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# FINITE ELEMENT ANALYSIS OF LAMINATED COMPOSITE PRESSURE VESSELS

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## Abstract:

The weight component plays vital role for any structure if it is moving opposite the gravity. Generally, rockets, missiles & aeroplanes will travel opposite to the gravity. To reduce weight of the structure most of the parts replacing with the composite materials because of their high strength to weight ratio. Generally in rockets, motors having the huge weight because the rocket motor will the fluid for combustion. These are generally treat as pressure vessels. In the present case, the motor will treated as the pressure vessel and analysed for composite materials. The composite materials chosen for the analysis are E-glass, S-glass, Kevlar and Graphite fibre with epoxy resin with volume fraction of 60%. The cylinder was analysed as laminated composite cylinder which contains the 8 layers. Static structural, pre-stressed modal analysis and eigen value buckling analysis were done by using the finite element simulation software Ansys workbench. From these two analyses, best composite layup and best material was recommended.

**Keywords:** Finite element analysis, Fibre reinforced composites, Ansys workbench, Pre-stressed Modal Analysis

## 1. Introduction

Pressure vessels are usually consisting of cylindrical and spherical with dome end. Cylindrical pressure vessels with integrated end domes develop hoop stresses that are twice longitudinal stresses and when isotropic materials, like metals, are used, the material is not fully utilized in the longitudinal direction, resulting in over weight components. This indicates that using an ordinary isotropic material such as steel, would be wasteful due to the material being able to unnecessarily take twice the pressure resultant loading in the longitudinal direction. For this reason we can use composite material. A composite material is made commonly by combining of two or more distinct materials each of which retains its distinctive properties to create a new material. In those two materials one is a solid material and the other a binding material which holds both materials together. Due to their high strength and light weight fibre reinforced has wide range of applications. Amin Paykani [1] shows that fatigue life of composite pressure vessel depends on the finite element mesh size, crack density and ratio in an element, cyclic loading amplitude and stress status at the liner. RAO [2], performed structural analysis on the composite pressure vessels with different layup sequences. He compared the analytical results with finite element results. Rakesh potluri [3] performed the buckling analysis for ring stiffened cylinders fabricated by using hybrid composite with design of experiments procedure. J.Shen [4] introduced the basic principles, implementation procedures and software applications of local buckling of pressure vessel. Baopingcai [5] performed the buckling analysis of long composite cylinder subjected to external pressure said that thickness of composite layer, inside radius, longitudinal modulus and transversal modulus plays a vital role in performance of composite in buckling. Lekhnitskii [6] made a deep investigation on Composite cylinders under internal pressure, twisting moment, axial load or bendingmoment. Sreelatha [7] said nonlinear analysis is more important for prediction of failure in design of submarine hull. MullaNiyamat [8] did the design and analysis of the Pressure vessel based on thermo-mechanical loads.

## 2. Problem Statement

To study the effect of the composite material and layup sequence on the pressure vessels in Static Structural, Pre-Stressed Modal analysis and eigen value Buckling Analysis point of view.

### 2.1 Methodology

Finite element method simulation software Ansys workbench 17.0 was used to perform the analysis. A composite pressure vessel was modelled using Ansys Composite Pre-Post (ACP) 17.0.The schematic view of the static structural, pre-stressed and eigen value buckling were shown in the figure 1,2.

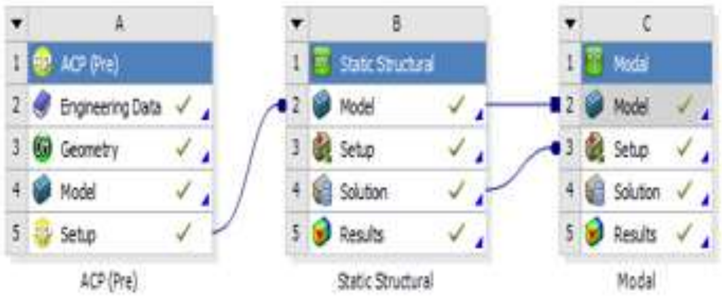


**Figure 1.** Schematic view of the structural & Modal Analysis for composite pressure vessel in Ansys Workbench

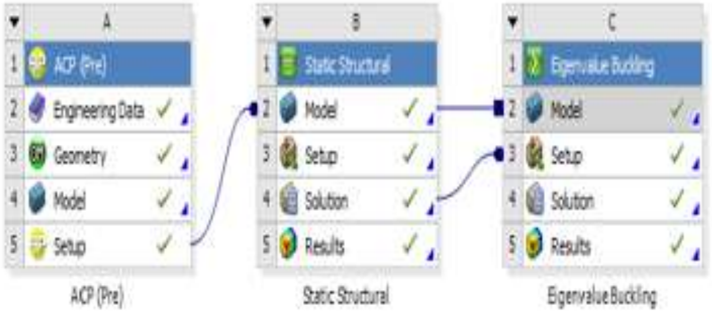


**Figure 2.** Schematic view of the buckling Analysis for composite pressure vessel in Ansys Workbench

## Problem Modelling

### Geometry

The composite pressure vessel was modelled using finite element simulation software Ansys workbench 17.0. The Pressure vessel was modelled in such a way that the both ends are opened [1].

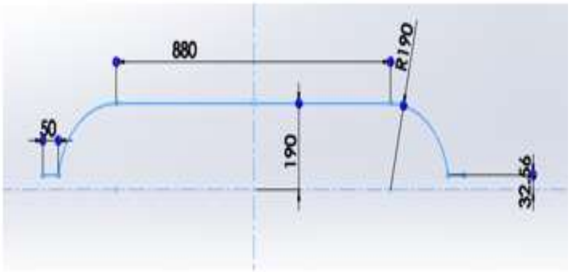


**Figure 3.** Geometry and Dimensions of Vessel.

**Figure 4.** 3D-View of the vessel

The layup sequence considered for the analysis are

1. $[0/45/90/-45]_s$
2. $[0/90/45/-45]_s$
3. $[45/-45/45/-45]_s$
4. $[0/45/-45/90]_s$
5. $[45/90/-45/0]_s$
6. $[0/90/90/0]_s$

### *3.2 Finite Element Meshing*

It is the method of converting the geometrical entities to finite element entities. Cylindrical coordinate system was assigned for cylinder and spherical coordinate system was assigned to the ends of the vessel in order to orient the nodes and elements.8 node shell element was used with layer option.

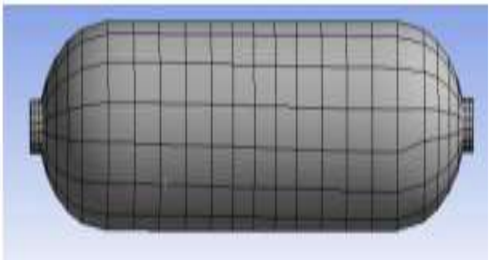
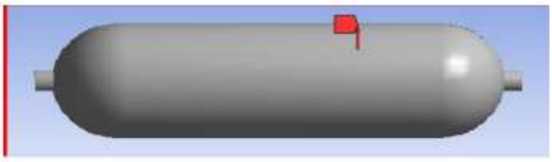


Figure 5. Meshed View of the Pressure Vessel

### *3.3* Loads and Boundary Conditions

Both ends of the pressure vessel was given as cylindrical supports Pressure load of magnitude 50 MPa was applied on the i ner surface of the pressure vessel..



a) Internal Pressure

b) Cylindrical Supports

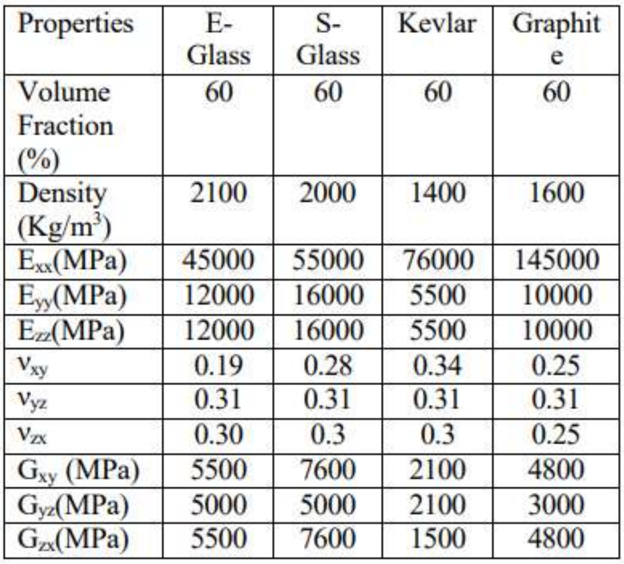
Figure 6. Loads & Boundary Conditions

The schematic view of loads were shown in the figure 6.

### *3.4* Material Properties

Four types of composite materials were chosen for analysis. Those are E-Glass, S-Glass, Kevlar and Graphite with epoxy matrix. The properties of the materials are given in Table-1

Table 1. Material properties



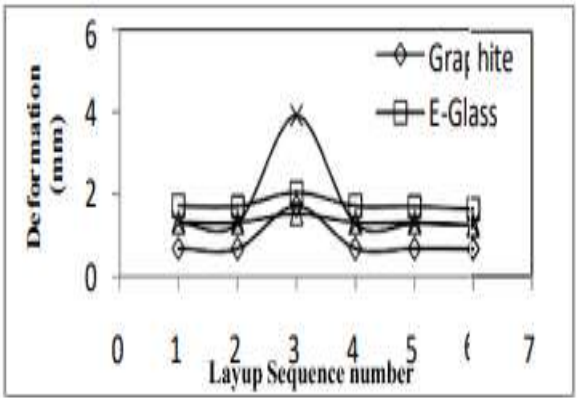
| Properties | E-Glass | S-Glass | Kevlar | Graphite |
|---|---|---|---|---|
| Volume Fraction (%) | 60 | 60 | 60 | 60 |
| Density (Kg/m$^3$) | 2100 | 2000 | 1400 | 1600 |
| $E_{xx}$(MPa) | 45000 | 55000 | 76000 | 145000 |
| $E_{yy}$(MPa) | 12000 | 16000 | 5500 | 10000 |
| $E_{zz}$(MPa) | 12000 | 16000 | 5500 | 10000 |
| $\nu_{xy}$ | 0.19 | 0.28 | 0.34 | 0.25 |
| $\nu_{yz}$ | 0.31 | 0.31 | 0.31 | 0.31 |
| $\nu_{zx}$ | 0.30 | 0.3 | 0.3 | 0.25 |
| $G_{xy}$ (MPa) | 5500 | 7600 | 2100 | 4800 |
| $G_{yz}$(MPa) | 5000 | 5000 | 2100 | 3000 |
| $G_{zx}$(MPa) | 5500 | 7600 | 1500 | 4800 |

## 4.Results and Discussion

### 4.1Static Structural Analysis

### 4.1.1 Total Deformation

Deformation indicates the stiffness of the structure. The effect of material and sequence on the total deformation in static structural analysis was plotted in the figure 7.



From the figure 7, it was observed that among the materials considered, graphite shows the lowest deformation, it represents higher stiffness. In view of the sequences, the layup [0/90/90/0]s shows thelowest deformation. The figure 8 shows the schematic view of the total deformation of graphite for the sequence [0/45/90/-45]s. The deformation was observed in the surface

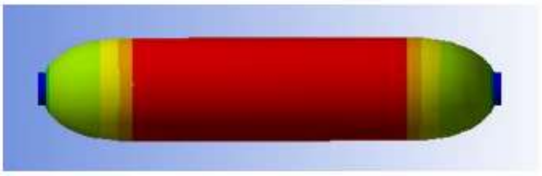


Figure 8. Total Deformation Graphite [0/45/90/-45]s

### 4.1.2 Hoop Stress

Hoop stress is the critical stress in the pressure vessels. The variation of the hoop stress w.r.t the material and layup sequence figure 9

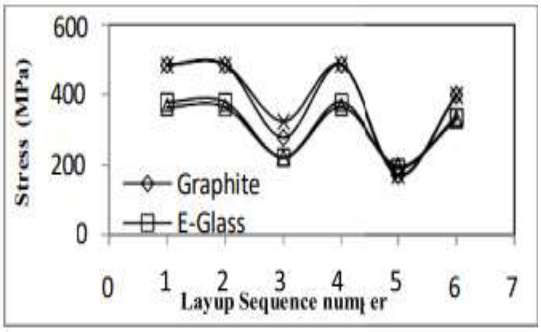


Figure 9. Variation of the hoo stress w.r.t the material and layup sequence

From the figure 9 it was sequence-5 [45/90/-45/0]s sh stresses among the sequences observed that the ws the lower hoop considered. At this sequence both Kevlar and graphite shows the same stress magnitudes. But except at this sequence, for remaining all sequences, s-glass shows the lower hoop stress.

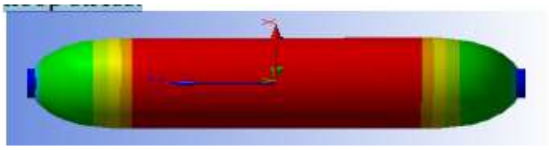


Figure 10. Schematic View of Hoop Stress, Graphite [0/45/90/-45]s

## 4.2 Modal Analysis

### 4.2.1 Mode-1

It is used to find out the natural frequencies of the structure. From the modal analysis first three mode shapes were analysed for all sequences and materials. The variation of the mode-1 w.r.t the layup sequence and material were plotted in the Figure 11.

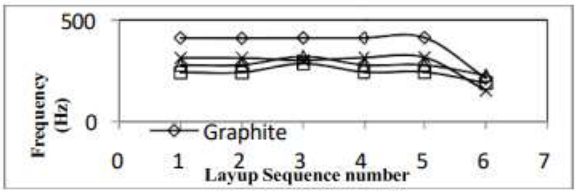


Figure 11. Variation of the mode-1 w.r.t the material and layup sequence

From the figure 11, it was observed that graphite material shows the highest natural frequency

compared to remaining materials considered. In view of the layup sequence, except sequence 3 and 6, remaining sequences shows the same natural frequencies. The behaviour of the structure for the variation of the sequence is not the predictable manner. But from the figure, graphite with sequence-5 [45/90/-45/0]s shows highest natural frequency

The schematic view of the mode shape-1 for graphite material was plotted in the figure 12.

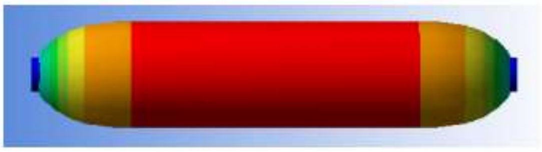


Figure 12. Schematic View of Mode Shape 1, Graphite [0/45/90/-45]s

### 4.2.2 Mode-2

The variation of the mode-2 w.r.t the material and layup sequence were plotted in the figure 13.

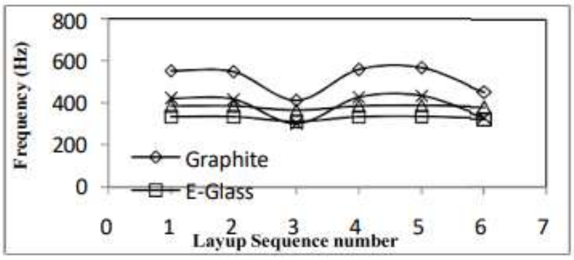


Figure 13: Variation of Mode-2 w.r.t material and layup sequence

From the figure 13, it was observed that graphite having the higher natural frequency among the materials selected. Graphite with sequence-5 [45/90/-45/0]s shows the highest natural frequency. The schematic view of the mode shape-2 for the graphite material was shown the figure 14.

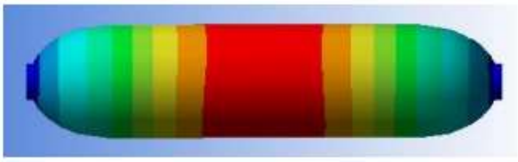


Figure 14. Schematic View of Mode Shape 2,

Graphite [0/45/90/-45]s

### 4.2.3 Mode-3

The variation of the mode-3 w.r.t the material and layup sequence were plotted in the figure 15.

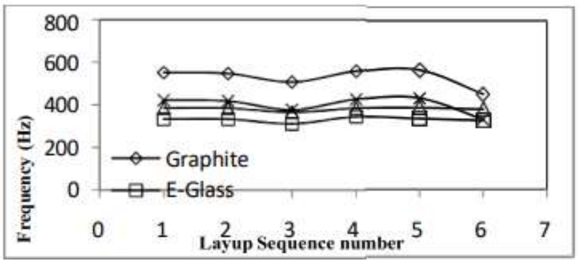


Figure 15. Variation of the mode-3 w.r.t the material and layup sequence

From the figure 15, it was observed that graphite material shows the highest natural frequency compared to remaining materials selected. Graphite Material with sequence-5[45/90/-45/0]s shows the highest natural frequency. The contour image of the mode shape-3 for the graphite material was shown the figure 16.

Figure 16. Schematic View of Mode Shape 3,

Graphite [0/45/90/-45]s

### 4.3 Buckling Analysis

### 4.3.1 Buckling load-1:

Buckling analysis was used to find out the stability of the structure. The more the buckling load, the structure will contain the more stability The variation of the buckling load-1 w.r.t the material and layup sequence were plotted in the figure 17.

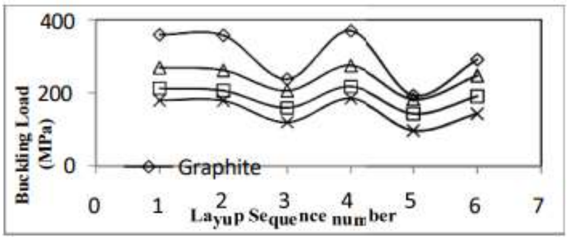


Figure 17. Variation of the buckling load w.r.t material and layup sequence

From the figure 17, it was observed that graphite shows higher buckling strength among the selected materials. In view of the layup sequences considered sequence-4 [0/45/-45/90]s having the better buckling strength. The contour image of the first buckled mode shape for graphite was shown in the figure 18.

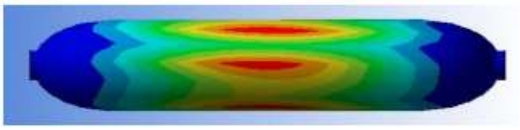


Figure 18. Schematic View of Buckling Load 1,

Graphite [0/45/90/-45]s

### 4.3.2 Buckling load-2:

The variation of buckling load-2 w.r.t the material and layup sequence were plotted in the figure 19.

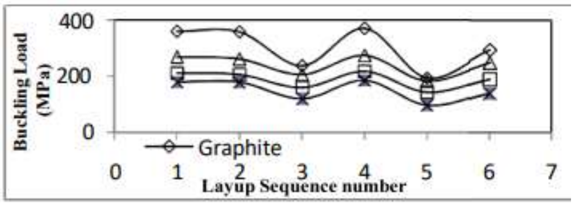


Figure 19. Variation of the buckling load-2 w.r.t material and layup sequence

From the figure 19, it was observed that graphite shows the higher buckling strength selected materials. In view of layup considered, sequence-4 [0/45/-45/90]s good buckling strength. shows the higher buckling strength selected materials. In view of layup considered, sequence-4 [0/45/-45/90]s good buckling strength. The schematic view of the second buckled mode shape for graphite was plotted in the figure 20.

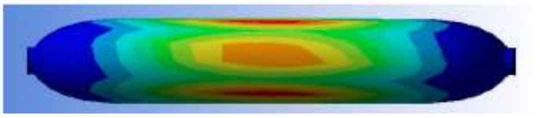


Figure 20. Schematic View of Buckling Load 2

Graphite [0/45/90/-45] s

From the above observations, it can recommend that, Graphite epoxy with [0/45/-45/90]s having good buckling strength among the considered materials and layup sequences. In view of modal analysis graphite shows the higher natural frequency for the sequence of [45/90/-45/0]s. In view of static structural, for good stiffness graphite material with [0/90/90/0]s was recommended. But in strength point of view S-glass epoxy with [45/90/-45/0]s was recommended.

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