Design and Analysis of Carbon-Epoxy Composite Rocket Motor Casing

Shaik Shaheen[1], Dr. G. Srinivasa Gupta[2]

[1] PG student, Department of Mechanical Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, INDIA
[2] Professor, Department of Mechanical Engineering, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, INDIA

ABSTRACT

The rocket motor case is an inert or non-energy contributing missile component; the design objective is to make the case as lightweight as possible, within the bounds of technology and cost. The rocket motor casing materials must be able to withstand high pressures and elevated temperatures due to the combustion of the fuel. In this paper, the design of the rocket motor case is done by considering the maximum expected operating pressure, design safety factor of 1.25 with diameter of 11 inches and thickness of 0.06 inches. The 3-D model of rocket motor case is developed using CATIA V5R16 software. The static structural analysis and linear buckling analysis is done for stack ups [0/90/0/90], [45/-45/-45/45], [0/45/-45/90], [0/90/45/-45/90/0] of unidirectional carbon-epoxy IM10/8552 composite and the steady-state thermal analysis is done on carbon-epoxy IM10/8552 shell model and solid model of the rocket motor casing by using ANSYS 15.0 software and the results are compared with the results of static structural, steady-state thermal, linear buckling analysis of D6AC steel material rocket motor casing to specify the better efficient material.

Keyword: - *Rocket Motor Case, Design, Analysis, CATIA, ANSYS, Carbon-Epoxy IM10/8552, D6AC Steel*

1. Introduction

The typical rocket motor case is basically a double-domed right circular cylinder with opening in both domes and cylindrical extensions called skirts. The aft opening interfaces with the nozzles [2]. The forward opening accommodates the igniter and safe arm. The motor case for a solid propulsion rocket motor serves, to protect and store the propellant grain until the motor is used, as a combustion chamber for high pressure, high temperature burning of the grain during motor operations, to mechanically/structurally interface with other motor components like the nozzle, igniter, internal insulation, handling/carrying brackets, etc. Since the motor case is an inert or non-energy contributing missile component, the design objective is to make the case as lightweight as possible. This will result in a higher motor mass fraction and high motor and missile performance. The important factors calling for adequate caution during material selection are as follows: material strength, high temperature properties of the material, stiffness or deformation characteristics, corrosion resistance and ease of fabrication. The selection of materials which have a high specific strength is an important consideration in the design of the rocket motor cases. Maraging steel represents one of the highest specific strength single case materials used in the manufacture of rocket motor cases. Attempts to use higher specific strength steels, have because of their reduced ductility and is some instances brittle behaviour, created serious quality control problems. Composites, on other hand, can be constructed so that their effective specific strength is greater than that of any steel.

Carbon fibers are prepared by carbonisation of a precursor fiber in inert atmospheres at high temperatures. The precursor can be an organic polymer fiber like rayon or polyacrylonitrile, or it can be petroleum or coal tar pitch fiber. The structure and properties of carbon fibers depend on the nature of the precursor and the conditions of carbonisation. In this paper the HexTow® IM10 carbon fiber is the fiber that is considered, it is a continuous, high performance, intermediate modulus, PAN based fiber available in 12,000 (12K) filament count tows. This fiber has been surface treated and can be sized to improve its interlaminar shear properties, handling characteristics and structural properties. Epoxy resins are the thermosets that have been mostly used as polymer matrices for carbon fiber composites. Epoxy is chosen primarily because it happens to be most commonly used polymer and because of its insulating nature (low value of thermal conductivity). In this paper HexPly® 8552 epoxy matrix is used, it is an amine cured, toughened epoxy resin system supplied with unidirectional or woven carbon or glass fibers. HexPly® 8552 is recommended for structural applications requiring high strengths, stiffness, and damage tolerance.

2. Material Properties of Carbon-Epoxy IM10/8552 and D6AC Steel

2.1 Carbon-Epoxy IM10/8552

The carbon fiber HexTow® IM10 properties that are considered in this paper are shown in the Table 1.

Table -1: Carbon Fiber IM10 Properties

Carbon Fiber IM10 Properties	Tensile Strength	Tensile Modulus	Poisson's Ratio	Density	Specific Heat	Thermal Conductivity	Coefficient of Thermal Expansion
Units	6964 MPa	310 GPa	0.27	1.79 g/cm^3	0.21 Cal/g-^{0}C	6.14 W/m-^{0}K	-0.70 ppm/^{0}C

The HexPly® 8552 Epoxy matrix properties that are considered in this paper are shown in the Table 2.

Table -2: Epoxy 8552 matrix Properties

Carbon Fiber IM10 Properties	Units
Tensile Modulus	4.6677 GPa
Matrix apparent Tensile Strength	0.12 GPa
Matrix apparent Compressive Strength	0.13 GPa
Matrix apparent Shear Strength	0.06 GPa
Density	1.3g/cm^3
Poisson's Ratio	0.35
Thermal Conductivity	0.18 W/m-^{0}K
Moisture Expansion Coefficient	0.38
Thermal Expansion Coefficient	-64.3 ppm/^{0}C

Theoretical calculations for forming Carbon-Epoxy IM10/8552 composite material are as follows:

- Volume fraction

Consider a composite consists of fiber and matrix

$$V_f = \frac{v_f}{v_c} \qquad V_m = \frac{v_m}{v_c}$$

$$V_f + V_m = 1$$

Where, V_f is the volume fraction of fiber which is taken as 0.6, V_m is the volume fraction of matrix, v_f is the volume of fiber, v_m is the volume of matrix and v_c is the volume of composite.

From the properties of Carbon Fiber IM10 and Epoxy 8552, the properties of the composite are calculated as given below.

- Density of composite (ρ(c))

$$m(c) = m(f) + m(m)$$

Where m(f) is mass of fiber, m(m) is mass of matrix and m(c) is mass of composite.

$$\rho\ (c)\ \times\ v(c)\ =\ \rho\ (f) \times\ v(f)\ +\ \rho\ (m)\ \times\ v(m)$$

$$\rho(c) =\ \rho(f) \times V(f) +\ \rho(m) \times V(m)$$

Where ρ(c) = density of composite, ρ(f) = density of fiber = 1.79 g/cm^3, ρ(m) is density of matrix = 1.3 g/cm^3.

$$\rho(c) = 1.79(0.6) +\ 1.3(0.4)$$

$$\rho(c) = 1.594\ g/cm^3$$

- Longitudinal young's modulus (E_1)

$$E_1 =\ E_f(V_f) +\ E_m(V_m)$$

$$E_1 =\ 310(0.6) +\ 4.6677(0.4)\ GPa$$

$$E_1 =\ 187.9\ GPa$$

- Transverse young's modulus (E_2)

$$\frac{1}{E_2} = \frac{V_f}{E_f} + \frac{V_m}{E_m}$$

$$\frac{1}{E_2} = \frac{0.6}{310} + \frac{0.4}{4.6677}$$

$$E_2 =\ 11.41\ GPa$$

- In-plane poisson's ratio (ϑ_{12})

$$\vartheta_{12} =\ \vartheta_f(V_f) +\ \vartheta_m(V_m)$$

$$\vartheta_{12} =\ 0.27(0.6) +\ 0.35(0.4)$$

$$\vartheta_{12} =\ 0.302$$

- Intralaminar poisson's ratio (ϑ_{23})

$$\vartheta_{23} =\ 0.4953$$

- In-plane shear modulus (G_{12})

$$G_{12} =\ G_m \left[\frac{(1+V_f) + (1-V_f)\ {G_m}/{G_f}}{(1-V_f) + (1+V_f)\ {G_m}/{G_f}} \right]$$

$$G_{12} =\ 4.919 GPa$$

Where G_m is the shear modulus of matrix = 1.278 GPa and G_f is the shear modulus of fiber = 122 GPa

- Intralaminar shear modulus (G_{23})

$$G_{23} = G_m \left[\frac{(V_f) + \eta_4(1 - V_f)}{\eta_4(1 - V_f) + (V_f)\, {G_m}/{G_f}} \right]$$

$$G_{23} = 4.265\ GPa$$

Where $\eta_4 = \frac{3 - 4\vartheta_m + {G_m}/{G_f}}{4(1 - \vartheta_m)}$ = 0.6194

- Longitudinal thermal conductivity (K_1)

$$K_1 = K_f(V_f) + K_m(V_m)$$

$$K_1 = 6.14(0.6) + 0.18(0.4)$$

$$K_1 = 3.756 \text{ W/m-}^0\text{K}$$

- Transverse thermal conductivity ($K_2 = K_3$)

$$K_2 = K_3 = K_m \left[\frac{1 + \xi \eta_4 V_f}{1 - \eta V_f} \right]$$

$$(where\ \xi = 1)$$

$$K_2 = 0.393 \text{ W/m-}^0\text{K}$$

The values of carbon-epoxy IM10/8552 composite properties are calculated as given above.

2.2 D6AC Steel

Table 3: D6AC Steel Properties

Carbon Fiber IM10 Properties	Tensile Strength	Tensile Modulus	Poisson's Ratio	Density	Specific Heat	Thermal Conductivity	Coefficient of Thermal Expansion
Units	6964 MPa	310 GPa	0.27	1.79 g/cm^3	0.21 Cal/g-^{0}C	6.14 W/m-^{0}K	-0.70 ppm/^{0}C

D6AC Steel is a low alloy vacuum melted steel containing several other elements and with a carbon content of 0.42 to 0.48%. The hardenability of this alloy is better than that of AISI 4340 and D6AC can be heat treated to strengths ranging from 180 to 260 ksi. The cost of D6AC steel is lower than 15CDV6 and maraging (M)250 steel. The properties of D6AC steel are taken as shown in Table 3.

3. Design and Modeling of Rocket Motor Case

The basic principles of rocket motor case design and analysis are essentially the same as those of the plate-and-shell approach that has been used for many years in the design and analysis of boiler-type, pressure containing structures and aircraft-type structures. Recently, improved methods of analysis that can consider great numbers of design variables through the use of electronic computers have provided the motor case designer with the ability to analyse, in a reasonable time, more complex load junctions and to treat structural shapes in much smaller elements. The case design should be established to obtain positive margins of safety as close to zero as possible [1].

3.1 Design Assumptions

- Failure criterion is defined as ultimate tensile failure
- Ultimate tensile strength of the carbon-epoxy (IM10/8552) material is 613026 psi (allowable stress).
- Limit internal pressure, often referred to as the maximum expected operating pressure (MEOP) is specified as 4280.04 psi.
- The design safety factor is as 1.25.
- The motor case cylinder diameter "D" is 11 in.
- Cylinder-wall thickness "t" is 0.06 in.

3.2 Case Design Calculations

- Design Pressure P = MEOP × design safety factor = 4280.04 × 1.25 psi = 5350.05 psi
- Cylinder design hoop stress $(\sigma_h) = \frac{PD}{t2} =$ 490421.25 psi
- Margin of Safety $MS = \frac{1}{R} - 1 =$1.25-1 = 0.25

3.3 Modeling of Rocket Motor Case

The modeling of Rocket Motor Case is done by using CATIA V5R16 software. The 2D model of the rocket motor case as shown in Fig -1 is sketched in sketcher workbench. The 2D model is then imported to part design workbench then it is revolved around 360^0 by using shaft option about V-direction axis to convert into 3D model of rocket motor case as shown in Fig -2 and Fig -3.

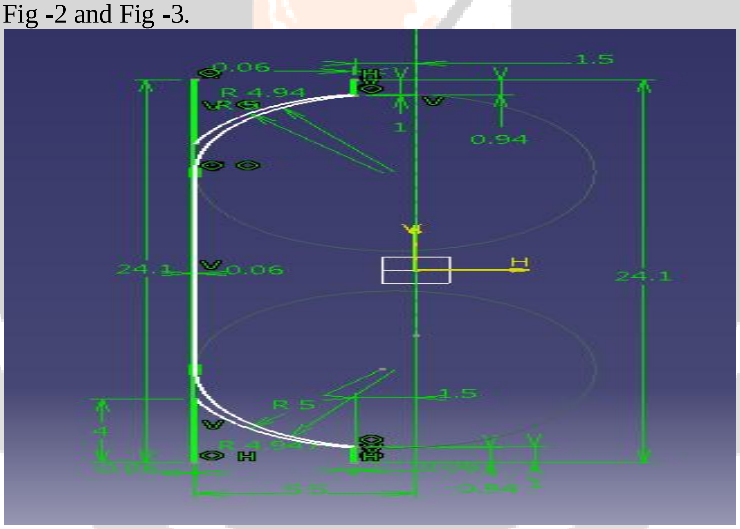


Fig -1: 2D model of rocket motor case

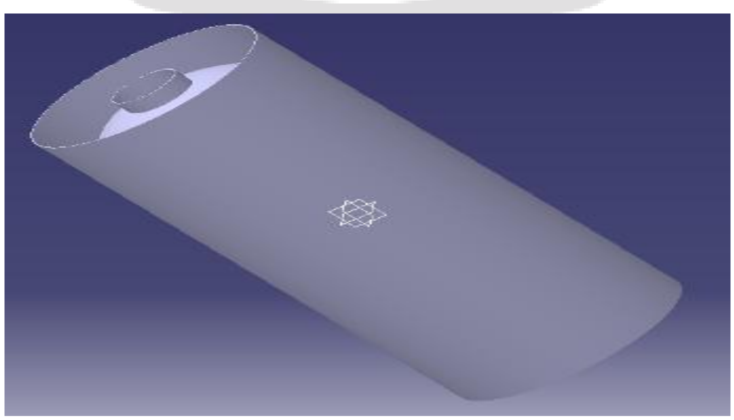


Fig -2: 3D model of rocket motor case

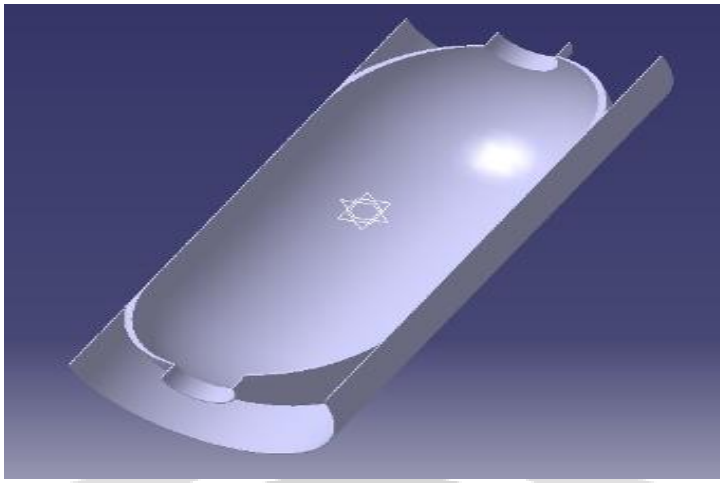


Fig -3: Sectional view of 3D model of rocket motor case

4. Analysis of Rocket Motor Case

The rocket motor case analysis is performed by using ANSYS 15.0. This paper consists of Static Structural analysis, Steady-State Thermal analysis and Linear Buckling analysis of rocket motor case.

4.1 Static Structural Analysis

A static structural analysis determines the displacements, stresses, strains and forces in structures or components caused by loads that do not induce significant inertia and damping effects. The 3D model of sectional view of rocket motor case as shown in Figure 3 is imported into geometry of static structural cell. After importing the geometry and now give the material properties of carbon-epoxy IM10/8552 and D6AC steel in Engineering Data. The geometry of the 3D model is converted to thin shell structure using 'Thin' option in DesignModeler of geometry. The next cell is model where we can see a refresh symbol i.e., the given geometry and engineering data are updating for analysis. Now clicking on model which opens static structural-mechanical [ANSYS Multiphysics] window. In geometry, add layers as shown in Table 4, 5, 6 and 7 by using 'Layered Section' option.

Table 4: Layered Section for stack up [0/90/0/90] carbon-epoxy IM10/8552 composite

Layer	**Material**	**Thickness (inches)**	**Angle (^{0})**
1	Carbon-Epoxy IM10/8552	0.015	0
2	Carbon-Epoxy IM10/8552	0.015	90
3	Carbon-Epoxy IM10/8552	0.015	0
4	Carbon-Epoxy IM10/8552	0.015	90

Table 5: Layered Section for stack up [45/-45/-45/45] carbon-epoxy IM10/8552 composite

Layer	**Material**	**Thickness (inches)**	**Angle (^{0})**
1	Carbon-Epoxy IM10/8552	0.015	45
2	Carbon-Epoxy IM10/8552	0.015	-45
3	Carbon-Epoxy IM10/8552	0.015	-45
4	Carbon-Epoxy IM10/8552	0.015	45

Table 6: Layered Section for stack up [0/45/-45/90] carbon-epoxy IM10/8552 composite

Layer	**Material**	**Thickness (inches)**	**Angle (^{0})**
1	Carbon-Epoxy IM10/8552	0.015	0
2	Carbon-Epoxy IM10/8552	0.015	45
3	Carbon-Epoxy IM10/8552	0.015	-45
4	Carbon-Epoxy IM10/8552	0.015	90

Table 7: Layered Section for stack up [0/90/45/-45/90/0] carbon-epoxy IM10/8552 composite

Layer	**Material**	**Thickness (inches)**	**Angle (^{0})**
1	Carbon-Epoxy IM10/8552	0.01	0
2	Carbon-Epoxy IM10/8552	0.01	90
3	Carbon-Epoxy IM10/8552	0.01	45
4	Carbon-Epoxy IM10/8552	0.01	-45
5	Carbon-Epoxy IM10/8552	0.01	90
6	Carbon-Epoxy IM10/8552	0.01	0

Now generate mesh by using 'Mesh'. After meshing, apply fixed support, pressure of 5350.05 psi and force of 1079083.3187 lbf on the model as shown in Fig -4.

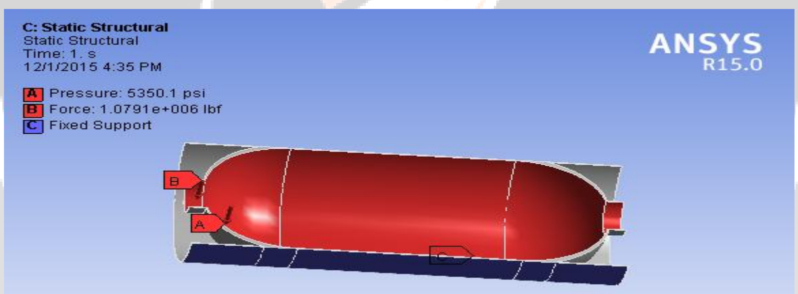
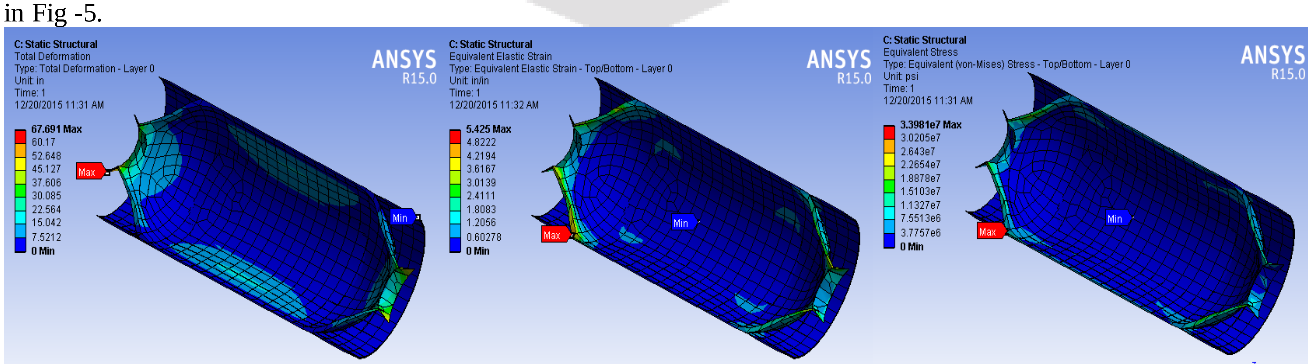


Fig -4: Support and Loads applied on rocket motor case

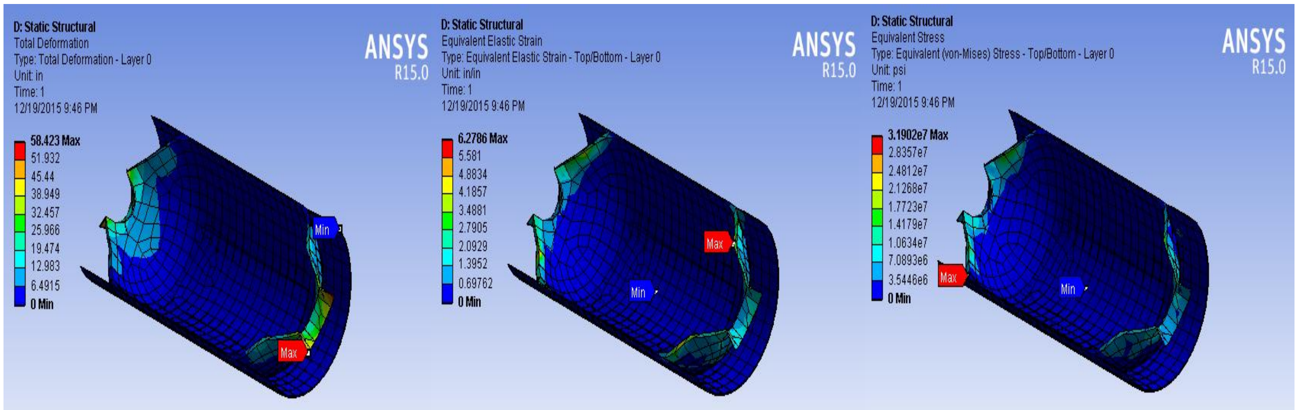
After applying the fixed support, pressure and force. Before solving, insert the total deformation, equivalent stress and equivalent elastic strain in the solution folder by right click on it, we get the option to insert them. Now click on 'Solve' option. The results of static structural analysis for stack up [0/90/0/90] carbon-epoxy IM10/8552 are shown in Fig -5.



Total Deformation of [0/90/0/90] carbon-epoxy IM10/8552 Equivalent Strain of [0/90/0/90] carbon-epoxy IM10/8552 Equivalent Stress of [0/90/0/90] carbon-epoxy IM10/8552

Fig -5: Static Structural analysis results of [0/90/0/90] carbon-epoxy IM10/8552

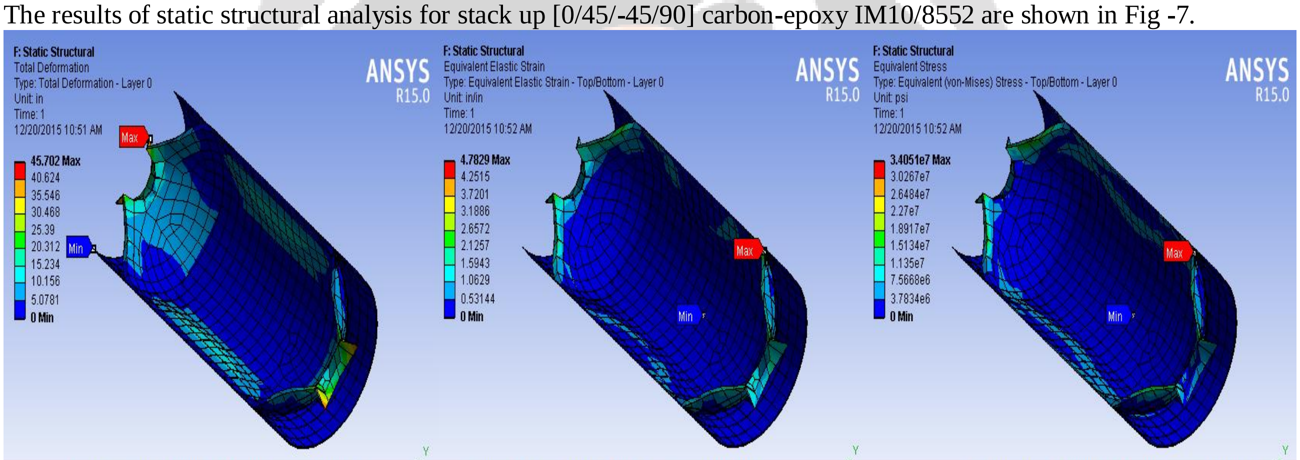
The results of static structural analysis for stack up [45/-45/-45/45] carbon-epoxy IM10/8552 are shown in Fig -6.



Total Deformation of [45/-45/-45/45] carbon-epoxy IM10/8552 Equivalent Strain of [45/-45/-45/45] carbon-epoxy IM10/8552 Equivalent Stress of [45/-45/-45/45] carbon-epoxy IM10/8552

Fig -6: Static Structural analysis results of [45/-45/-45/45] carbon-epoxy IM10/8552

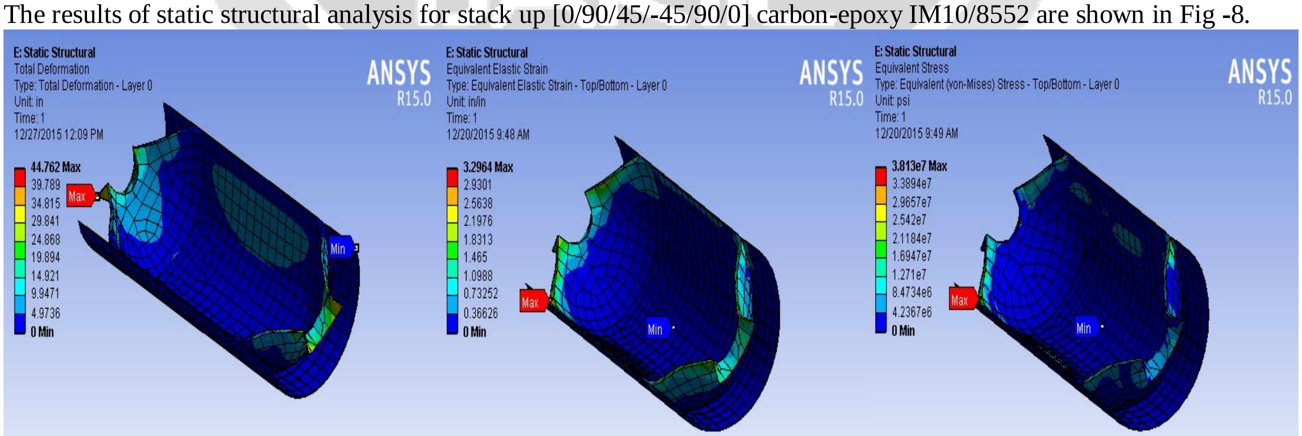
The results of static structural analysis for stack up [0/45/-45/90] carbon-epoxy IM10/8552 are shown in Fig -7.



Total Deformation of [0/45/-45/90] carbon-epoxy IM10/8552 Equivalent Strain of [0/45/-45/90] carbon-epoxy IM10/8552 Equivalent Stress of [0/45/-45/90] carbon-epoxy IM10/8552

Fig -7: Static Structural analysis results of [0/45/-45/90] carbon-epoxy IM10/8552

The results of static structural analysis for stack up [0/90/45/-45/90/0] carbon-epoxy IM10/8552 are shown in Fig -8.



Total Deformation of [0/90/45/-45/90/0] carbon-epoxy IM10/8552 Equivalent Strain of [0/90/45/-45/90/0] carbon-epoxy IM10/8552 Equivalent Stress of [0/90/45/-45/90/0] carbon-epoxy IM10/8552

Fig -8: Static Structural analysis results of [0/90/45/-45/90/0] carbon-epoxy IM10/8552

The results of static structural analysis of D6AC steel are shown in Fig -9.

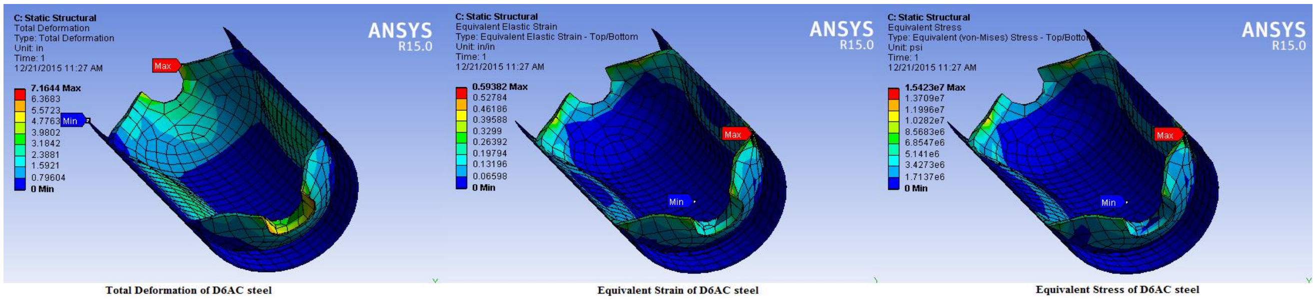


Fig -9: Static Structural analysis results of D6AC Steel

The static structural analysis results of both the carbon-epoxy IM10/8552 composite and D6AC steel material are obtained as shown in the Table 8.

Table 8: Results of static structural analysis

Carbon-Epoxy IM10/8552 Composite stack ups	Total Deformation		Equivalent Strain		Equivalent Stress	
	Maximum	minimum	maximum	minimum	Maximum	minimum
[0/90/0/90]	67.91	0	5.425	0	3.3981e7	0
[45/-45/-45/45]	58.423	0	6.2786	0	3.1902e7	0
[0/45/-45/90]	45.702	0	4.7829	0	3.4051e7	0
[0/90/45/-45/90/0]	44.762	0	3.2964	0	3.813e7	0
D6AC Steel	7.1644	0	0.59382	0	1.5423e7	0

4.2 Steady-State Thermal Analysis

A thermal analysis determines temperatures, thermal gradients, heat flow rates, and heat fluxes in an object that are caused by thermal loads that do not vary over time. A steady-state thermal analysis calculates the effects of steady thermal loads on a system or component.

The 3D model of sectional view of rocket motor case as shown in Figure 3 is imported into geometry of steady-state thermal analysis system cell. After importing the geometry and now give the material properties of carbon-epoxy IM10/8552 and D6AC steel in Engineering Data. The geometry of the 3D model is converted to thin shell structure using ‘Thin’ option for shell structure in DesignModeler of geometry. The next cell is model where we can see a refresh symbol i.e., the given geometry and engineering data are updating for analysis. Now clicking on model which opens static structural-mechanical [ANSYS Multiphysics] window. Now generate mesh by using ‘Mesh’. After meshing, apply maximum temperature as 6000^0F and convection of 1000 W/m^2K (0.00033972 $BTU/s.in^{20}F$) on the model as shown in Fig -10.

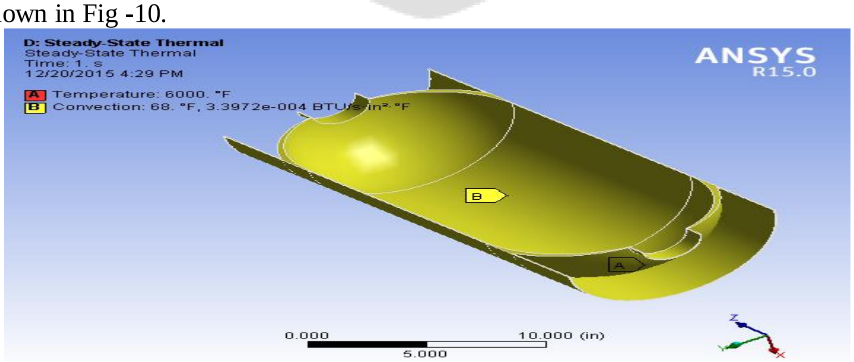
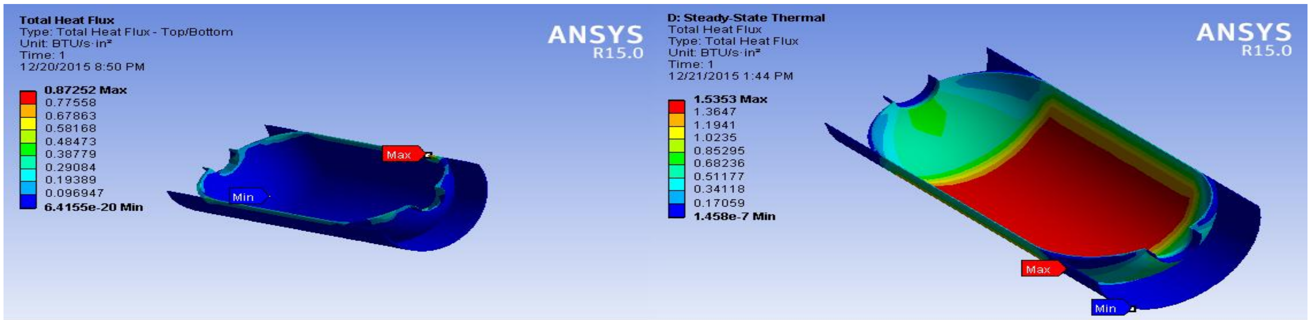


Fig -10: Temperature and Convection applied on rocket motor case

After applying, the temperature and convection on the rocket motor case. Before solving, insert the total heat flux in the solution folder by right click on it, we get the option to insert them. Now click on ‘Solve’ option. The results of steady-state thermal analysis of shell structure and solid structure carbon-epoxy IM10/8552 are shown in Fig -11.



Total Heat Flux of shell structure of carbon-epoxy IM10/8552 Total Heat Flux of solid structure of carbon-epoxy IM10/8552

Fig -11: Steady-state thermal analysis results of carbon-epoxy IM10/8552

The results of steady-state thermal analysis of D6AC steel are shown in Fig -12.

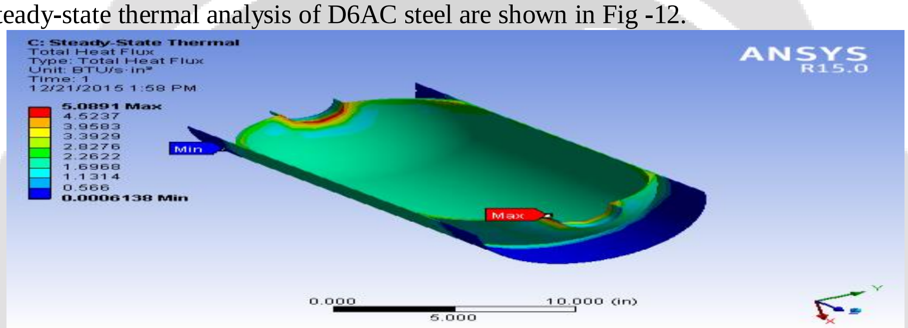


Fig -12: Steady-state thermal analysis results of D6AC Steel

The static structural analysis results of both the carbon-epoxy IM10/8552 composite and D6AC steel material are obtained as shown in the Table 9.

Table 9: Results of steady-state thermal analysis

Materials		**Total Heat Flux**	
		Maximum	**minimum**
Carbon-Epoxy IM10/8552	**Shell structure**	0.87252	6.4155e-20
	Solid structure	1.5353	1.458e-7
D6AC Steel		5.0891	0.0006138

4.3 Linear Buckling Analysis

Linear buckling analysis predicts the theoretical buckling strength of an ideal elastic structure. Linear buckling analysis often yields quick but non-conservative results. A linear buckling analysis must follow a prestressed static structural analysis. The 3D model of rocket motor case as shown in Figure 2 is imported into geometry of static structural cell. After importing the geometry and now give the material properties of carbon-epoxy IM10/8552 and D6AC steel in Engineering Data. The geometry of the 3D model is converted to thin shell structure using ‘Thin’ option in DesignModeler of geometry. The next cell is model where we can see a refresh symbol i.e., the given geometry and engineering data are updating for analysis. Now clicking on model which opens static structural-mechanical [ANSYS Multiphysics] window. In geometry, add layers as shown in Table 4, 5, 6 and 7 by using ‘Layered Section’ option. Now generate mesh by using ‘Mesh’. After meshing, apply fixed support, pressure of 5350.05 psi and force of 1079083.3187 lbf on the model as shown in Fig -13.

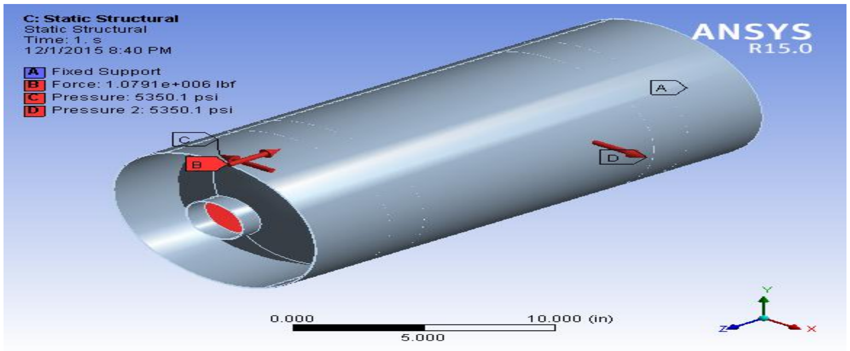


Fig -13: Support and Loads applied on rocket motor case

After applying the fixed support, pressure and force. Before solving, insert the total deformation, equivalent stress and equivalent elastic strain in the solution folder by right click on it, we get the option to insert them. Now add linear buckling template to the project schematic and we have to transfer the prestressed static structural data to the linear buckling analysis system for that right click on solution cell of static structural and select transfer data to new linear buckling. Now right click on setup cell of linear buckling, multiple systems Multiphysics window is opened and in linear buckling folder add total deformation in the solution folder. Now click on 'Solve' option. The results of linear buckling analysis for stack up [0/90/0/90] carbon-epoxy IM10/8552 is shown in Fig -14.

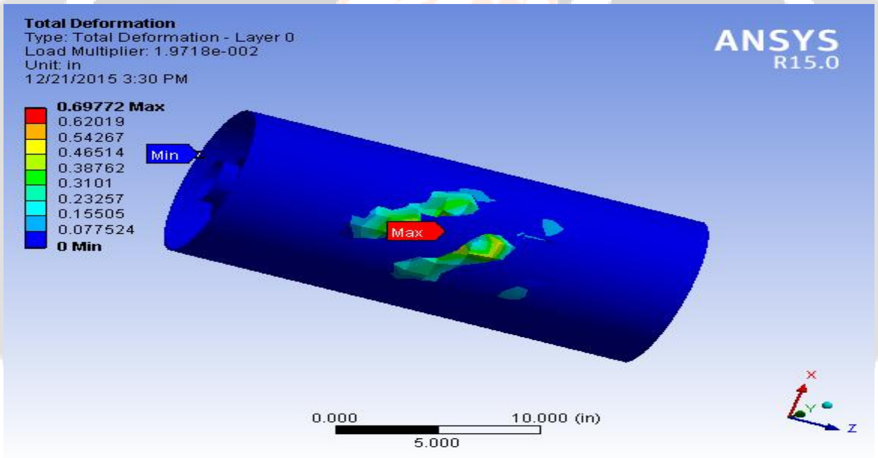


Fig -14: Linear buckling total deformation of [0/90/0/90] carbon-epoxy IM10/8552

The results of linear buckling analysis for stack up [45/-45/-45/45] carbon-epoxy IM10/8552 are shown in Fig -15.

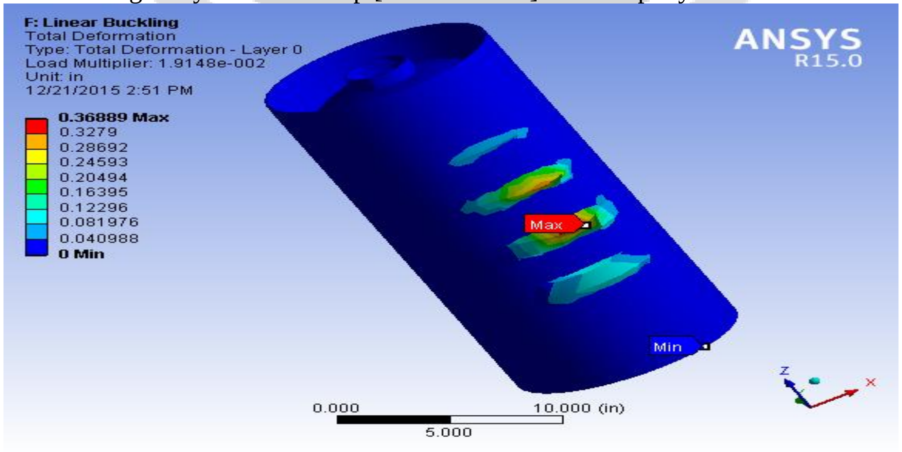


Fig -15: Linear buckling total deformation of [45/-45/-45/45] carbon-epoxy IM10/8552

The results of linear buckling analysis for stack up [0/45/-45/90] carbon-epoxy IM10/8552 are shown in Fig -16.

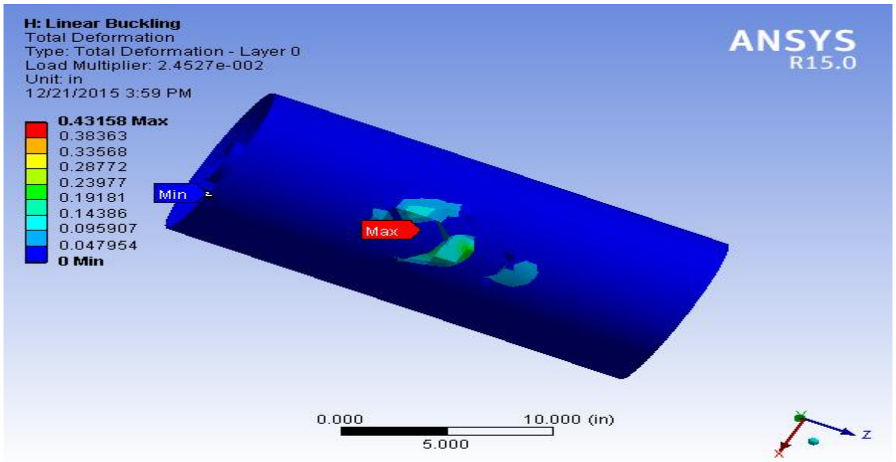


Fig -16: Linear buckling total deformation of [0/45/-45/90] carbon-epoxy IM10/8552

The results of linear buckling analysis for stack up [0/90/45/-45/90/0] carbon-epoxy IM10/8552 are shown in Fig -17.

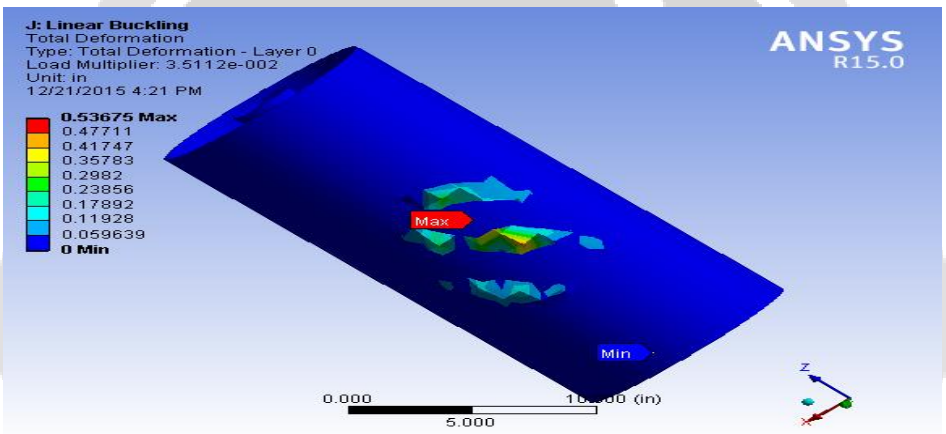


Fig -17: Linear buckling total deformation of [0/90/45/-45/90/0] carbon-epoxy IM10/8552

The results of linear buckling analysis of D6AC steel are shown in Figure 18.

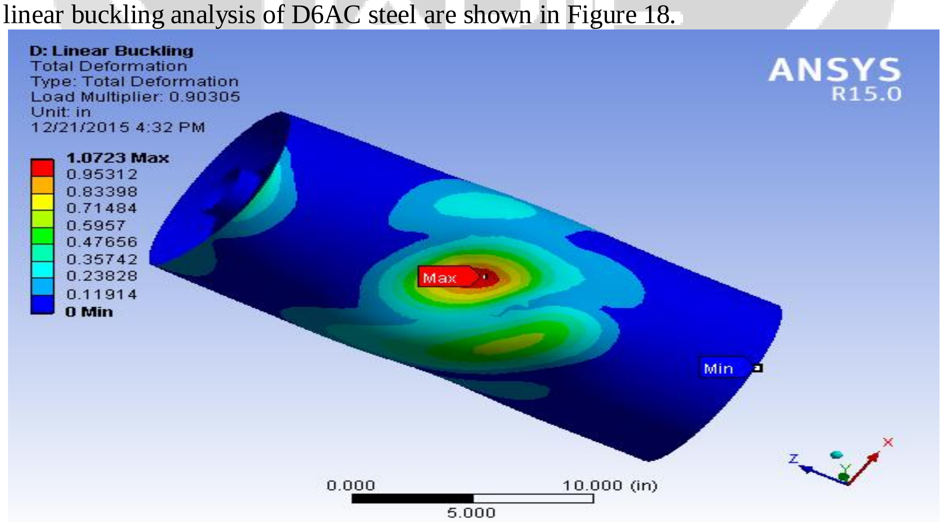


Fig -18: Linear buckling total deformation of D6AC Steel

The linear buckling analysis results of carbon-epoxy IM10/8552 composite and D6AC steel material are obtained as shown in the Table 11.

Table 11: Results of linear buckling analysis

Materials		**Total Deformation**	
		maximum	**minimum**
Carbon-Epoxy IM10/8552	**[0/90/0/90]**	0.69772	0
	[45/-45/-45/45]	0.36889	0
	[0/45/-45/90]	0.43158	0
	[0/90/45/-45/90/0]	0.53675	0
D6AC Steel		1.0723	0

5. Conclusion

From the structural analysis of rocket motor case, the maximum equivalent stress, deformation and maximum equivalent strain values are larger in carbon-epoxy IM10/8552 composite material compare than D6AC steel material when internal pressure and force considered as the loads, which implies that the composite rocket motor case withstand large stresses and can deform more when compared to steel alloy material. Hence it can be concluded that carbon-epoxy IM10/8552 composite is efficient material. The carbon-epoxy IM10/8552 composite is efficient with stack up [0/90/45/-45/90/0] when compared with stack ups [0/90/0/90], [45/-45/-45/45], [0/45/-45/90].
From thermal analysis of rocket motor case, the heat flux is more in D6AC steel than carbon-epoxy IM10/8552 composite and composite material has large difference between the minimum and maximum heat flux values. Hence it can be concluded that carbon-epoxy IM10/8552 composite is efficient material.
From linear buckling analysis of rocket motor case, the total buckling deformation is more in D6AC steel than carbon-epoxy IM10/8552 composite. Hence it can be concluded that carbon-epoxy IM10/8552 composite is efficient material.

6. Reference

[1] Harold K. Whitfield, Russell B. Keller, Jr. of Lewis, Howard W. Douglass, John H. Collins Jr., “Solid Rocket Motor Metal Cases”, NASA Space Vehicle Design Criteria SP-8025 April, 1970.
[2] Dr. P. Evans, “Composite Motor Case Design”, “Design Methods in Solid Rocket Motors”, Advisory Group for Aerospace Research & Development-Lecture Series No.150, September 27th, 1988.
[3] Devon K. Cowles, “Design of a Rocket Motor Casing, Engineering Project”, May, 2012.
[4] Narendra Kumar Shrivastava, G. Avinash, Dr. S. Rama Krishna, “Design and Analysis of Composite Rocket Motor Casing”, International Journal of Emerging Technology and Advanced Engineering, Volume 4, Issue6, June 2014, pp. 231-236.
[5] M.K.Sridhar, “Fibre Reinforcements for Composites”, Defence Science Journal, Volume 43, No 4, October 1993, pp. 365-368.
[6] P. Mahesh Babu, G. Bala Krishna, B Siva Prasad, “Design & Analysis of Solid Rocket Motor Casing for Aerospace Applications”, International Journal of Current Engineering and Technology, Volume 5,No. 3, June 2015, pp. 1947-1954.
[7] Siva Sankara Raju R, Karun Kumar Y, Pragathi Kumar G, “Design and Analysis of Rocket motor Casing by Using Fem Technique”, International Journal of Engineering and Advanced Technology, Volume 2, Issue 3, February 2013, pp. 70-74.
[8] Suresh Kumar, K.V.V.S. Murthy Reddy, Anil Kumar, G. Rohini Devi, “Development and Characterization of polymer-ceramic continuous fiber reinforced functionally graded composites for aerospace application”, Aerospace Science and Technology ELSEVIER, No.26, 2013, pp. 185-191.