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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 gases or liquids 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 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. 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 widely used in the commercial and aerospace industries. On the other hand FRP composite materials with their higher specific strength characteristics will result in reduction of weight of the structure.

In this paper Finite element analysis of steel pressure vessel and FRP composite pressure vessel is carried out. On the basis of analysis it is found that FRP pressure vessel has more strength than steel pressure vessel and it is also concluded that the pressure inside the vessel can be reduced up to 75 % by replacing steel with FRP material. FRP material is available in various winding angle. Analysis is also carried out to find optimum fiber angle of FRP material used for pressure vessel.

KEYWORDS: FRP, Pressure vessel, composite material, E-glass, Epoxy Resine.

1. INTRODUCTION

A pressure vessel is defined as a container with a pressure differential between inside and outside. Damage of a pressure vessel has a potential to cause extensive physical injury and property damage so leak-proof design and manufacturing is important [1]. Shape of pressure vessel may be spherical, cylindrical or cone shape. Spherical pressure vessel has more strength than other shape but its manufacturing is very complicated [1].

Material used for pressure vessel must be sufficiently ductile and tough. Its elongation is not less than 14% and its impact toughness is not less than 27J. Metallic pressure vessels are having more 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. 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].

2. COMPOSITE MATERAL

A composite is basically a combination of two or more structural materials. It is classified into two types- Carbon Fiber Reinforcement Plastic (CFRP) and Glass Fiber Reinforcement Plastic (GFRP). CFRP is a composite of carbon and polymer. It is of very high strength, low weight but highly expensive. While GFRP is a polymer (the resin) and a ceramic (the glass fibers) It is of good strength, low weight compare to CFRP but less costly than CFRP. [2]

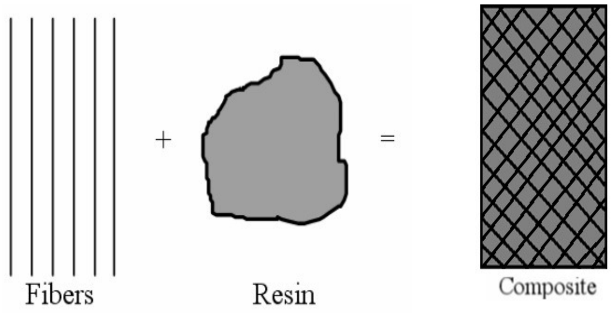


Figure 2.1: Formation of a composite material using fibers and resin**.**

3. FILAMENT WINDING MATERIAL

3.1 Fiber: The mechanical properties of fibers improve the overall mechanical properties of the fiber/resin composite. The contribution of the fibers depends on four main factors as the fundamental mechanical properties of the fiber, the surface contact of fiber and resin (interface), the quantity of fibers in the composite, and the fiber angle of the fibers in the composite. [2]

Fibers can be divided into groups according to their chemical composition. Well known are A-glass, C-glass, S-glass and E-glass fibers. E-Glass is a low alkali glass with a typical nominal composition of SiO2 54wt%, Al2O3 14wt%, CaO+MgO 22wt%, B_2O_3 10wt% and Na_2O+K_2O less than 2wt%. Some other materials may also be present at impurity E-Glass or electrical grade glass was originally developed for standoff insulators for electrical wiring. It was later found to have excellent fiber forming capabilities and is now used almost exclusively as the reinforcing phase in the material commonly known as glass fiber. These fiber mostly used in aerospace design. [1]

Glass fibers are generally produced by melt spinning techniques. These involve melting the glass composition into a platinum vessel which has small holes for the molten glass to flow. Continuous fibers can be drawn out through the holes and wound onto spindles [3]

3.2 Epoxy resin: This resin first prepared by American scientist Dr. S.O. Greenlee and Switzerland scientist Dr. Pierre Castanin 1936. It is basically the glue that keeps the composite together. A resin must have good mechanical properties, good adhesive properties, good toughness properties and good environmental properties. Epoxy has a wide range of applications, including metal coatings, used in electronics / electrical components, high tension electrical insulators, fiber-reinforced plastic materials, and structural adhesives. [1]

4. MANUFACTURING PROCESS OF COMPOSITE PRESSURE VESSEL

FRP laminates consist of outer corrosion barrier it is generally a thin coating of wax or paint. Structure of FRP is in laminates or plies form. It consists of epoxy resin and E-glass fiber plies with some angle ranging from 45^0 to 88^0 and thickness of plies is depending on application. This structure is coated with inner corrosion barrier of thin coating of aluminum material or any suitable anticorrosive material.

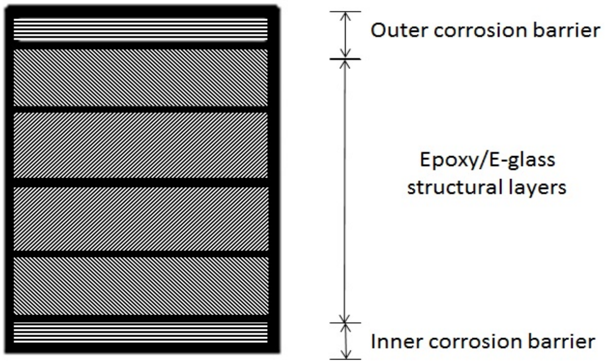


Figure 4.1: Basic FRP Laminates Cross section

4.1 Classification of Composites Processing:

Composite materials involve two or more different materials, hence processing techniques used with composites are different than those for metals processing. There are various types of composites processing techniques available to process the various types of reinforcements and resin systems [2].

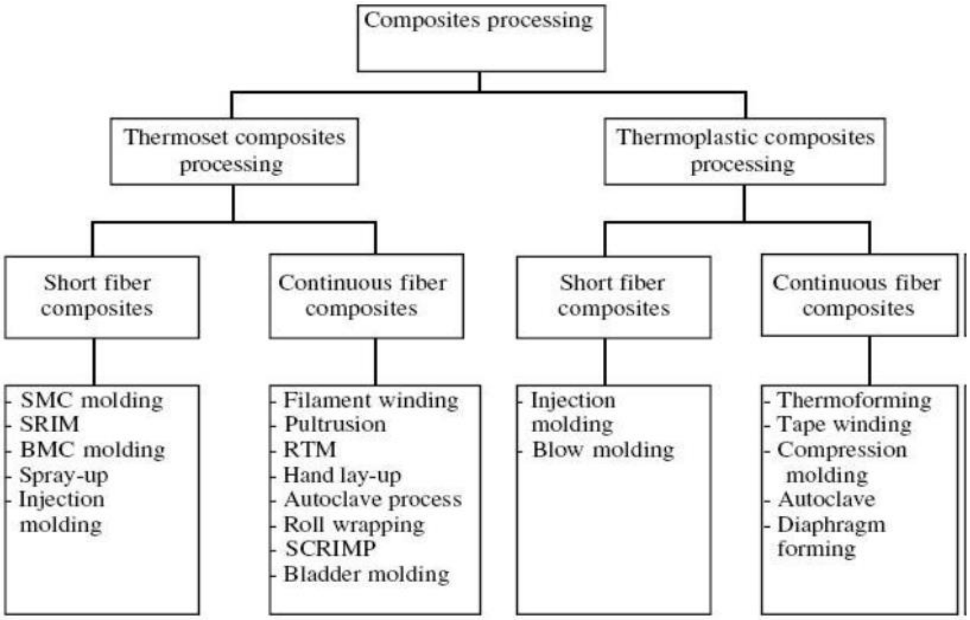


Figure 4.2: Classification of composites processing techniques

4.2 Filament winding-process technology: The process of filament winding is primarily used for hollow, generally circular or oval sectioned products. Fibers can either be use dry or be pulled through a resin bath before being wound around the mandrel. The winding angle is controlled by the rotational speed of the mandrel and the movement of the fiber feeding mechanism. Fig. 4.2 shows filament winding process. Filament winding usually refers to the traditional filament winding process [3].

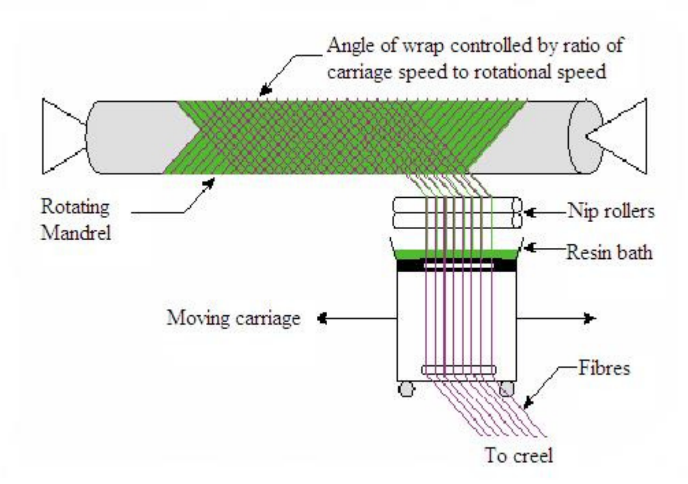


Figure 4.2: Schematic representation of the filament winding process

After winding, the filament wound mandrel is subjected to curing and post curing operations during which the mandrel is continuously rotated to maintain homogeneity of resin content around the circumference. After curing, product is removed from the mandrel, either by hydraulic or mechanical ejector.

4.2.1 Cutting of FRP: laminated composites is required in both uncured and cured states Uncured materials (prepress, preforms, SMCs, and other starting forms) must be cut to size for lay-up, molding, etc.

- Typical cutting tools: scissors, power shears and steel-rule blanking dies
- Other methods are also used, such as laser beam cutting and water jet cutting
- Cured FRPs are hard, tough, abrasive, and difficult-to-cut
- Cutting of FRPs is required to trim excess material, cut holes and outlines.
- For glass FRPs, cemented carbide cutting tools and high speed steel saw blades can be used.
- Water jet cutting is also used, to reduce dust problems with straight sawing methods [2].

5. INTRODUCTION TO FEA

Finite Element Analysis (FEA) is a computational technique that uses the finite element method to analyze a material, object or mechanism and find how applied stresses will affect the material or design. Finite element modeling involves the discretization of the structure into finite nodes and elements. Nodes are used to represent geometric locations in the structure. Domains that are defined by nodes which describe as elements

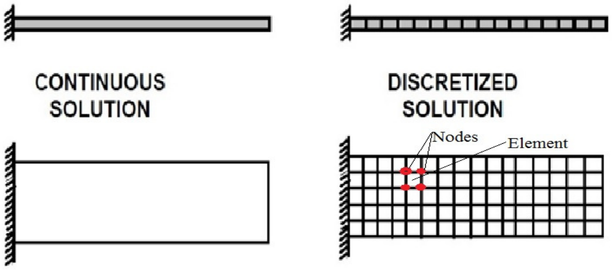


Figure 5.1: Finite element modeling

6. PROBLEM DEFINATION

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.

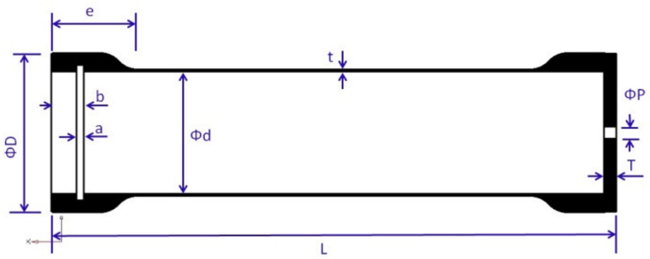


Figure 6.1: Pressure vessel model

7. ANALYSIS OF STEEL PRESSURE VESSEL

7.1 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.

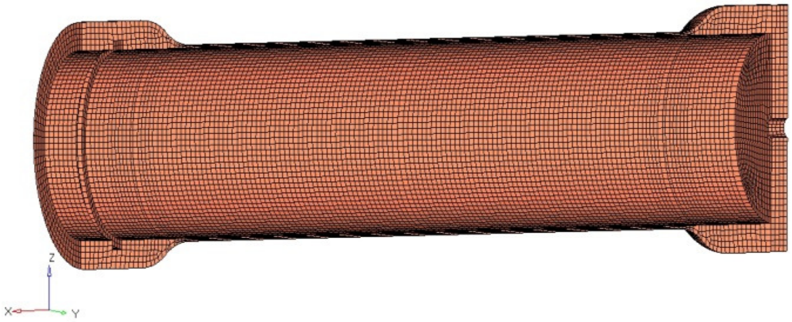


Figure 7.1: FE Model of pressure vessel**.**

7.2 Material Properties

Steel material used for the analysis is of grade' ASME SA537Class 2' [4].

Table 7.1 Material properties of the steel model

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

7.3 Boundary condition and Loading

Model is fixed at both the ends. Symmetric Boundary conditions are applied as half model symmetry is considered for analysis to reduce model size. Inside pressure 60 bar is applied on pressure vessel.

7.4 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 postprocessing.

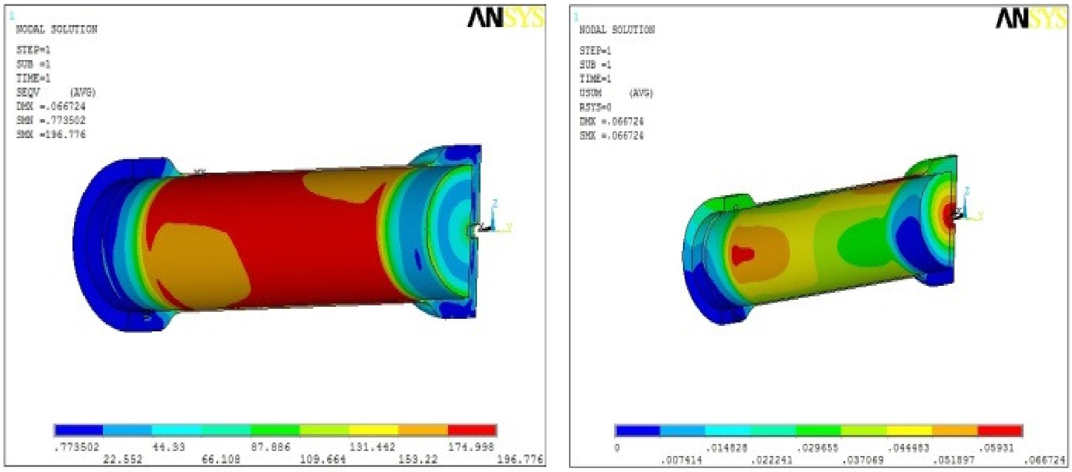


Figure 7.2: Stress and deflection plot for steel pressure vessel**.**

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.

8. ANALYSIS OF FRP PRESSURE VESSEL

Layered structure of FRP pressure vessel is represented by using SOLID46 elements. E-glass Epoxy material properties are applied for pressure vessel [5].

Table 7.1 Material properties of the FRP model

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

Boundary condition and loading for the FRP pressure vessel is same like steel pressure vessel.

8.4 Analysis and result

Analysis and postproessing 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.

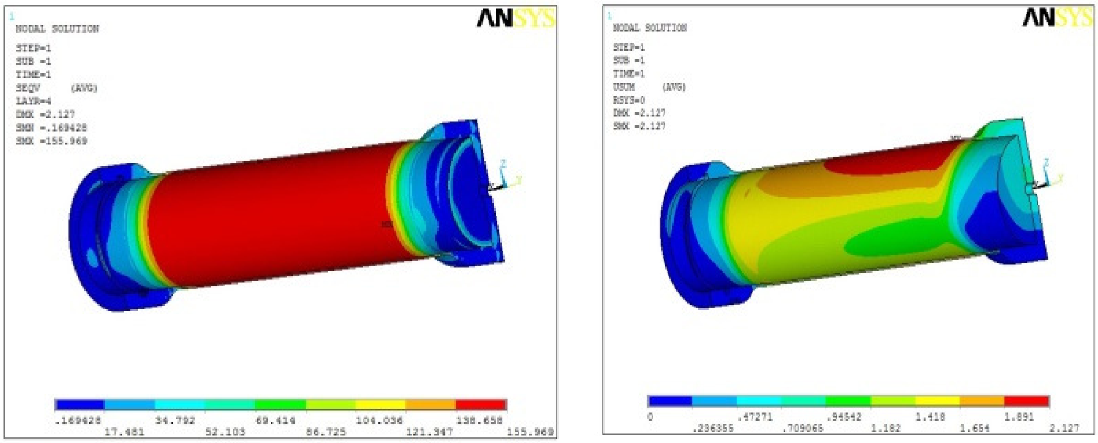


Figure 8.1: Stress and deflection plot for FRP pressure vessel**.**

9. NETTING ANALYSIS FOR FIBER ANGLE OPTIMIZATION

Netting analysis is simple technique used in rationalizing behaviour of fiber reinforcement composite material and most suitable for pressure vessel analysis. The analysis of filament-wound structures which assumes

(1) The stresses induced in the structure are carried entirely by the filaments, and the strength of the resin is neglected

(2) The filaments possess no bending or shearing stiffness and carry only the axial tensile loads and circumferential loads.

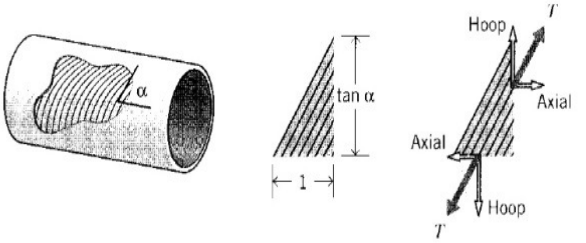


Figure 7.3: Netting Analysis

Consider a cylindrical pressure vessel to be constructed by filament winding, in which fibers are laid down at a prescribed helical angle α (Figure 7.3). Taking a free body of unit axial dimension along which n fibers transmitting tension T are present, the circumferential distance cut by these same n fibers is then tan α. To balance the hoop and axial stresses, the fiber tensions must satisfy the relations

Hoop stress = $nT\sin\alpha\ (pr/t)\ (t)$

Axial stress= $nt\cos\alpha\ (pr/2t)(\tan\alpha)(t)$

Dividing the first of these expressions by the second and rearranging, we have

$\text{Tan}^{2}\alpha = 2$,

α= 54.7◦

This is the “magic angle” for filament wound vessels, at which the fibers are inclined just enough toward the circumferential direction to make the vessel twice as strong circumferentially as it is axially. Firefighting hoses are also braided at same angle, since otherwise the nozzle would jump forward or backward when the valve is opened and the fibers try to align themselves along the correct direction. [6]

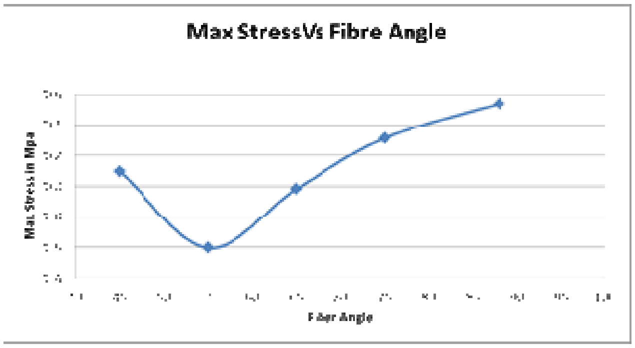
10. FE ANALYSIS FOR FIBER ANGLE OPTIMIZATION

For the optimization composite pressure vessel the internal pressure and thickness of the pressure vessel are kept constant and analysis are made for different fiber angles.

Table 10.1 Different fiber angle orientation and stress value

S. No.	Fiber Angle	Max Stress(Mpa)
1	[+45/-45/-45/+45]	160.97
2	[+55/-55/-55/+55]	155.96
3	[+65/-65/-65/+65]	159.82
4	[+75/-75/-75/+75]	163.12

Above table shows the results for different fiber angle in which iterations are made for angles $[45^{o}/-45^{o}]_{s}$, $[55^{o}/-55^{o}]_{s}$, $[65^{o}/-65^{o}]_{s}$, $[75^{o}/-75^{o}]_{s}$ and $[88^{o}/-88^{o}]_{s}$ which are symmetrical



The above graph shows that the fiber angle 55° is optimizing angle for the composite pressure vessel.

11. WEIGHT CALCULATION

Table 11.1 Weight calculation of pressure vessel

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%**

12. STRUCTURAL EFFICIENCY

The structural efficiency of pressure vessels is defined as:

e=PV/W.......Where P=Internal pressure,
V=container volume,
W=weight

Table 12.1 Structural efficiency calculation of pressure vessels

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

13. CONCLUSION

In this study the FE analysis of Steel pressure vessel and filament wound FRP pressure vessel is done using ANSYS software. In these study analytical results is compared with Ansys results of steel material.

Following points are concluded.

i) In the stress analysis, it is found that the maximum stress in the FRP pressure vessel is less than allowable stress for FRP Material. Hence design of pressure vessel using FRP is safe.
ii) Graph of Maximum Stress Vs. varying pressure at constant thickness and fiber angle is linear
iii) From Table 10.1 it is found that optimum fiber angle for fiber wounded pressure vessel is 55^o
iv) For current design weight of FRP pressure vessel is less than steel pressure vessel. Percentage weight reduction in case of FRP pressure vessel is 75.89%
v) Structural efficiency of FRP pressure vessel more than steel pressure vessel. Increase in structural efficiency in case of FRP pressure vessel is 75.86%
vii) Use of FRP pressure vessel instead of steel pressure vessel can reduce weight of pressure vessel about 75% and corrosion problem of steel pressure vessel also get solved.

REFERENCES

[1] Wikipedia, the free encyclopedia.html.
[2] Aziz ÖNDER" first failure pressure of composite Pressure vessels", dokuz eylül university Graduate school of natural and applied Sciences, 2007
[3] M. Madhavi, K.V.J.Rao and K.N.Rao. "Design and Analysis of Filament Wound Composite Pressure Vessel with Integrated-End Domes", Defence science journal, vol. 59, No. 1, January 2009, pp. 73-81, 2009.
[4] ASME SA537 Class
[5] Syed Altaf Hussain, B. Sidda Reddy and V. Nageswara Reddy" Prediction of elastic Properties of FRP composite lamina for longitudinal loading", ARPN Journal of Engineering and Applied Sciences. VOL. 3, NO. 6, DECEMBER 2008.
[6] Devid k. Roylance. "Netting analysis for filament wound pressure vessel", AMMRC TN 76-3, August 1976

[7] ANSYS Basic Analysis Procedure Guide, Release version 12.0 (2008). Ansys, Houston, Pennsylvania.
[8] Hearn, E.J. (1997). Mechanics of Materials 1, an Introduction to the Mechanics of Elastic And Plastic Deformation of Solids and Structural Materials Third Edition
[9] I.M.Jamadar, S.M.Patil, S.S.Chavan, G.B.Pawar and G.N.Rakate, "Thickness Optimization of Inclined Pressure Vessel Using Non Linear Finite Element Analysis Using Design by Analysis Approach" International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 3, 2012, pp. 682 - 689, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.
[10] Mane S.S, Prof. Wankhede P.A, "The Design of Vertical Pressure Vessels Subjected To Applied Forces and Vibrational Conditions" International Journal of Mechanical Engineering & Technology (IJMET), Volume 3, Issue 2, 2012, pp. 38 - 45, ISSN Print: 0976 – 6340, ISSN Online: 0976 – 6359.