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"Weight Reduction of Pressure Vessel Using FRP Composite Material"

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Abstract:*Pressure vessel is a closed container designed to hold fluids at a pressure substantially different from the ambient pressure. The metallic pressure vessels are having more strength but due to their high weight to strength ratio and corrosive properties they are least preferred. These industries are in need of pressure vessels which will have low weight to strength ratio without affecting the strength. On the other hand FRP (Fiber reinforced plastic) composite materials with their higher specific strength characteristics will result in reduction of weight of the structure. E-Glass Filament-wound composite pressure vessels are an important type of high-pressure container that is used widely. On the other hand FRP composite materials will result in reduction of weight of the structure. In this seminar report FEA of steel and FRP composite pressure vessel is compared and found that FRP pressure vessel has more strength than steel vessel and also the weight reduction of 75 % can be obtained by replacing steel with FRP material.*
Keyword: *pressure, pressure vessel, composites.etc*

I. Introduction

Pressure vessels are important because many liquids and gases must be stored under high pressure. Most pressure vessels are required to carry only low pressures and thus are constructed of tubes and sheets rolled to form cylinders. Some pressure vessels must carry high pressures, however, and the thickness of the vessel walls must increase in order to provide adequate strength. Damage of a pressure vessel has a potential to cause extensive physical injury and property damage so leak-proof design and manufacturing is important. Material used for pressure vessel must be sufficiently ductile and tough. Fiber reinforcement plastic composite material is best suitable alternative for metallic pressure vessel due to its low weight to strength ratio and non-corrosive property [1].

In today's aerospace and aircraft industries, structural efficiency is the main concern. Due to their high specific strength and light weight, fiber reinforced composites find a wide range of applications. Light weight compression load carrying structures form part of all aircraft, and space vehicle fuel tanks, air cylinders are some of the many applications [1].

II. Problem statement

The metallic pressure vessels are having good strength but due to their high weight to strength ratio and corrosive properties they are least preferred in aerospace as well as oil and gas industries. These industries are in need of pressure vessels which will have low weight to strength ratio without affecting the strength in this paper a pressure vessel with both ends open is used and it is same as cylinder.

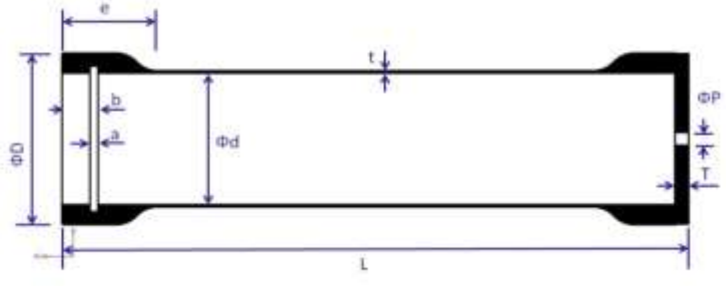


Figure2.1: Pressure vessel model[3].

III. Analysis of Steel Pressure Vessel

FE Mesh

The process of obtaining an appropriate mesh (or grid) is termed mesh generation (Grid generation), and has long been considered a bottleneck in the analysis process due to the lack of a fully automatic mesh generation procedure. In this work we used hexahedron elements (SOLID45) for FE Modeling.

Figure3.1:FE Model of pressure vessel[3].

Material Properties

Steel material used for the analysis is of grade' ASME SA537Class 2'.

Table 3.1: Material properties of the steel model[3].

S.No.	Material Property	Value
1	Density (ρ)kg/ m^3	7850
2	Young's modulus (E)Mpa	2.1 E5
3	Poisson's ratio (μ)	0.3
4	Stress induced (σ)Mpa	218.75

Analysis and result

Now a day various software available in market for FE Analysis. In this work ANSYS software is used for the analysis and post-processing.

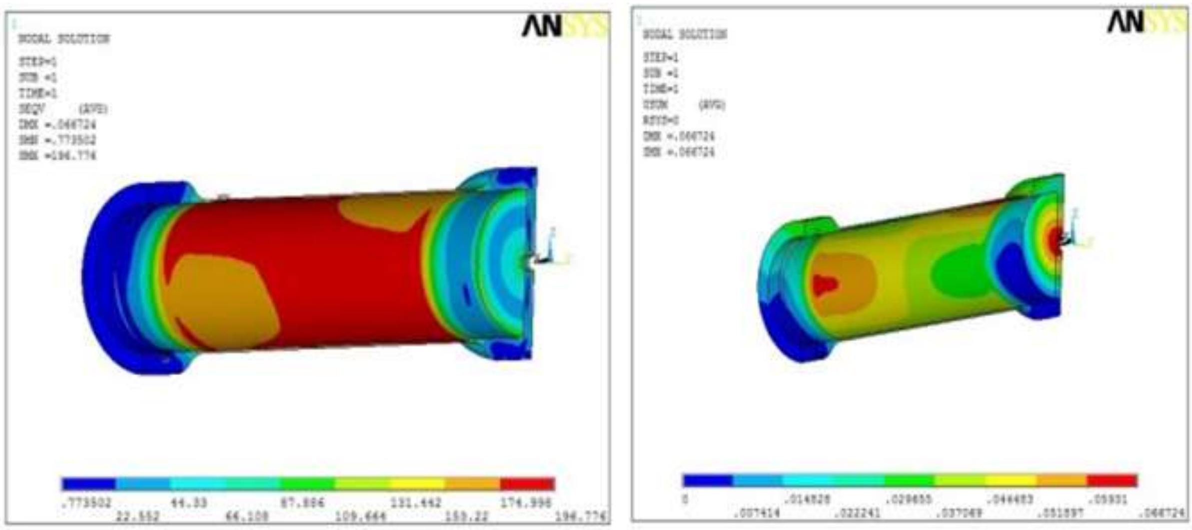


Figure3.2: Stress and deflection plot for steel pressure vessel[3].

In this analysis it is found that the maximum stress and deflection for steel pressure vessel is 196.77 Mpa and 0.06 mm respectively, maximum stress in model is less than allowable stress for steel material.

IV. Analysis of FRP Pressure Vessel

Material Properties

Layered structure of FRP pressure vessel is represented by using SOLID46 elements. E-glass Epoxy material properties areapplied for pressure vessel.

Table 4.1: Material properties of the FRP model[3].

S. No.	Properties	Epoxy Resin	Eglass
1	Density (ρ)tonnes/ mm^3	$1.2x10^{-9}$	$2.6x10^{-9}$
2	Longitudinal elastic modulus (E_1) Mpa	3400	85000
3	Transverse elastic modulus (E_2) Mpa	3100	85000
4	Poisson's ratio (N12)	0.3	0.25
5	Modulus of rigidity(G12) Mpa	1308	35000
5	Modulus of rigidity(G13) Mpa	1308	35000
6	Ultimate tensile strength (σTS) Mpa	82.74	2447

Analysis and Result

Analysis and post processing of FRP Pressure vessel is done by ANSYS software. In this analysis it is found that the maximum stress and deflection for FRP pressure vessel is 155.96 MPa and 2.12 mm respectively, maximum stress in FRP pressure vessel is less than maximum stress in steel pressure vessel.

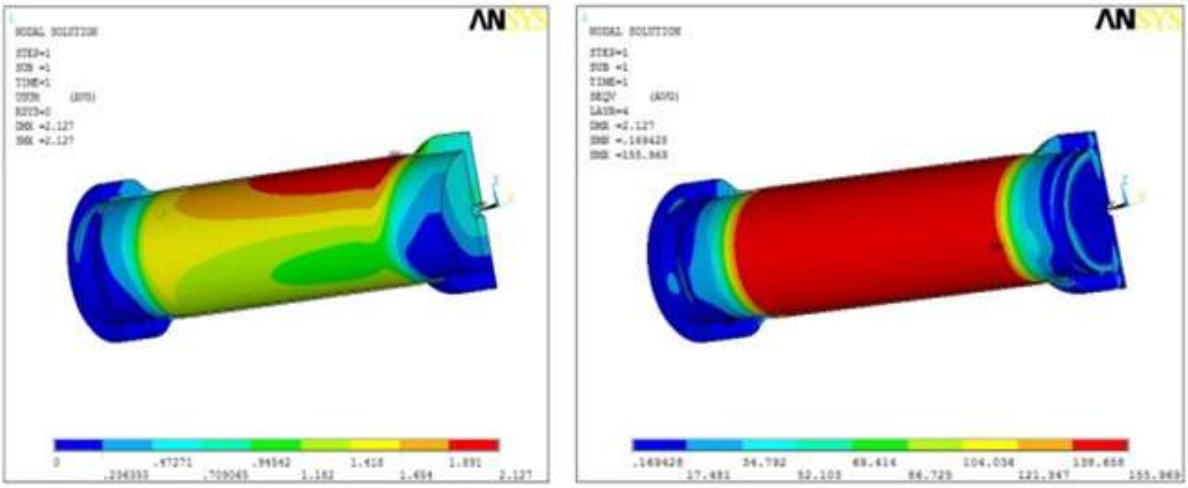


Fig4.1**:**Stress and deflection plot for FRP pressure vessel[3]**.**

Weight calculation

Table 4.2: -Weight calculation of pressure vessel[3].

S.No	Material	Density in Kg/mm^3	Volume in mm^3	Weight in Kg
1	Steel	$7.85x10^{-6}$	$8.2x10^5$	6.43
2	Composite	$1.90x10^{-6}$	$8.2x10^5$	1.55

Percentage of weight reduction = ((6.43-1.55)/6.43)*100=**75.89%**

By using the composite pressure vessel instead of steel pressure vessel weight has reduced to **75.89%**

Structural Efficiency

Table 4.3: Structural efficiency calculation of pressure vessels[3].

Sr. No	Material	Pressure(Mpa)	Volume in mm3	Weight in Kg	Efficiency
1	Steel	6	$8.2x10^5$	6.43	$7.65x10^5$
2	Composite	6	$8.2x10^5$	1.55	$3.17x10^6$

For the same pressure and volume of the cylinder the percentage of structural efficiency increased in composite pressure vessels is given by

Structural efficiency = ((3.17x106-7.65x105)/ 3.17x106)*100 = **75.86%**

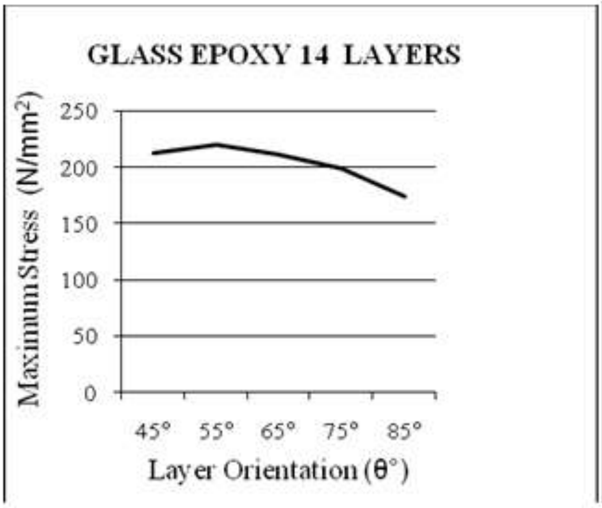
V. Lamina and Laminate Analysis

A lamina (considered a unidirectional composite) is characterized by having all fibers (either a single ply or multiple plies) oriented in the same direction. This model allows one to treat lamina as an orthotropic material. A lamina is a collection of laminates arranged in a specified manner as shown in fig.6.1. Adjacent lamina may be of the same or different materials and their orientations with respect to a reference axis may be arbitrary.

Angle-Ply Laminates: Angle-ply laminates have an arbitrary number of layers (n). Each ply has the same thickness and is the same material. The plies halt can be either symmetric or anti-symmetric.

Composite Material Properties

The properties of the composite materials used in the present work are given as below
Glass-Epoxy E1 = 60 Gpa,E2 = 7.3 Gpa,G12 = 3.78 Gpa, $\mu 12 = 0.3$, Volume fraction Vf= 0.55
Carbon-Epoxy E1 = 130 Gpa E2 = 11 Gpa G12 = 5.5 Gpa $\mu 12 = 0.27$ Volume fraction Vf= 0.55
Single –layered laminates: A single layered laminate is a unidirectional lamina with multiple layers. Symmetric Laminates: A symmetric laminates has both geometric and material symmetry with respect to the mid-surface. Geometric symmetry results from having identical lamina orientations above and below the mid surface. Material symmetry can result from either having all lamina the same material, or requiring different lamina to be symmetrically disposed about the mid-surface.



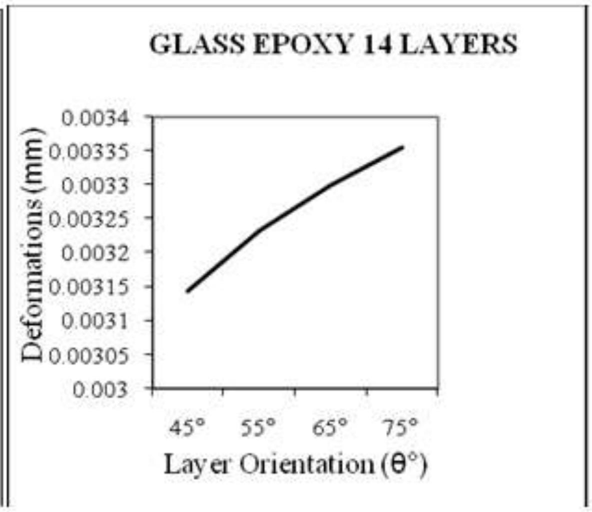
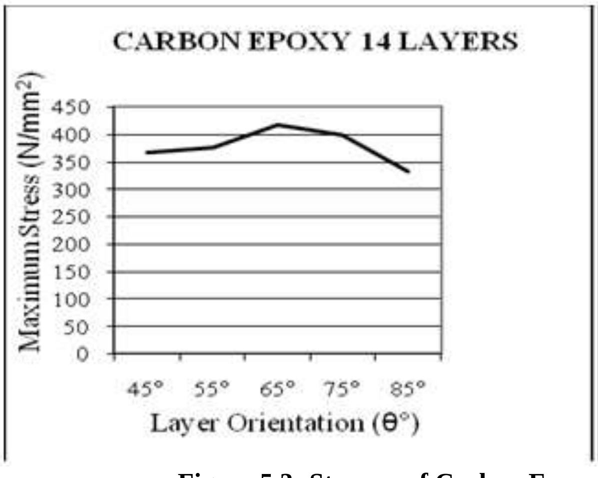


Figure 5.1: Stresses of Glass EpoxyFigure 5.2: Deformations of Glass Epoxy



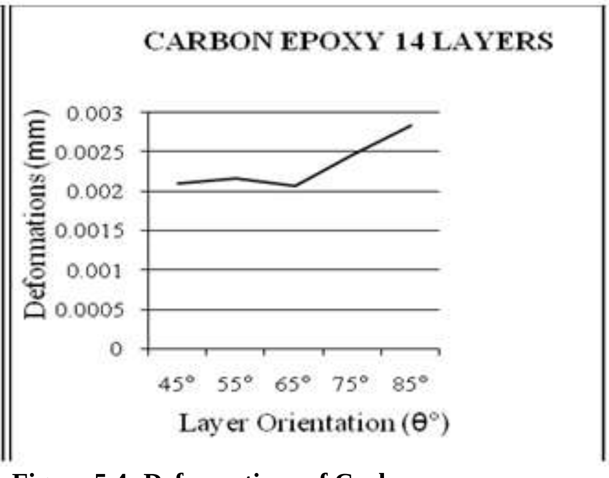


Figure 5.3: Stresses of Carbon EpoxyFigure 5.4: Deformations of Carbon

VI. Result

The fiber orientation ±55° for glass epoxy and ±65°angle for carbon epoxy is correct which optimum value is. From the finite element analysis report the maximum stress obtained in each lamina (for ±55, ±65 degrees winding angle) is less than the allowable working Strength of the FRP lamina. So shell design is safe [1].

VII. Summary

In these study ANSYS results are compared steel material and FRP material pressure vessel. Following points are summarized

i) In the stress analysis, it is found that the maximum stress in the FRP pressure vessel is lessthan allowable stress for FRP Material. Hence design of pressure vessel using FRP is safe.

ii) For current design weight of FRP pressure vessel is less than steel pressure vessel. Percentageweight reduction in case of FRP pressure vessel is 75.89%

iii) Structural efficiency of FRP pressure vessel more than steel pressure vessel. Increase instructural efficiency in case of FRP pressure vessel is 75.86%

iv) Use of FRP pressure vessel instead of steel pressure vessel can reduce weight of pressurevessel about 75% and corrosion problem of steel pressure vessel also get solved.

v) The optimum fiber orientation for glass epoxy is ±55° and for carbon epoxy is ±65°angle

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