Optimization In The Design Of Fiber Reinforced Plastic Storage Tank

Akash Tiwari, Dr. Suwarna Torgal

Abstract: In recent years, demand of composite materials has increased to a great extent because of their various advantageous properties when compared to other materials such as stainless steel. Fiber reinforced plastics (FRP) is a type of composite material that is used for storage tank construction. The main aim of this research is to optimize the design of a vertical cylindrical fiber reinforced plastic storage tank by varying the thickness of the cylindrical shell. Laminate construction having alternate layers of chopped strand mat (CSM) and woven roving (WR) is used for designing the cylindrical shell. Analysis is done using ANSYS 19 software and the results of the FRP storage tank is compared to a similar storage tank which is made of stainless steel. In this research, storage tank is designed for storing chemical liquids.

Index Terms: GFRP; Storage tank; CSM; WR.

1. INTRODUCTION

During operation, Storage tanks are subjected to internal pressure and high internal stresses are developed in them. The safety aspect is important due to build-up of high stresses in the Storage tank. Therefore, stress analysis is essential for the safe working and performance evaluation of such Storage tanks.

Fiber reinforced plastics is a type of composite material in which glass fiber is used as reinforcement and resin is used as matrix. Their properties are quite different from those of metallic materials of construction. They are neither brittle nor ductile (i.e.) their properties lie in between of brittle and ductile materials. In the design of FRP, thickness is not the measure of strength but the amount of glass present per kg. Counts. High factor of safety is considered for designing with plastics.

Nowadays, engineer's uses FRP constructed with Epoxy Vinyl Ester Resins. It enables them to use this material for various applications where stainless steel can easily get corroded. It is more reliable and provides a cost effective construction material. There are some materials that can be competitive with FRP cost wise but due to their high maintenance cost, the overall life cycle cost is higher.

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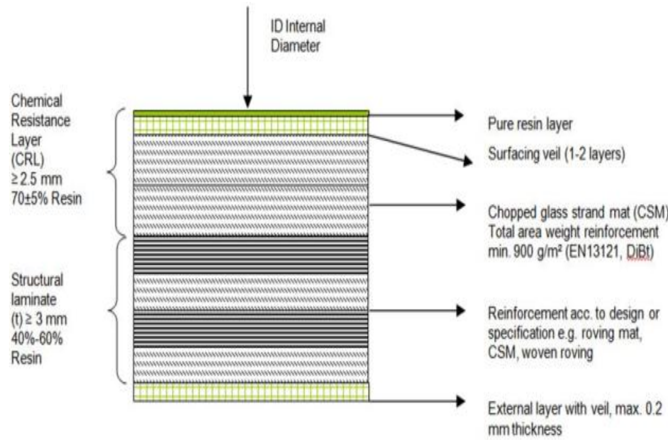


Figure1: Cross-section of FRP composite [12].

2. LITERATURE REVIEW

In 2012,V. Rishab Kanth, V. Balakrishna Murthy , A. V. Ratna Prasad studied separate analysis is done on various models of FRP composite (i.e.) cylindrical model with single and different volumes. Cylindrical shell model is also considered under analysis [8].

In 2014, Subhash N. Khetre, P. T. Nitnaware, Arun Meshram worked on the composite pressure vessel structure and various orientations of shells which are symmetric were designed [2].

In 2015, Lakshmi Nair, Yezhil Arasu, Indu V S. worked on laminated pressure vessel design. The main aim is to determine the laminate configuration of vessel. Composite pressure vessel is subjected to progressive failure analysis [3].

In 2016, M.A. Mujeeb Iqbal1, Mohd.Hasham Ali, Mohammed Fareed worked on filament wound GFRP pressure vessel and analysis is carried out for different orientations in winding. Burst pressure for the vessel is determined by applying a suitable failure criterion [9].

M. Priyashagadevan, K. A. Kalaiarasi (2017) worked on comparison between FRP and steel bars reinforced in columns. This study was conducted experimentally to investigate the physical and mechanical properties of the GFRP [7].

A Tripathi, Anil Kumar, M.K. Chandrakar (2017) worked on composite cylinder for LPG storage. This study proposed an alternative material for the design of cylinder and compared the results obtained to a steel cylinder [13].

TYPE	Shell cylindrical, Top cone 15°, Flat bottom
Design Temperature	Less than 90°C
Design Pressure	Hydrostatic pressure
Specific Gravity	1.839
Tank Dimension	3000mm x 4000mm
Tank thickness	15.85 mm

J. Ganesh, K. Sonu Kumar, B. Anil Kumar (2018) worked on design and analysis of composite pressure vessel. In this research, a graphical analysis is presented to find the Fiber orientation [4].

3. RESEARCH METHODOLOGY

3.1 Determining the data of stainless steel storage tank.

In this research, the design specifications of stainless steel storage tank are defined in table 1.

Table 1: Design Parameters for stainless steel tank.

3.2 Analysis of stainless steel storage tank according to the above specifications.

In this research, modeling of the stainless steel tank having above specifications is done using CREO software.

Analysis of the model is done using ANSYS software for determining the different stresses induced in the tank.

3.3 Design of vertical cylindrical Fiber reinforced plastic storage tank.

Step 1: First I considered that the tank is made up of 4 courses each of outer diameter 3000mm and the thickness varying from bottom to top. Height of each course is 1000mm.

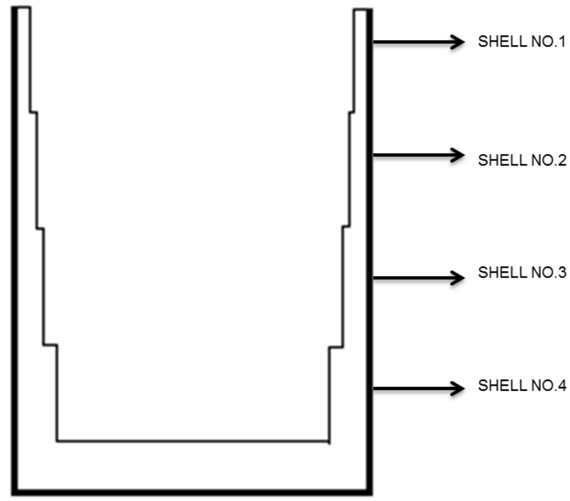


Figure 2: Variable thickness of shell

Step 2: **Calculation of thickness of shell for various courses.**

Thickness of shell =∑ [Number of layers (n) x Mass of reinforcement / unit area (m) x Thickness of fiber (t)]

- Laminate Design: [1]

$U_{ZCSM} \times m_{CSM} \times n_{CSM} + U_{ZWR} \times m_{WR} \times n_{WR} \geq$ Limiting load Capacity (Q)

U_Z = Design unit loading (N/mm per kg/ m^2 of glass)
The load limited allowable unit loading U_L = U/K where, k = design factor. In this case, the value of k is taken as 11.98 (i.e.) 12.

Design strain is ε_d = 0.119%

The strain limited allowable unit loading $U_S = X_Z \times \varepsilon_d$
Where, X_Z = unit modulus (N/mm per kg/ m^2 of glass)

If, U_S is less than U_L then U_Z is equal to U_S and if U_L is less than U_S then U_Z is equal to U_L.

For CSM, U = 200 N/mm per kg/ m^2 of glass
For WR, U = 250 N/mm per kg/ m^2 of glass

Thickness of fiber (t) is taken as:
For 450 CSM = 2.5 mm per kg/m^2 of glass
For 610 WR = 1.6 mm per kg/m^2 of glass

- Circumferential Unit Load Calculation (Q) :

Hydrostatic pressure at tank bottom, $p = \rho gh/10^6$ N/ mm^2 where ρ = density of liquid stored, g = acceleration due to gravity, h= height of liquid column.

For variable height, Q = pD/2 N/mm where, D = diameter of shell.

Consider laminate construction, as one of the two options:

For Laminate No. 1,

n= number of layers of 450 CSM

n= number of layers of 610 WR

$$19.11n \geq Q \qquad \text{(Eq. 1)}$$

For Laminate No. 2,

n = number of layers of 450 CSM

n - 1 = number of layers of 610 WR

$$19.11n \geq Q + 11.61 \qquad \text{(Eq. 2)}$$

Both the layers are laid alternately in such a way that the outermost layer is of 450CSM. In addition to this, a total of 1.5 kg/m^2 of CSM is distributed on both sides.

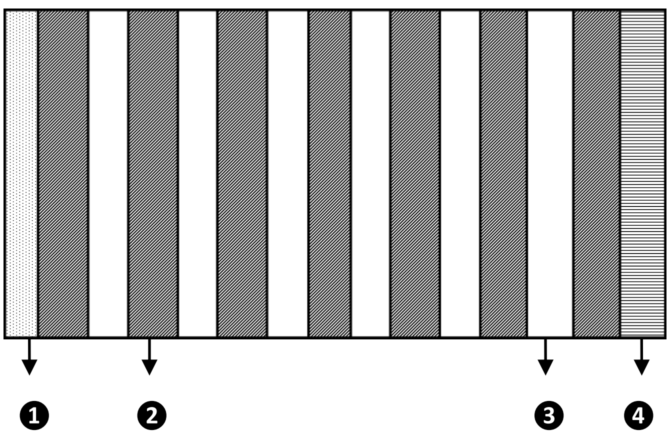


Figure 3: Laminate Layering

1. Chemical barrier.
2. Chopped strand mat.
3. Woven roving cloth.
4. External surface layer with binding tissues.

Table 2: Thickness of shells obtained

SECTION	THICKNESS (mm)	No. of CSM layers	No. of WR layers
SHELL NO.1	9.077	3	2
SHELL NO.2	11.178	4	3
SHELL NO.3	13.279	5	4
SHELL NO.4	17.481	7	6

Step 3: Calculation of base thickness and top thickness.

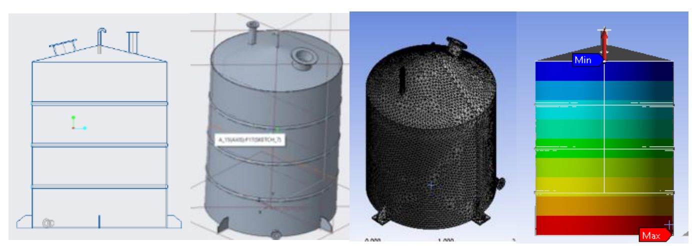
Base thickness is equal to the maximum thickness of the shell at bottom =17.481 mm

Consider knuckle reinforcement at the base corner. This thickness is half of the base thickness ≈ 9 mm

Therefore, total thickness at base = 17.481+9 =26.481 mm.

Top thickness should be able to take the load of personnel and minor structural load. Consider laminate thickness as 14mm.

Step 4: Analysis of fiber reinforced plastic storage tank according to the above specifications.



2-D 3-D Meshing Analysis

Figure 4: Generalized methodology

In this research, modeling of the fiber reinforced plastic storage tank having above specifications is done using CREO software.

Analysis of the model is done using ANSYS software for determining the different stresses induced in the tank.

4. RESULT:

Total Deformation in Fiber reinforced plastic storage tank:

The maximum deformation obtained in the FRP storage tank is equal to 0.96389 mm.

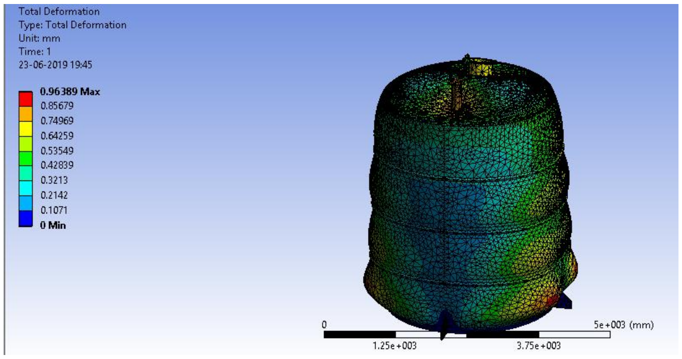


Figure 5: Total deformation

Equivalent Elastic Strain in Fiber reinforced plastic storage tank:

The equivalent elastic strain in the FRP storage tank is equal to 0.00096218.

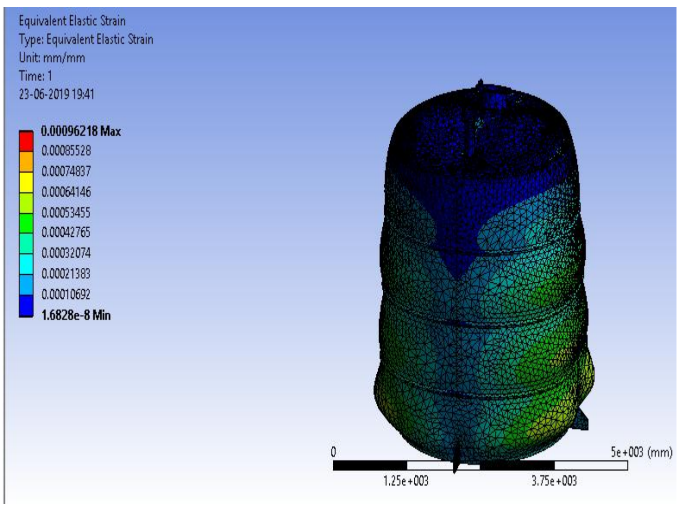


Figure 6: Equivalent Elastic strain for FRP tank

Maximum Principal Elastic Strain in Fiber reinforced plastic storage tank:

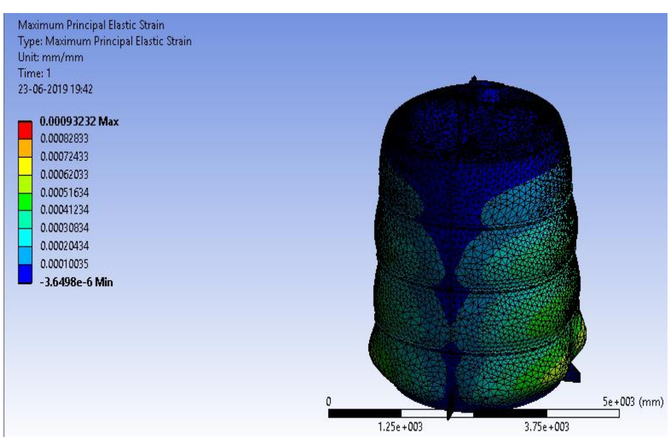


Figure 7: Maximum Principal Elastic strain for FRP tank

Maximum Shear Elastic Strain in Fiber reinforced plastic storage tank:

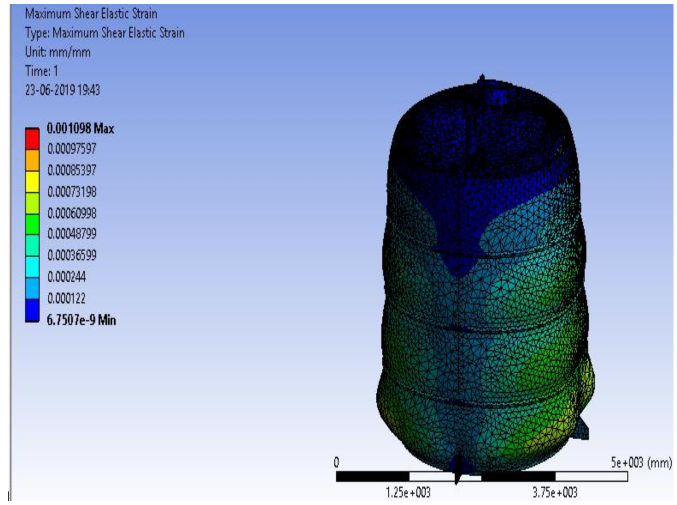


Figure 8: Maximum Shear Elastic strain for FRP tank

Equivalent Stress in Fiber reinforced plastic storage tank:

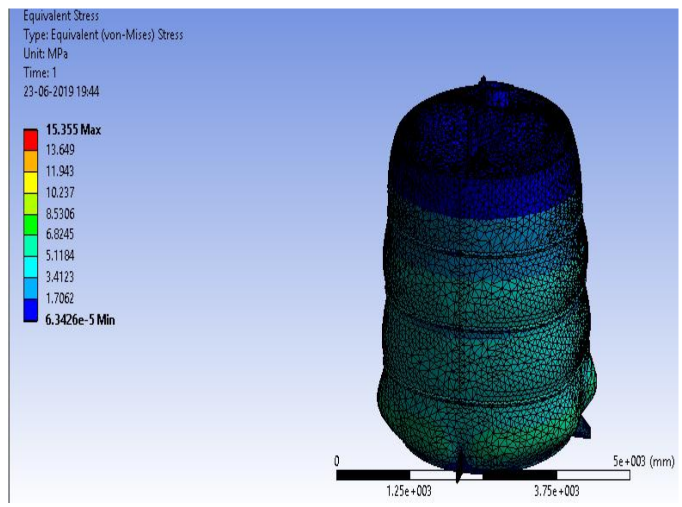


Figure 9: Equivalent (von-mises) stress for FRP tank

Strength to Weight ratio for Fiber reinforced plastic storage tank:

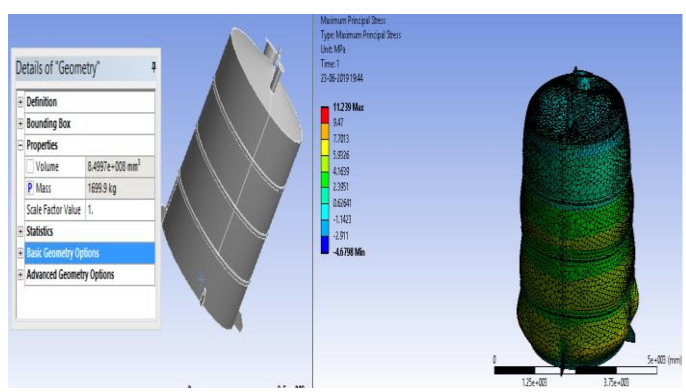


Figure 10: Mass and stresses for FRP tank

Strength to Weight ratio for Stainless steel storage tank:

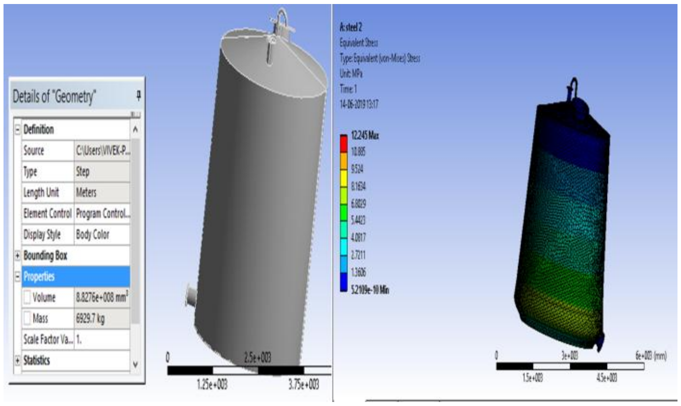


Figure 11: Mass and stresses for stainless steel tank

5. CONCLUSION

- The maximum allowable strain for the laminate is $1.3\varepsilon_d$ (From Data Book). The maximum strain obtained from the analysis is 0.001098 mm/mm which is less than the maximum allowable strain. Therefore, the proposed design is valid.
- The strength to weight ratio for fiber reinforced plastic storage tank is 673.961Pa/N and strength to weight ratio for stainless steel storage tank is 180.125Pa/N. Hence, strength/weight for FRP tank is more than that stainless steel which makes it more effective for construction.
- Fiber reinforced plastic storage tank has low installation cost as compared to stainless steel tank. It requires less maintenance and inspection can be done easily. Transportation is much easier as compared to stainless steel tank due to less weight.

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