MATRIX COMPOSITE (TI-6AL-4V-12TIC):

$$\text{Deflection: } \nabla = WL^3/8EI$$

$$W = 3 \text{ KN}$$

$$E = 1.14e+008 \text{ MPa}$$

$$I = 9.45E-4 \text{ m}^4$$

$$\nabla = 85.2 \text{ mm}$$

Stress:

$$\text{Using the equation: } (M/I) = (E/R) = (\sigma/Y),$$

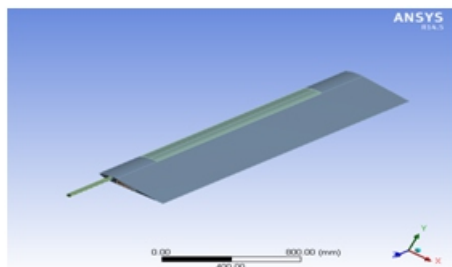
$$\text{Analytic Stress developed } \sigma = 967.3 \text{ MPa}$$

Strain:

$$\text{Using Hooks law : } E = \text{Stress/Strain}$$

$$\text{Strain} = 0.008$$

5.2 GEOMETRY VIEW OF HELICOPTER TAIL ROTOR SPAR IN ANSYS WORKBENCH



ANALYSIS PROCEDURE:

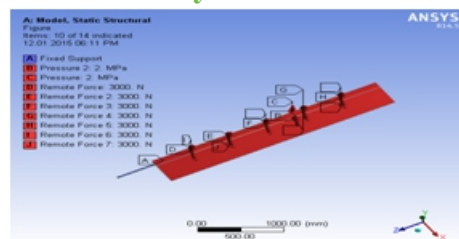
Open ansys work bench and select empty icon to open the empty window. Now click the new geometry option to open the new window. Go to file and select the import option to import the IGES file in to the ansys Select the unit and click the generate icon to open the geometry. Save file with a new name as ansys file Close the window and open the new mesh window by clicking the option provided. In the new window click the mesh option and change the mesh type as fine and right click on the mesh option to generate mesh Close the window and save the file Click simulation option and select the analysis type from new analysis icon and select the type as static structural By selecting the geometry option change the material from the option given below. Select the material file from where you have been saved in XML format. Or type the material properties and save it to library.

Select the support icon and select the fixing rod as a fixed support. Select the load icon and select the pressure option and select the surface on the geometry where the pressure should be applied. Type the magnitude value in the column given. Similarly apply on the other side of the geometry. Select the remote force option from the load icon and select the appropriate points on the geometry's one side and apply. Feed the load as 3000N in all the remote forces. Apply the remote forces as shown the figure below. The similarly apply the remote forces on the other side of the geometry. After applying all the forces right click on the solution icon and select the strain, stress and total deformation options Right click on the solution icon again and select the solve option so that the solving process will be carried out. After the solving the window displays the deformation occurred in the tail rotor. The colour difference mentions the deformation status.

INPUT VALUES APPLIED ON THE SPAR IN ANSYS WORKBENCH:

PRESSURE: 2.e+006PA
 PRESSURE 2: 2.e+006PA
 REMOTE FORCE: 3000 N
 REMOTE FORCE 2: 3000 N
 REMOTE FORCE 3: 3000 N
 REMOTE FORCE 4: 3000 N
 REMOTE FORCE 5: 3000 N
 REMOTE FORCE 6: 3000 N
 REMOTE FORCE 7: 3000 N
 REMOTE FORCE 8: 3000 N
 REMOTE FORCE 9: 3000 N
 REMOTE FORCE 10: 3000 N

Load and boundary conditions:



RESULTS AND COMPARISON OF ABOVE MATERIALS from FEM :

s.no	MATERIALS	TOTAL DEFORMATION (mm)	EQUIVALENT ELASTIC STRAIN (mm/mm)	EQUIVALENT STRESS S (Mpa)
1	ALUMINUM ALLOY	154.25	0.0139	988.1
2	CARBON FIBRE (HIGH MODULUS)	27.32	0.0024	965.74
3	MATRIX COMPOSITE (TI-6AL-4V-12TiC)	96	0.0085	979.55

RESULTS AND COMPARISON OF ABOVE MATERIALS FROM ANALYTICAL:

S.No	MATERIALS	TOTAL DEFORMATION (mm)	EQUIVALENT ELASTIC STRAIN (mm/mm)	EQUIVALENT STRESS (Mpa)
1	ALUMINUM ALLOY	140.3	0.021	975.4
2	CARBON FIBRE (HIGH MODULUS)	30.5	0.0015	960.2
3	MATRIX COMPOSITE (TI-6AL-4V-12TiC)	85.2	0.008	967.3

Graphs:

Plot of results of FEM:

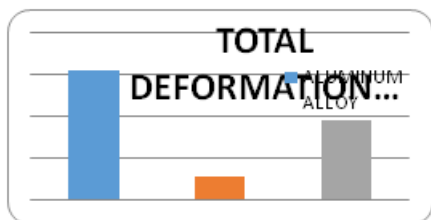


Figure shows deformation vs material as per result of Ansys

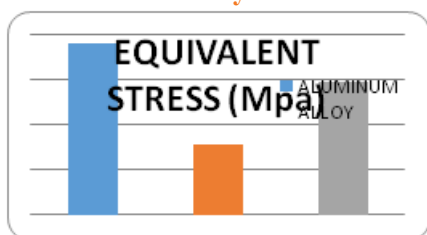


Figure shows stress vs material as per result of Ansys

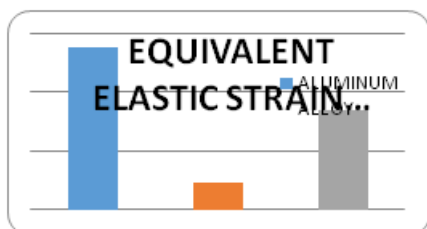


Figure shows strain vs material as per result of Ansys.

Plot of results of Analytical:

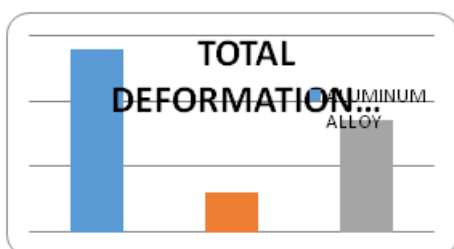


Figure shows Deformation vs. material as per result of Analytical.



Figure shows Strain vs. material as per result of Analytical.



Figure shows Stress vs. material as per result of Analytical.

Compression of Results of Analytical and FEM:

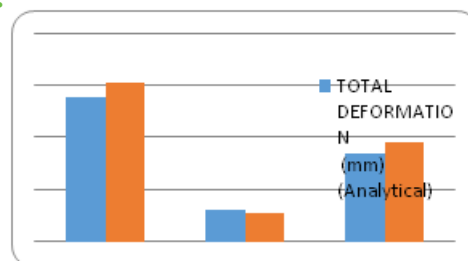


Figure shows deformation vs. material as per result of Analytical vs. ANSYS.

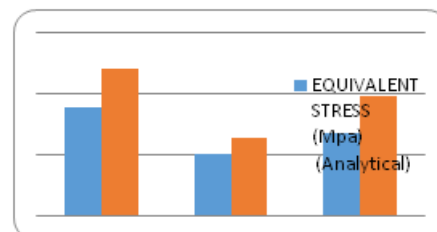


Figure shows Stress vs. material as per result of Analytical vs. ANSYS.

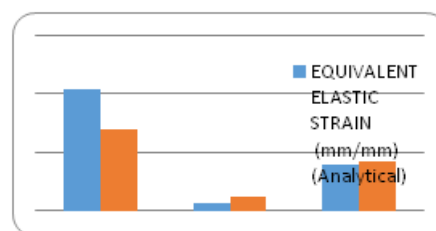


Figure shows Strain vs. material as per result of Analytical vs. ANSYS.

CONCLUSION:

The materials which are used for tail rotor have certain deformation due to the pressure and force acting on the spar. Since it has the withstanding capacity for such loads, it can be considered as a good material.

By this project we have learned 3D modelling software (PRO-E) and Study about the analyzing software (Ansys) to develop our basic knowledge to know about the industrial design. By using material optimization, like changing the material are Aluminum, CARBONFIBRE (HIGH MODULUS) & MATRIX COMPOSITE (TI-6AL-4V-12TIC). Seeing Results of Deformation, stress & Strain. We came to conclusion that best material of blade to manufacture for given load is MATRIX COMPOSITE (TI-6AL-4V-12TIC).

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