COMPARATIVE STUDY OF COMPOSITE MATERIALS USING FEM FOR AIRCRAFT WING STRUCTURE

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Abstract. *This paper deals with the analysis of composite material such as unidirectional carbon, woven carbon and compared with Aluminum 2024(Al 2024). Presently Aircraft wing was manufactured using Al 2024. The wing 3D model is designed in CATIA V5 R20 and analysis is done by using ANSYS. The results were taken based on the static structural analysis to find deformation, stress, and strain developed in the wing structure. Modal analysis is carried out to note amplitude variation.*

Keywords: *FEM, Modal analysis, Aircraft Wing, unidirectional carbon, woven carbon*

1. Introduction

Airplanes industry under gone great developments in terms of carrying huge loads, reducing costs and increasing safety factors by focusing on multifunctional materials that are composites. These materials satisfy many advantages by replacing the metals by equivalent composite components. The composite materials used in aviation industry are mainly fibers or resin-reinforced particles. Generally, the modern airplanes with composite parts are about 20-50% lighter than their conventional versions. The composites also have some inherent weaknesses. The laminated structure with weak interfaces is weakly resistant to tensile loads as well as to the degradation of high temperature work.

Traditional aircraft materials include aluminum, steel and titanium which have been replaced by fiberglass, such as composites. The performance benefits of reducing the weight of structural elements of aircraft have been a major impetus for the development of military aircraft.

Wings were manufactured from Aluminum alloys for civil applications or from Titanium alloys for military applications. Recently, composites are the most widely used materials in aircraft, including skin, control surfaces and the body core.

The main purpose of this paper is to find a suitable material for the wing such as composite to replace the conventional Aluminum 2024 (Al-2024) used to make the wing skin. A composite laminate is a collection of layers of fibrous materials, such as carbon fiber, fiberglass; aramids contained in a matrix material that can be combined to provide required specific and desired properties. The laminate is formed by arranging the individual layers one above another in desired orientation. The fiber which is dyed in the membrane in different orientations carries the load. The matrix material supports the fibers and protects fibers from damage. The main function of the matrix is to transfer load to the fiber and to hold the fiber in a predefined position and orientation.

2. Materials and Methods

In this paper wing 3D model was designed by using CATIA.

Table 1. Input parameters for wing design

Parameters	Dimensions
Root chord	2350mm
Tip chord	710 mm
Semi span length	5000mm

Exposed Length of wing	4800mm
Airfoil (Root)	NACA-64215
Airfoil (Tip)	NACA-64210
Front Spar	20-25% of chord
Rear spar	60-70% of chord

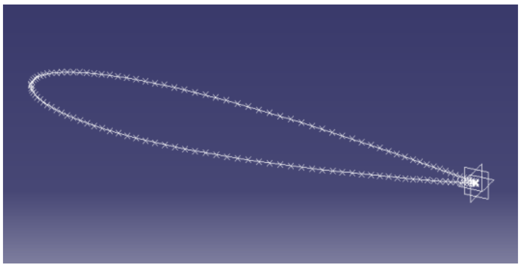


Figure 1. Airfoil Co-ordinates

The airfoil co-ordinates were taken from airfoil software and exported to CATIA and the wing model was designed. Before importing the CAT file to the ansys workbench, the file was converted into IGS format. The detailed input parameters mentioned as in Table.1.

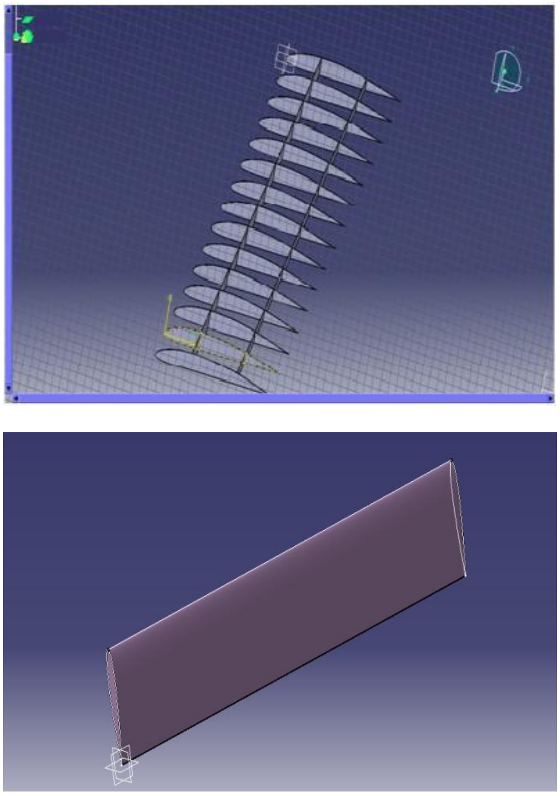


Figure 2. Wing Structure

2.1 Material Characteristics:

Young's modulus Ex, Ey and Ez are in along X, Y and Z directions respectively. Poison's ratios μ(xy), μ(yz), μ(zx) are in xy, yz, and zx plane respectively. Modulus of rigidity Gxy, Gyz and Gzx are in xy, yz and zx plane respectively.

Table 2. Material Properties

Materials	Unidirectional Carbon	Woven Carbon	Al-2024
Ex(Gpa)	121	61.34	
Ey(Gpa)	8.6	61.34	73.1
Ez(Gpa)	8.6	6.9	
μ(xy)	0.27	0.04	
μ(yz)	0.4	0.3	0.33
μ(zx)	0.27	0.3	
Gxy(Gpa)	4.7	19.5	
Gyz(Gpa)	3.2	2.6	27.6
Gzx(Gpa)	4.8	2.7	
ρ(kg/m^3)	1480	1415	2770

2.2 Boundary Condition:

One end of the wing is fixed as it penetrates inside of the fuselage, while other end remains free with 6 degree of freedom. A pressure of 500Pa is applied to the lower surface center of pressure. Center of pressure is a point at which total pressure is assumed to be act.

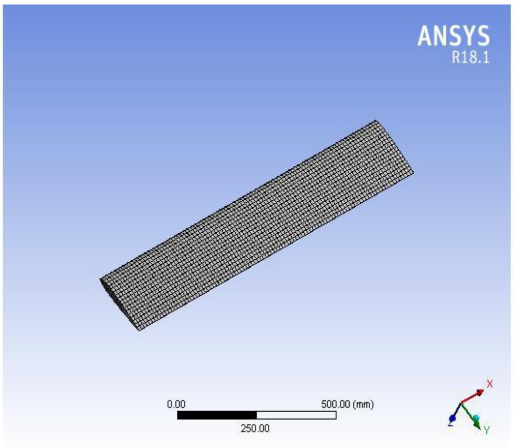


Figure 3. Mesh

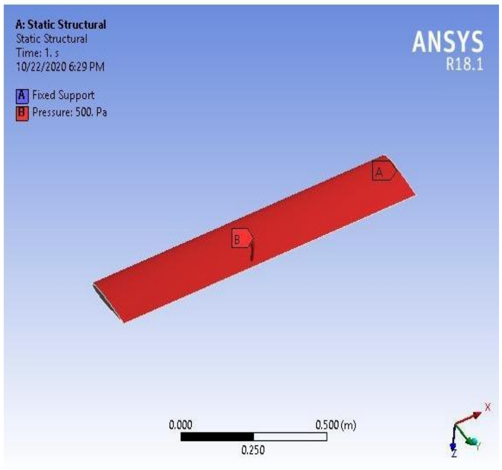


Figure 4. Boundary Condition

3. Static structural analysis results

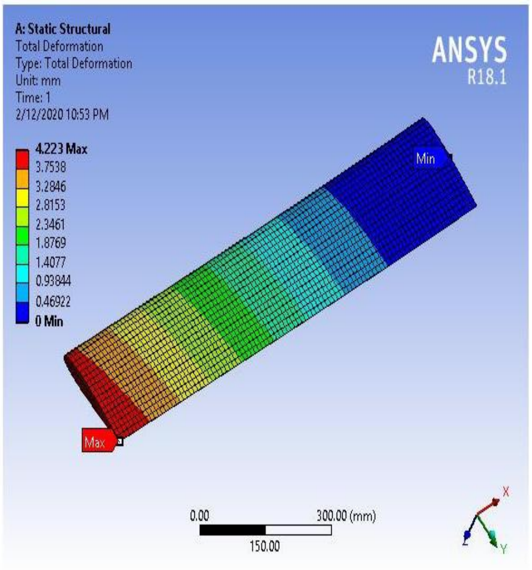
Table 3. Static Structural Analysis Results

Materials	Total deformation (mm)	Equivalent stress (Mpa)	Equivalent strain
Unidirectional Carbon	4.243	16.345	0.00015706
Woven Carbon	7.975	15.659	0.00030465
Aluminum 2024	6.7455	16.234	0.00023274

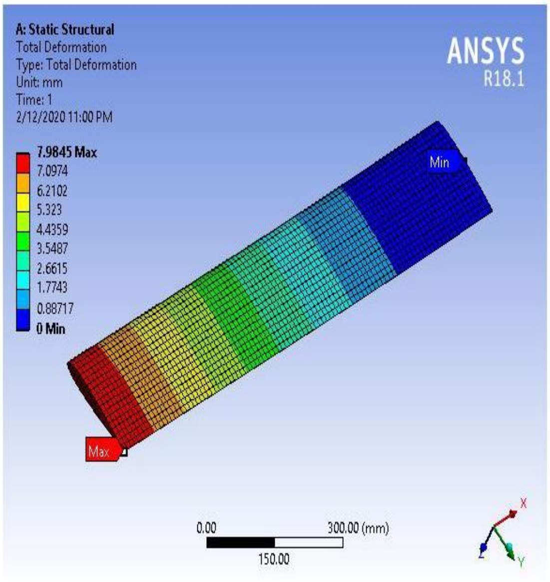
Table 4. Static Structural Analysis under different Speeds

Materials	Speed (km/hr)	Total deformation (mm)	Equivalent stress (Mpa)	Equivalent strain
Unidirectional Carbon	200	4.1124	17.392	0.00018043
	400	4.1206	48.269	0.00048840
	600	4.1605	102.59	0.00010383
	800	4.2652	179.26	0.00181151
	1000	4.4751	277.72	0.00280721
Woven Carbon	200	8.2113	17.070	0.00033361
	400	8.2690	46.256	0.00089541
	600	8.3916	98.265	0.00190540
	800	8.6583	171.43	0.00331470
	1000	9.1702	265.53	0.00513490

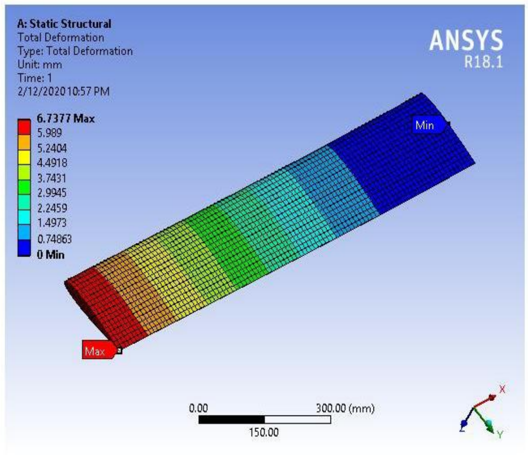
Aluminum 2024	200	6.6501	25.061	0.00035280
	400	6.7484	84.151	0.00118511
	600	7.0610	183.69	0.00258862
	800	124.94	321.86	0.00453193
	1000	462.51	502.14	0.00707101



(a) Total deformation using Unidirectional Carbon



(b) Total deformation using Woven Carbon



(c) Total deformation using Aluminum 2024

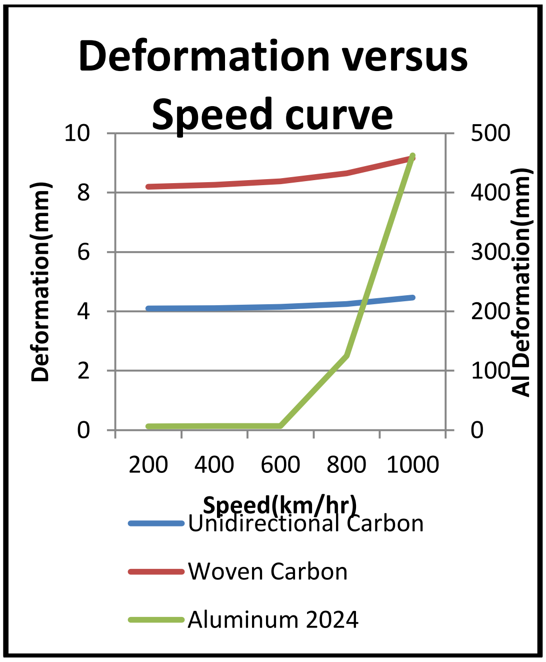


Figure 6. Deformation versus Speed curve for different materials

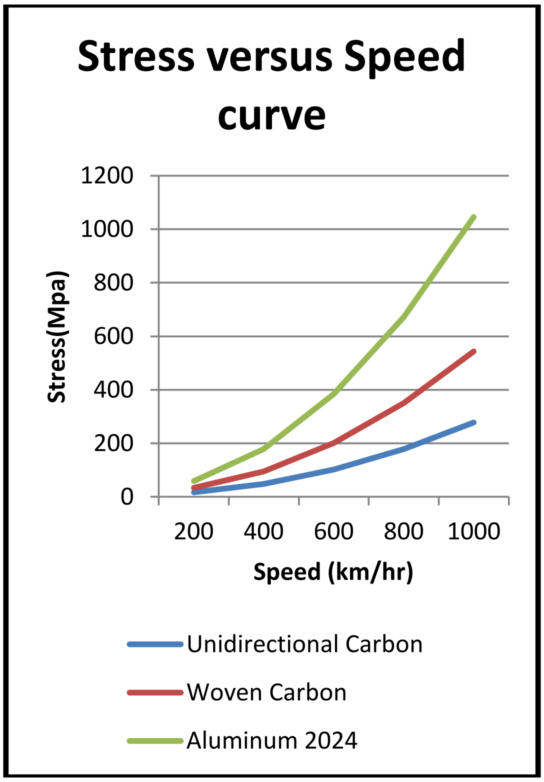


Figure 7. Stress versus Speed curve for different materials

4. Modal Analysis Results

Modal analysis is the study of dynamic properties of vibrating structures. It is used to determine the natural frequency of continuous structural members. Lowest frequency mode is desired because vibration will be less as compared to higher frequency modes. The results of the model analysis show that Unidirectional Carbon has a relatively higher natural frequency than other materials. At high natural frequency resonance can be delayed.

Table 5. Natural frequency (Hz) for different materials

Mode shape	Unidirectional Carbon	Woven Carbon	Aluminum 2024
1	20.146	14.708	11.556
2	95.874	91.134	71.426
3	124.66	118.17	91.457
4	149.76	177.97	159.58
5	295.85	250.85	198.83
6	339.52	480.27	385.87

Table 6. Maximum amplitude(mm) of vibration

Mode shape	Unidirectional Carbon	Woven Carbon	Aluminum 2024
1	0.83036	0.8565	0.61774
2	1.3978	0.8516	0.61325
3	1.1166	0.8461	0.6058
4	0.7319	1.5079	1.0868
5	1.6400	0.8657	0.62033
6	1.6239	0.9027	0.63568

5. Fatigue Life Analysis Results:

Table 7. Fatigue life analysis data

Materials	Life	Damage	Factor Of Safety
Unidirectional Carbon	1.00E+08	10	5.1696
Woven Carbon	1.00E+08	10	5.2869
Aluminum 2024	1.00E+08	10	5.2344

6. Results:

As per the calculated design requirement, the modeling of wing of a trainer aircraft was done with the aid of CATIA V5R20 and FEM was carried out to find deformation, stress, strain, frequency and life of wing. The structural analysis of the wing section was carried out for materials such as Unidirectional Carbon, Woven Carbon and Aluminum 2024 with the aid of ANSYS Static Structural. The modal analysis was performed to find the frequency and maximum amplitude of vibration for same materials. From the above analysis it can be concluded that epoxy-carbon gives better strength, low weight and minimum deformation than aluminum 2024. It can be seen from the above graph.1 that the deformation and stress value is increasing with increasing rotational speed. But for aluminum 2024 the deformation curve abruptly increases beyond 600rad/sec. Carbon material offers less stress an aircraft wing than aluminum alloy. 6 mode shapes have been created from the modal analysis for the different materials to find the natural frequency and maximum amplitude of vibration. Lowest frequency mode is desirable for any structure (wing) because it has less amplitude of vibration. The results may vary accordingly with different aircraft wing and design.

7. Conclusion:

From the comparisons of results it shows that Unidirectional Carbon has better structural characteristics than other materials. It has less deformation, high strength, light weight as compared to Aluminum 2024 T3 and other materials. So it is concluded that Unidirectional Carbon is suitable material for making aircraft wing.

As future enhancement, different materials can be tested with different boundary conditions to find more suitable materials with good aerodynamic and structural characteristics, number of main load carrying members can be changed and analysis can be performed.

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