Fatigue Analysis on a Vertical Tail Fin (Stabilizer) Using Finite Element Method

Basavaraj Devakki[1], Imran Adam Khan[2], Saddam Hussain H[3]

[1,2,3]UG Students, Dept. of Mechanical Engineering, R.V. College of Engineering, Bangalore, India

***Abstract*: In this work, it is proposed to carry out a detailed finite element fatigue analysis using ANSYS to evaluate fatigue life of vertical tail fin made up of Glass Fiber Reinforced Polymer (GFRP) and Carbon Fiber Reinforced Polymer (CFRP). CAD modeling of the vertical tail fin will be done in CATIA V5 which will be followed by importing to ANSYS for fatigue analysis by feeding the boundary conditions and the mechanical properties. As composite materials have different mechanical properties in different directions, all the mechanical properties will be calculated using available formulae. The fatigue parameters are evaluated for different volume of fractions of fibers for both composite materials (CFRP and GFRP). Results are compared for both the composite material. The tail assembly of an aircraft structure commonly referred to as empennage, which provides directional stability to aircraft. Tail assembly includes horizontal fin (stabilizer) and vertical fin. A lot of research has been made on improving the fatigue life of an aircraft. Fatigue analysis of an aircraft includes determination of fatigue life, damage factor, safety factor, SN curve etc. Composite materials have been widely used in aerospace applications because of their low density and high strength property. Fatigue occurs when a material is subjected to repeated loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the surface. The vertical fin will have infinite fatigue life i.e., it will not see any cracks over its surface below a stress level called Endurance limit.**

***Keywords*: Fatigue analysis, composite materials, vertical tail fin, Finite Element Method.**

1. INTRODUCTION

Fatigue is the weakening of a material which is caused by repeatedly applied loads. Fatigue is progressive and localized structural damage that occurs when a material is subjected to cyclic loading. The maximum stress values that cause such damage may be much less than the strength of the material typically quoted as the ultimate tensile stress limit, or the yield stress limit. The vertical stabilizers or fin of aircraft, bombs or missiles are typically found on the aft end of the fuselage, and are intended to reduce aerodynamic side slip and provide direction stability. There is one more part called Rudder which is connected to vertical tail fin which helps in providing directional stability. Vertical tails designed for aircrafts suffer from reduced stability and control effectiveness at high dynamic pressures due to aeroelastic effects. Adequate tail performance requires a detailed study on dynamic performance before investigating aeroelastic effects. Vertical tail is attached to the fuselage through attachment brackets. The joint locations between the major components of the aircraft are considered to be critical locations. Tail fin is usually made up of composite materials [6] because of their low density and high strength property. Loads received by the vertical tail will get transferred to fuselage at the root. It is almost like a cantilever action, which induces maximum bending moment at the root [7]. However lots of research has been made on improving the mechanical properties of composite materials by adding different materials which have high strength but low density compared to composite materials. The materials which are added to composite materials are called as filler materials. Latest survey says addition different filler materials such as rubber particles, coal ash, PCB powder etc[3]. in certain ratio increases the fatigue strength, safety factor. However there is a certain ratio for filler material to be added, if they are added exceeding the limit then the mechanical properties of composite materials start decreasing.

Carbon fiber–reinforced polymer (CFRP) (fig.1)is an extremely strong and light fiber-reinforced polymer which contains carbon fibers. CFRPs can be expensive to produce but are commonly used wherever high strength-to-weight ratio and rigidity are required, such as aerospace, automotive and civil engineering, [11]sports goods and an increasing number of other consumer and technical applications.

Glass-reinforced plastic ***(GRP)*** or alternatively ***glass-fiber reinforced plastic (GFRP)***(Fig.2) is commonly called as fiber glass[2]**.** Fiber glass is a fiber reinforced polymer made of plastic reinforced by glass fibers, commonly woven into a mat. The plastic may be a thermosetting plastic- most often epoxy, polyester- or vinylester or a thermoplastic. The glass fibers are made of various types of glass depending upon the fiberglass use. These glasses all contain silica or silicate, with varying amounts of oxides of calcium, magnesium, and sometimes boron. Boron-containing fiber glasses consume half the global production of boron minerals, and are the largest commercial consumer of the element.

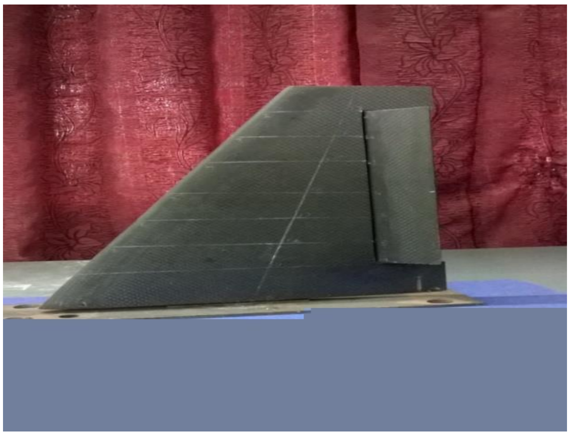


Fig.1 Vertical tail made up of CFRP

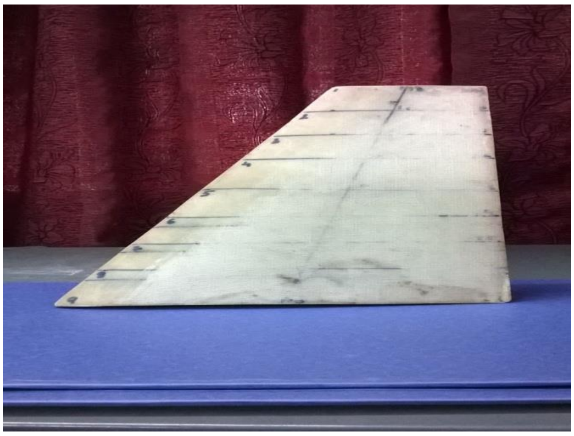


Fig.2 Vertical tail fin made up of GFRP

2. FATIGUE

Any load that varies with time can potentially cause fatigue failure. The character of these loads may vary substantially from one application to another. In rotating machine, the loads tend to be consistent in amplitude over time and repeat with the same frequency. In service equipment, the loads tend to be quite variable in amplitude and frequency over time and may even be random in nature. Usually the shape of the waveform of the load-time function does not to have any significant effect on fatigue failure. Therefore we usually depict the function schematically as a sinusoidal form. The stress-time waveform has the same general shape and frequency as the load-time waveform. The significant factors are the amplitude and the average value of the stress-time waveform and total number of stress cycle that the part will experience some basic definitions about fatigue phenomena and variation of service equipment loading are discussed in the following sections.

3. LITERATURE REVIEW

Vignesh T., Hemnath B.G., Chinagounder C et.al, April 2014[1], In this paper static and fatigue analysis of vertical stabilizer have been carried out at +4g factor condition. Using CATIA V5 software the stabilizer was modeled and imported to Patran and Nastran software for static stress analysis. Material used for component design is Aluminium 7075 T6 and has high fatigue strength. From static stress analysis, it was found that maximum principal stress value is less than the yield strength of Al 7075 T6. The safe number of factored fatigue life hours for the component has been obtained using maximum principal stress value and von mises stress at the bottom end of the leading edge spar. The fatigue life hours have been calculated for component from the fatigue analysis (stress- life method) and found to be 91743 Flight hours which is greater than the required fatigue life hours of range 60,000-80,000. The results in this work conclude the efficient number of factored fatigue life hours for the vertical stabilizer which would reduce the service cost of the component and ensures structural safety to the component.

Shanmugavel P, Bhaskar G.B et.al, Feb-Mar 2014 [4], This paper present that experimental study on fatigue characteristics of Aluminium and Al-SiC Composite Material Edge Crack Specimens under Flexural Loading Conditions. Crack propagation studies were done experimentally on Aluminium plate and Aluminium-Silicon Carbide composite plate under three point bend test conditions. The specimens with different crack length (l) to the depth (d) ratios (l/d

Ratios) were prepared and the fatigue characteristics of the specimens with different l/d ratios have been obtained experimentally and thus obtained results are compared. The fatigue results of isotropic and Al-SiC composites have been plotted for different l/d ratios. It has been found that Al-SiC has fatigue strength than isotropic Aluminium for same l/d ratio.

Bandaru Swetha, Gundlathoti Sowmya, Nov 2013 [5], In this, paper it has been stated about the design and fatigue analysis of WIG(Wing In Ground) vehicle both experimentally and numerically. Initially design of WIG has been carried out in CATIA and imported MSc Nastran/Patran software for analysis. Analysis will be carried out by inputting material properties and loading conditions. From the experimental and numerical analysis it has been found that under repeated loading or unloading, failure can produced by stresses and that magnitude of these stresses required to produce failure decreases as the number of cycles of stresses increases. This phenomenon of the decreased resistance of a material to varying stresses is called fatigue.

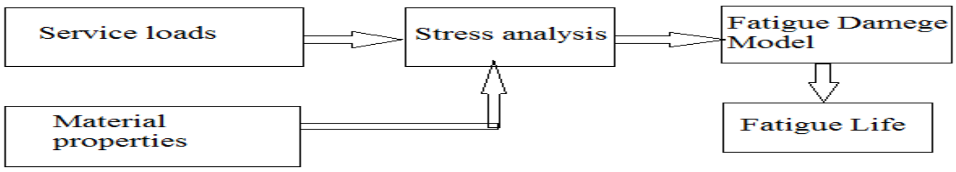


Fig: 3 step by step fatigue analysis.

Objectives of this paper:

1. To study the fatigue behavior of CFRP and GFRP vertical tail fin using Finite Element Method.
2. Carrying out iteration of fatigue analysis for different volume fraction.
3. Comparison of fatigue behavior for both materials

Methodology used:

1. CAD modeling of vertical tail structure will be done in CATIA V5R19 according to standard dimensions.
1. FEA analysis of model using appropriate element types, material properties, loading and boundary conditions.
2. Interpretation of the results for the fatigue behavior of the component for given set of elastic constants.
3. Carryout the same analysis for different volume fractions for both CFRP and GFRP.
4. Optimizing the life of the components based on different parameters.

Modeling in CATIA V5:- The drawing (fig.4) of an existent design of the vertical tail fin of a standard Unmanned Aerial Vehicle was procured. The drawings are depicted in the following figure. The vertical tail fin has been modeled in CATIA V5 software using the available dimensions. The commands used are spline and swept commands which are available in the software. Fig.5 shows CAD model of the vertical tail fin.

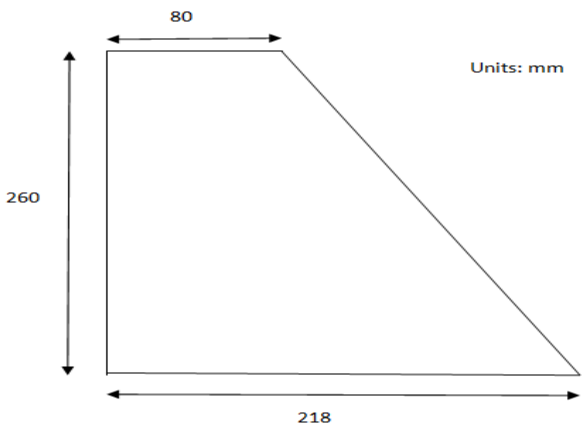


Fig.4 drawing of tail fin

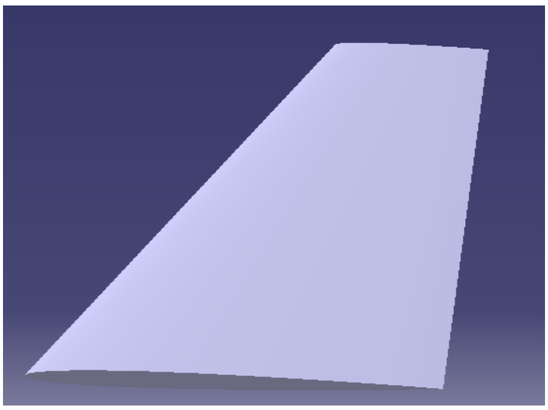


Fig.5 Modeled view of Tail fin in CATIA V5

5. FATIGUE ANALYSIS IN ANSYS

The table.1 shows composite materials properties to be input to ANSYS for different volume of fraction [10] of fiber and matrix for both Carbon and Glass fiber. These values can be obtained using available formulae. Once the materials properties are input then necessary boundary conditions are to be given. That is bottom end of vertical tail fin fixed and other end is kept free as the case. Fig.6 shows meshing of vertical tail fin done in ANSYS 12. The number of elements and number nodes are 6897 and 35851 respectively. Fatigue analysis includes determination of fatigue life and safety factor for 100kN load applied at repeatedly on vertical tail fin in cyclical manner and all other surface of fin has been under fatigue load.

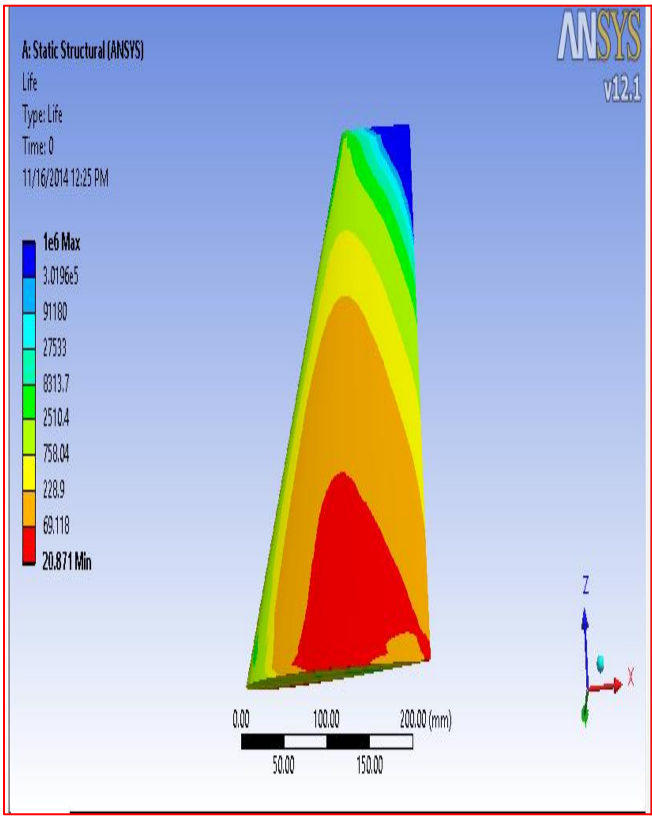
Table.1 Materials properties to be input for different V_f

Material Properties	CFRP			GFRP		
	V_F=.55	V_F=.60	V_F=.65	V_F=.55	V_F=.60	V_F=.65
E_1 (GPa)	87	94	101	44.1	47.2	50.3
E_2 (GPa)	20.54	22.72	25.432	18.997	20.689	22.71
E_3 (GPa)	20.54	22.72	25.432	18.997	20.689	22.71
$\mu_{12}=\mu_{23}=\mu_{31}$	0.587	0.604	0.621	0.2955	0.286	0.2765
$G_{12}=G_{21}=G_{13}$	8.21	9.03	10.01	7	7.56	8.34
σ_{ult} (Mpa)	2400	2592.5	2785.5	1897.7	2070.1	2242.6
σ_y (Mpa)	1200	1296	1392	948.5	1035	1121.3

6. RESULTS AND DISCUSSION

Fatigue life:

1. V_f=0.55, V_m=0.45



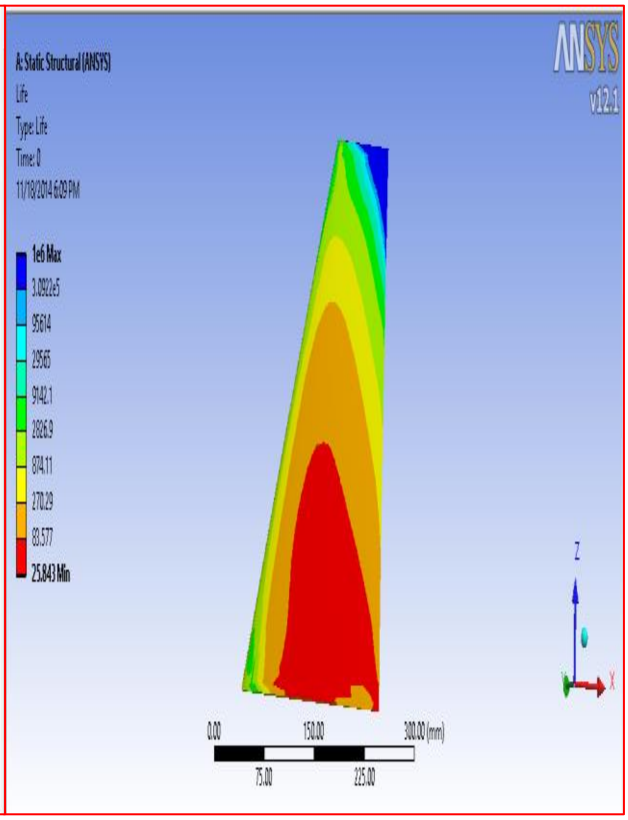
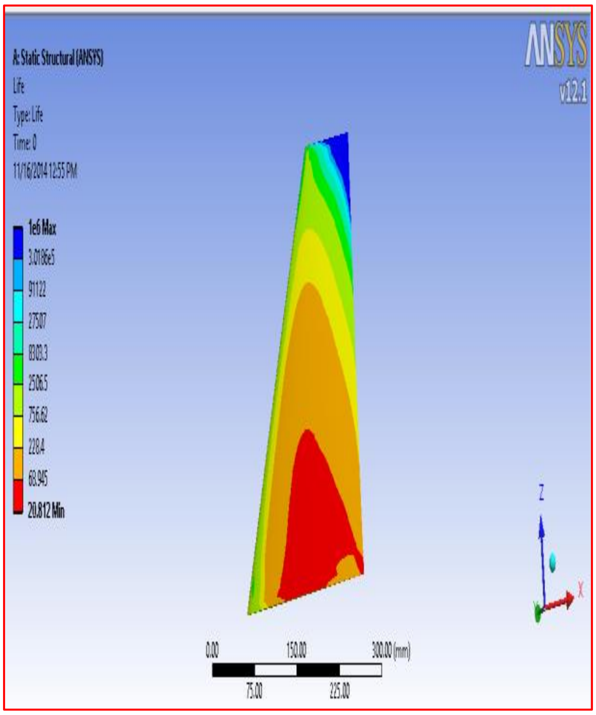


Fig.7 GFRP Fatigue life @V_f=0.55 **Fig.8 CFRP Fatigue life @V_f=0.55**

From the figures it can be notified that GFRP (min 20 cycles) has less fatigue life than CFRP (min 25 cycles) for same amount of fatigue load acting on it.

2. V_f=0.60, V_m=0.40



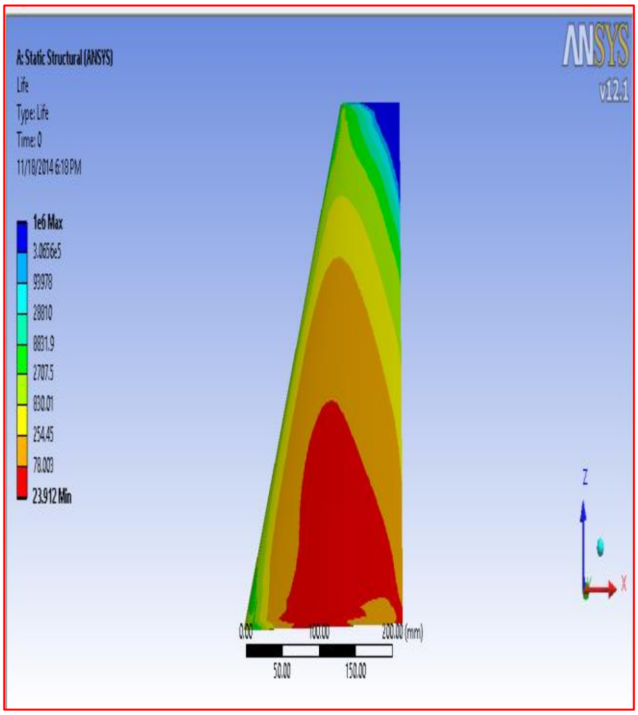
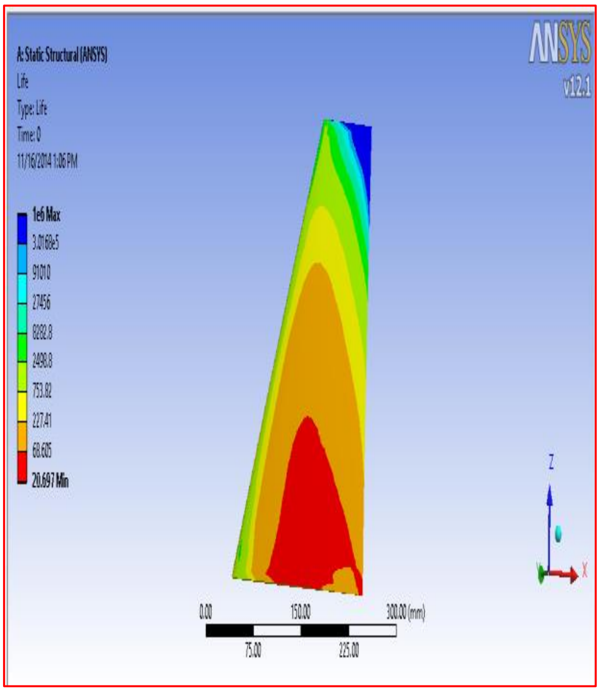


Fig.9 GFRP Fatigue life @V_f=0.60 **Fig.10 CFRP Fatigue life @V_f=0.60**

From the above both figures it is noticed that increase in percentage of amount of fiber decreases the fatigue life.

3. V_f=0.65, V_m=0.35



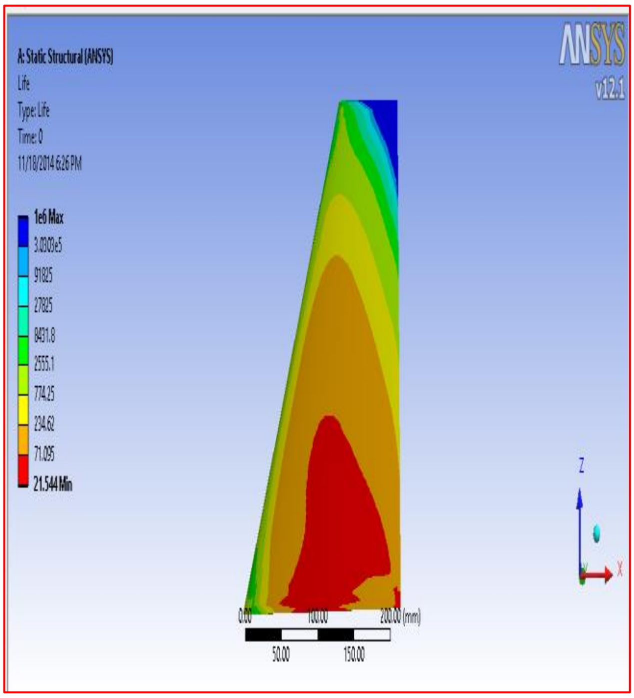
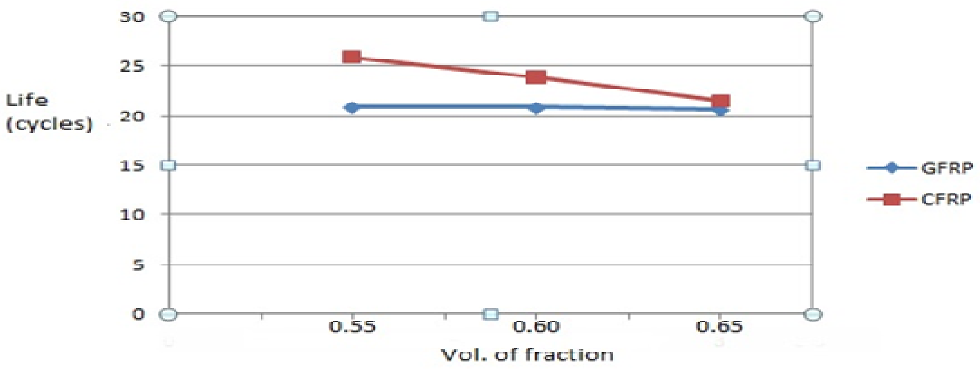


Fig.11 GFRP Fatigue life @V_f=0.65 **Fig.12 CFRP Fatigue life @V_f=0.65**

From the above fig it can be said that fatigue life of tail fin is decreasing as amount of matrix decreases. From the fig. 7 to fig. 12 one can that fatigue life of an vertical tail fin decreases with increase in fiber amount.



Graph of Fatigue life vs Vol. of Fraction

Safety Factor:

1. V_f=0.55, V_m=0.45

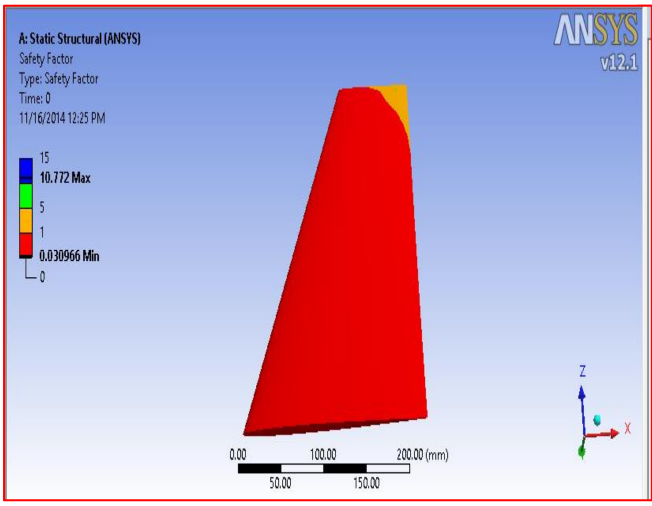


Fig.13 GFRP Safety factor @ V_f=0.55

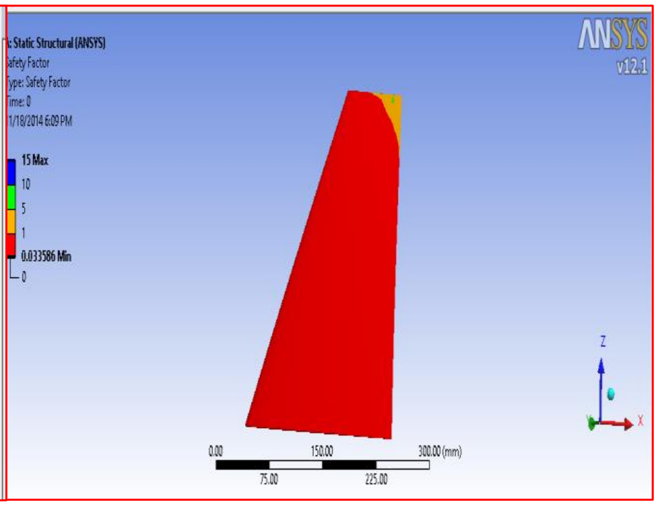


Fig.14 CFRP Safety factor @ V_f=0.55

From the above figures it can be said that safety factor of CFRP is higher than GFRP because of it's brittle nature.

2. V_f=0.60, V_m=0.40

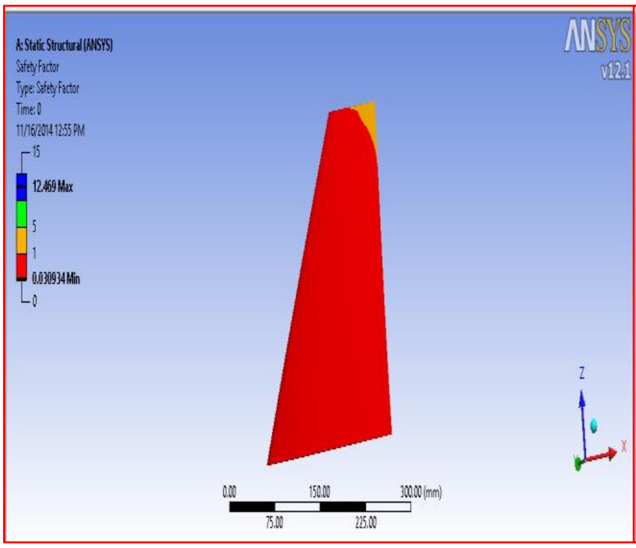


Fig.15 GFRP safety factor @ V_f=60

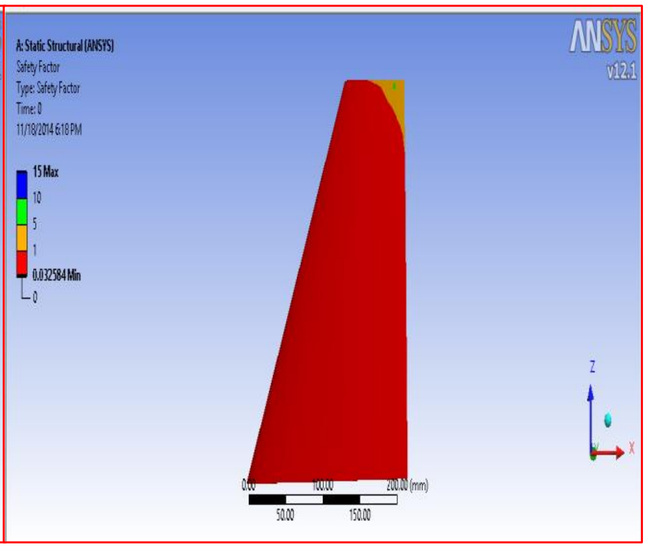
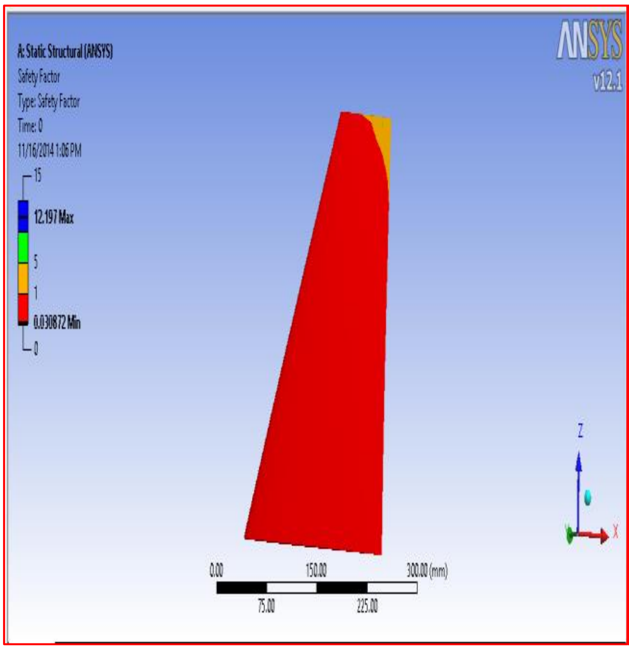


Fig.16 CFRP safety factor @ V_f=60

From the above both figures it is noticed that increase in percentage of amount of fiber decreases the safety factor.

3. V_f=0.60, V_m=0.40



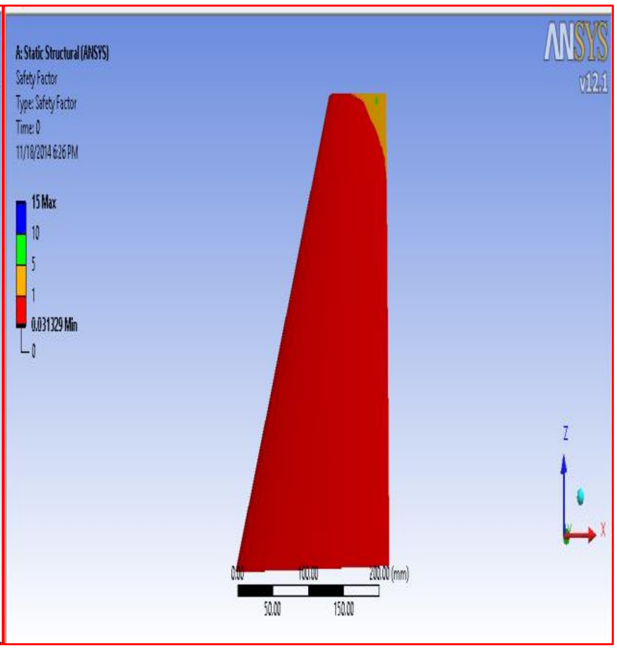


Fig.17 GFRP safety factor @ V_f=65 **Fig.18 CFRP safety factor @ V_f=65**

From the above figures it can be said that safety factor of tail fin is decreasing as amount of matrix decreases. From the fig. 13 to fig. 18 one can that safety factor of an vertical tail fin decreases with increase in fiber amount.

4. CONCLUSION

In this paper Fatigue analysis is performed on the GFRP and CFRP composites using Finite element method for different volume fractions of fiber. The conclusions drawn from the present work are that fatigue life cycles obtained from Numerical analysis for CFRP at 55% volume of fiber is higher than other volume fractions of fibers. In GFRP composites there was no significant change in fatigue life cycles for different volume fractions of fibers. The other observation was that CFRP has high fatigue life than GFRP composites for all volume fractions of fibers. No significant effect is observed on safety factor for both GFRP and CFRP composites.

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