# Study to Use Composite Materials in LNG Domestic Cylinder Structure

**Mohamed Rahuma G. Rahuma1 ,*, Dr. Ramadan Shamiss Wadi2**

**1 Libyan Authority for Scientific Research, Libyan Center For Plasma Research, Tripoli-Libya**

***e-mail: mohammed2003b@yahoo.com**

**2 Libyan Academy For Postgraduate Studies**

***e-mail *r.wadi@academy.edu.ly**

***Abstract:***

*This paper explores the utilization of ANSYS software to replace traditional stainless steel in Liquid Natural Gas (LNG) cylinders with a lightweight composite material called E Glass Epoxy. The goal is to reduce the cylinder's weight through finite element analysis using ANSYS, adhering to Libyan market standards. Stresses under internal pressure are analyzed and compared with analytical solutions for steel cylinders. The study highlights weight reductions for steel and composite LNG cylinders, emphasizing the practicality, utility, and safety considerations in addressing the challenges faced by the Indian Gas supply system, especially for housewives dealing with heavy stainless steel cylinders.*
*This project aims to provide a user-friendly alternative, maintaining gas storage efficiency while significantly reducing cylinder weight.*

*The results also showed that the use of E Glass Epoxy is highly effective in relieving the pressures resulting from the gas on the cylinder walls, despite the slight increase in wall thickness, and is better than steel at high pressure, taking into account that the weather in Libya is hot in the summer, with temperatures reaching 45C,$^{0}$ at pressure 1 a Safety factor of Steel gas cylinder is 1.9039 and Safety factor of E-glass gas cylinder is 2.94671and at pressure 2.5 Safety factor of Steel gas cylinder is 0.76 and Safety factor of E-glass gas cylinder is 1.17.*

**(Key words)**

Liquid Natural Gas: (LNG), Finite Element Method, Composite Materials, ANSYS Software, Steel Cylinder

## 1. Introduction

Gas cylinders find extensive applications in various fields, including chemical processes, soldering, welding, flame cutting, medical and laboratory uses, and household applications. Typically constructed from different types of steel, this project specifically focuses on household cylinders made of plain carbon steel. These cylinders, weighing around 14 Kg, pose challenges for housewives who find them difficult to lift. Addressing this issue, modern composite materials are employed, proven to be more effective. These materials are layered over a metal liner, forming an overwrapped composite pressure vessel[1]. Utilizing high-tensile strength carbon fiber, these cylinders become lighter and more manageable for lifting. Additionally, the manufacturing process of traditional cylinders, involving rolling and forging, results in material wastage. In contrast, the composite cylinders can take various shapes. For this project, the chosen cylinder design features a cylindrical body with two hemispherical ends. This innovative approach not only addresses the weight concern but also contributes to reducing material wastage in cylinder production.[1]

## 2. Literature survey

**Sumeyra sayman**[2], (2003) studied develop an explicit analytical formulation based on the anisotropic elasticity theory that determines the behavior of fiber reinforced composite vessel under hygrothermal loading. The loading is studied for three cases separately, which are plane strain case, free ends and pressure vessel cases. For freeend and pressure vessel cases, the vessel is free to expand, on the other hand for plane strain case, the vessel is prevented to expand. Throughout the study, constant, linear and parabolic temperature distributions are investigated and for each distribution, separate equations are developed. Then, a suitable failure theory is applied to investigate the behavior of fiber reinforced composite vessels under the thermal and moisture effects.

Throughout the study, two computer programs are developed which makes possible to investigate the behavior of both symmetrically and antisymmetrically oriented layers. The first program is developed for plane strain case, where the second one is for pressure vessel and free-end cases.

Finally, several thermal loading conditions have been carried out by changing the moisture concentration and temperature distributions and the results are tabulated for comparison purposes. “Analysis of fiber reinforced composite vessel under hygrothermal loading” MS thesis The middle east technical university.

**Ch.Bandhavi and N.Amar Nageswara Rao**[3], (2012) studied and used the finite element analysis of Liquefied Petroleum Gas (LPG) cylinders made of Steel and Fiber Reinforced Plastic (FRP) composites has been carried out. Finite element analysis of composite cylinder subjected to internal pressure is performed. Layered shell element of a versatile FE analysis package ANSYS (version 9.0) has been used to model the shell with FRP composites.

**T.Ashok and A.Harikrishna**[4], (2013) have studied an Analysis of LPG Cylinder Using Composite Material, International Journal of Mechanical and Civil Engineering, he It was found that the weight of the LPG cylinder that can be significantly saved by using FRP compounds and stress values also well within the limit of capability of materials. This gives a clear justification for it’s use in household applications.

**Pankit M. Patel1 Prof**. Jaypalsinh Rana[5], (2013) worked for the design and optimization of LNG/CNG cylinder for optimum weight. In the literature, design and analysis of composite pressure vessel are carried, which are made of thermoplastic linear, glass fiber and polymer raisin. Analysis showed that there is a good arrangement between experimental results and elasto-plastomodelling for mechanical behavior of high-density polythene linear under internal pressure. The study gives the influences of temperature and winding angle on filament wound composite pressure vessels. The result showed that the cylinder with 34 CrMo with 1.7 thickness and carbon fibre thickness of 4mm experienced stress less than the stress achieved in existing cylinders,. The weight was reduced from 19.45 to 6.16 Kg, thus the lighter weight are easy to handle and assemble.

**Alok Tom *(et al)*** [6],(2014) design and analysis of LPG cylinder ,International Journal of Engineering & Applied Sciences.

**K Sahitya Raju, Dr. S. Srinivas Rao**[7], (2015) studied Design optimization of a composite cylindrical pressure vessel using FEA An LPG cylinder of composite materials is designed and analysis is done using ANSYS software and the comparison is made with existing steel cylinder, on the basis of displacement and Stress produced due to the application of internal pressure to the cylinder. To validate the model the results of stresses and deformation for steel cylinders are compared with the analytical solution available in literature. It was observed that besides less weight, stresses are also less for composite compared to steel cylinder.

## 3. Problem Statement and main goals:

The current design in the Libyan market is a gas cylinder made of steel, and one of its most important defects is the heavy weight, which increases the cost of transportation and makes it difficult for housewives to lift the existing cylinder, while some countries in the world suggested replacing gas cylinders made of steel with gas cylinders made of composite materials, and some opposed This idea, which made us discuss in this research the comparison between the cylinder of composite materials and the cylinder of steel to know the disadvantages and advantages of each of them, and in this study will use in Composite material gas cylinder (E-glass Epoxy), The same cylinder measurements as those used in the Libyan market.
This study aims to:

- investigate the analysis of stresses, strains, and deformation in both composite domestic LNG cylinders and steel cylinders already exist in local market from its effectiveness, on the structure and how safely it is.
- It also intends to investigate this both cylinders under different type of loading including mobility, and impact loading numerically using Finite Element Method.

## 4. Material and Method

- The stresses for the steel gas cylinder will be calculated manually (theoretical analysis) and compared with the results that obtained from the software.
- If it is found that the percentage of confusion is small, two cylinders are designed separately using ANSYS WRKBENCH software with the same measurements, then an internal pressure is applied to both the steel gas cylinder and composite gas cylinder.[6] The maximum stress for each cylinder and the maximum strain are found, the physical and

mechanical properties of each cylinder are found, and several experiments are conducted using software on the two cylinders.

- The internal pressure of the two cylinders is increased to make the comparison between the two metals more accurate.

The most important physical properties of the two metals used must be known, and the most important results that are useful in comparison, such as stresses, strains, fatigue, and others.

- 3D modeling using ANSYS work bench by FEA software analysis.[6]
- Theoretical strength analysis Calibration of analysis and theoretical result, fabrication of composite material.

### 4.1 Geometrical Dimensions & Existing design of Gas Cylinder:

- We have to consider 15.9 kg of LNG gas cylinder as shown in figure (1)
- Empty gas cylinder weight = 15.9 Kg with frame holder = 13 Kg without frame holder
- Gas weight = 14.2 Kg
- Volume of gas = 47.8 L
- The existing gas cylinder in the Libyan market shown in figure (3.1), It is identical in dimensions and shape to the steel LNG cylinder used in the Libyan market. The overall height is ( 640 ) mm.
- The height of the cylindrical side is (390 ) mm.
- The inner diameter is (290 ) mm and the thickness is (3 ) mm.
- The volume capacity is ($1.32*10^8$) $mm^3$.
- The base-ring is of (140 ) mm .

**Figure.1** Steel gas cylinder which currently used in Libyan market

### 4.2 Theoretical Calculation

- The prototype used in this study is shown in **Figure1**, It is identical in dimensions and shape to the steel LNG cylinder used in the Libyan market. The overall height is ( 640 ) mm.
- The height of the cylindrical side is (390 ) mm.
- The inner diameter is (290 ) mm and the thickness is (3) mm.

- The volume capacity is ($1.32*10^8$) $mm^3$.
- Assume a thin wall of gas cylinder because the wall thickness (t) is less than (1/20) of the inner diameter (d).
- Hoop stress = $\sigma_h = \frac{Pd}{2t}$
- Axial stress = $\sigma_a = \frac{Pd}{4t}$

The results that obtain by ANSYS and that obtain theoretical presented in sections (6), table(3).

## 5. Software Analysis

### 5.1 Designing of gas cylinder on ANSYS Software:

The gas cylinder currently in the Libyan market will be designed with the same measurements, using ANSYS WORKBENCH software as shown in (Fig.2).

- Draw the cylinder by ANSYS Software as shown in the following figure(2) and figure (3).
- A software analysis process involves the design of a gas cylinder, comparing plain Steel and E Glass Epoxy materials. Theoretical calculations are based on extensive literature research and defining system boundary conditions. Following this, a 3D model of the cylinder is created using ANSYS WORKBENCH after obtaining dimensions.
- Material selection involves short listing E Glass Epoxy, alongside the existing plain Steel. FEA simulation is conducted for Steel, and Advance Material (E Glass Epoxy) using ANSYS WORKBENCH.
  assume athickness of composite cylinder is 5 mm, (5 layer with angles $[[0,66,0,-66,0]_\alpha]$ and a thickness of e each layer is 1mm around a polyethylene with thickness 3mm.) as shown in figure (4) and figure(5).
- By using ACP(pre) and divide the surface of the cylinder into squares, using the Mesh feature or icon, Arrange the layers of composite materials and arrange the corners of the fibers, as shown in (Fig.4), (Fig.5).
- At final steps include comparing simulation results with theoretical values, considering various factors, and concluding the best-suited design. Results and conclusions are presented in section (6).
  The internal pressure of the two cylinders is increased to 2.5Mpa to make the comparison between the two metals more accurate, as shown in section (6), table(5).

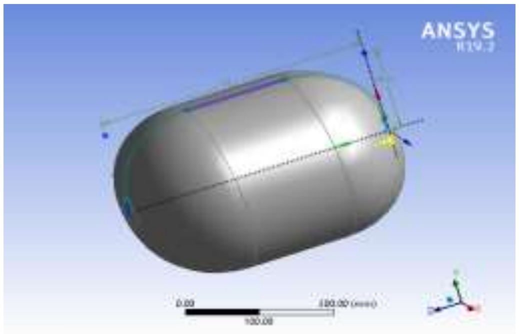


**Figure .2** Preparing a steel cylinder by FEA

**Figure.3** Preparing a composite cylinder by FEA

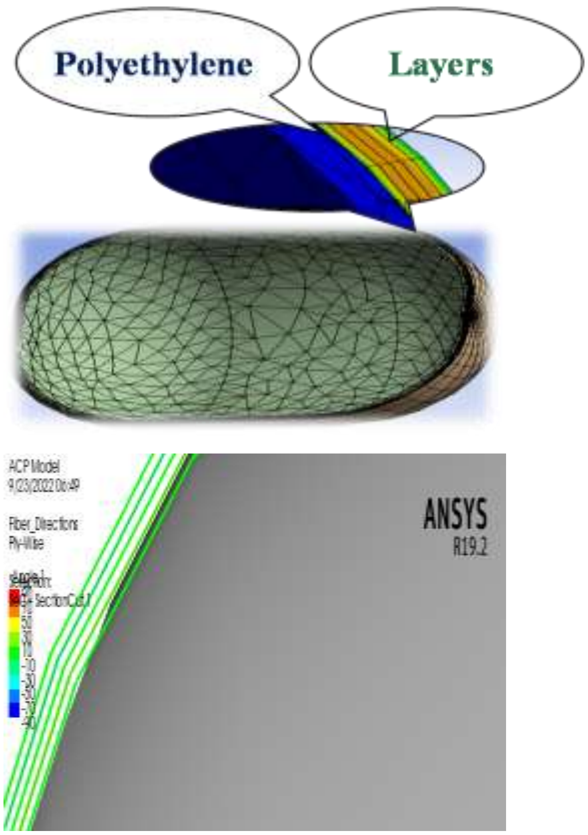


**Figure.4** Cross section of composite cylinder by FEA

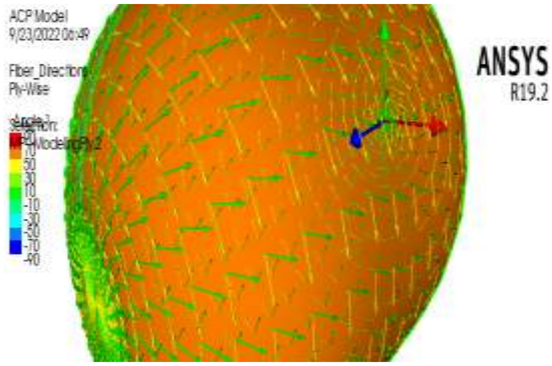


**Figure.5** Arrange and Angels of layers

### 5.2 Analysis on ANSYS Software:

- ANSYS workbench (FAE) analysis to determine [hoop stress and axial stress in steel gas cylinder, ets..], Specify the data we need to test the strength and durability of the cylinder (such as the force that will be applied, pressure, support, etc.) as show in Figures from Figure (6) to Figure (18) **.**
- Defined the material properties of the elements which are[8]-

| ✓ **E Glass** | ✓ **Steel** |
|---|---|
| Epoxy Density=2100kg/m3<br>Young's Modulus in Axial DirectionE1=45GPa<br>Young's Modulus in Transverse Direction E2=12GPa<br>Poisson's Ratio μ=0.28<br>Yield Strength=1020MPa | Density, $\rho$= 7800 kg/m3<br>Young's modulus, E=210 GPa<br>Poisson ratio, μ=1/m=0.28<br>Ultimate strength =399.82 MPa<br>Yield strength=220.59 MPa |

- An analysis in ansys of some properties in Steel and composite gas cylinder which thickness of steel cylinder is 3 mm and internal pressure is 1 MPa as shown in table (1), and a Composite material cylinder depends on arranging the resin layers on top of each other, an appropriate number of layers with different angles can be chosen to reach the best possible results as shown in table (2).

- An analysis in ANSYS and results as shown in Figures from figure(7) to figure(18) at internal pressure is 1MPa.

Table(1): A Thickness and Internal pressure of Steel Cylinder

| Thickness of steel gas cylinder | Internal pressure | Mass of steel gas cylinder |
|---|---|---|
| 3mm | 1Mpa | 10.35kg |

Table(2): A Thickness and Internal pressure of Composite Cylinder

| Thickness of polyethylene | Thickness of each layer in composite cylinder | Angles of plies | Thickness of layers in composite cylinder | Internal pressure | Mass of Composite gas Cylinder |
|---|---|---|---|---|---|
| 3mm | 1mm | [0,66,0,-66,0]$_{\alpha}$ | 5mm | 1Mpa | 5.1429 kg |

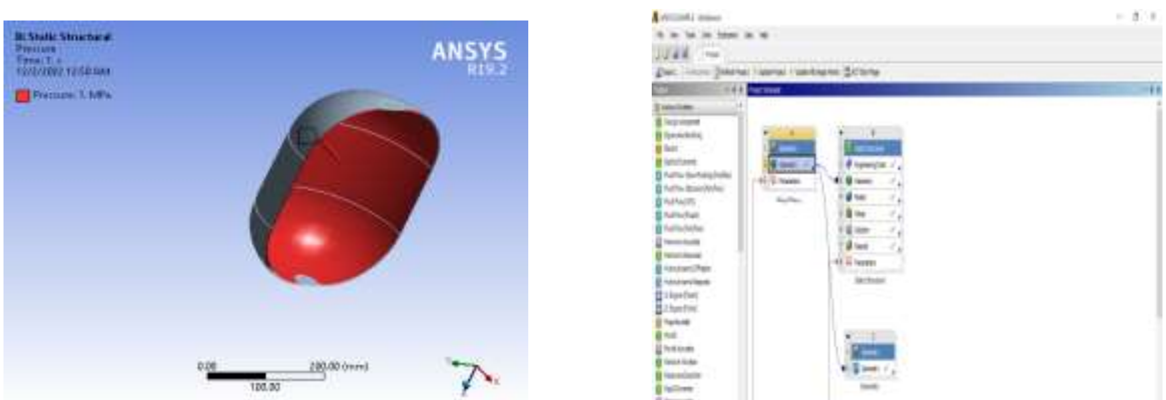


**Figure.6** Internal pressure and analiysis interface

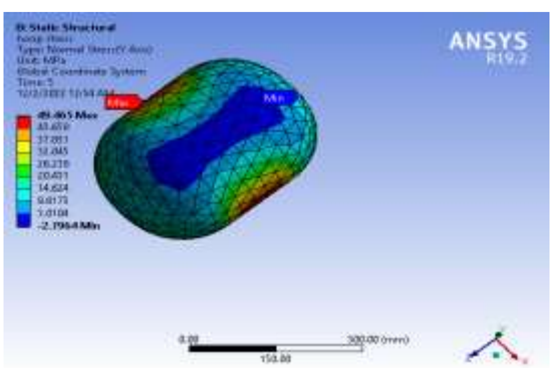


**Figure.7** Hoop stress $\sigma_h$ of steel cylinder by (FAE)

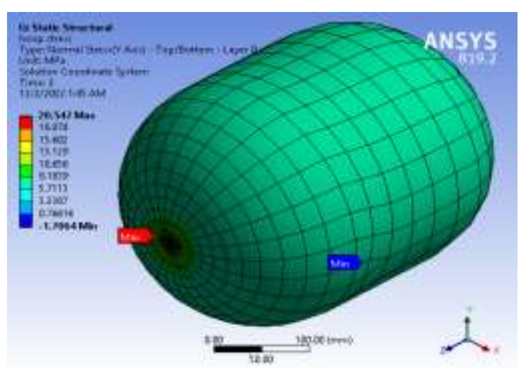


**Figure.13** Hoop stress $\sigma_h$ of composite cylinder by (FAE)

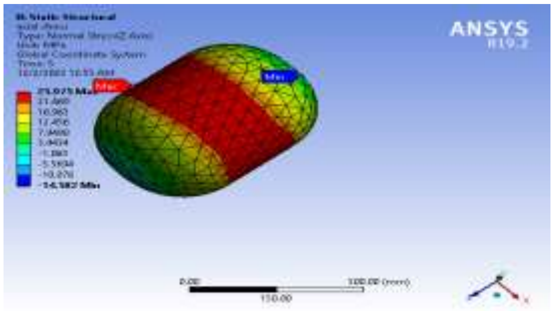


**Figure.8** Axial stress FAE) $\sigma_a$ of steel cylinder by (FAE)

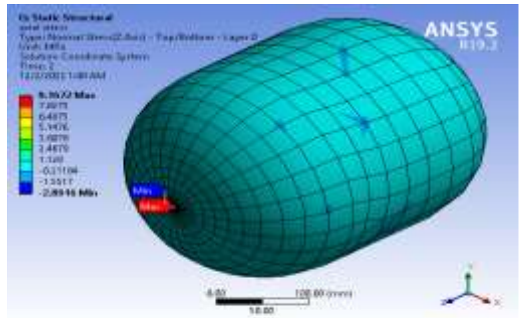


**Figure.14** Axial stress of composite cylinder by (FAE)

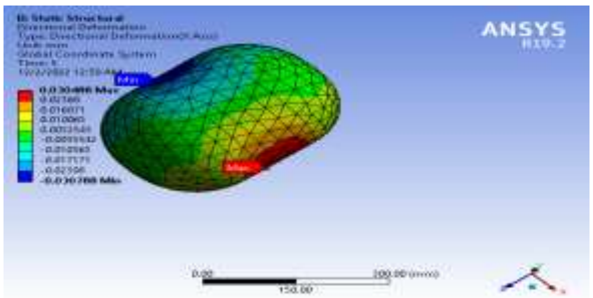


**Figure.9** Directional deformation of steel cylinder by (FAE)

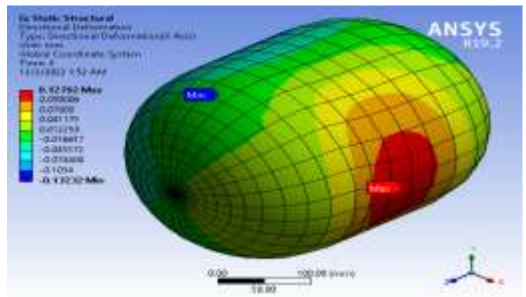


**Figure.15** Directional deformation of composite cylinder by (FAE)

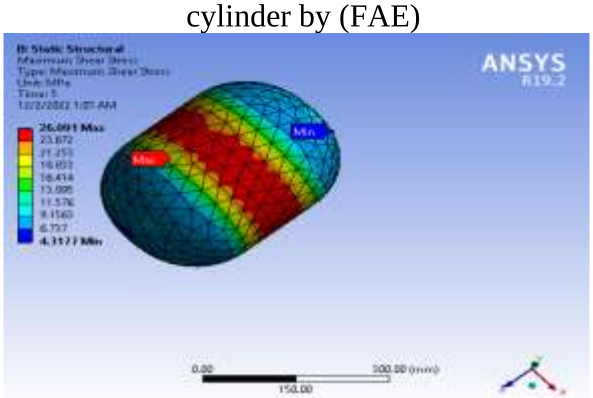


**Figure.10** Maximum Shear Stress of steel cylinder by (FAE)

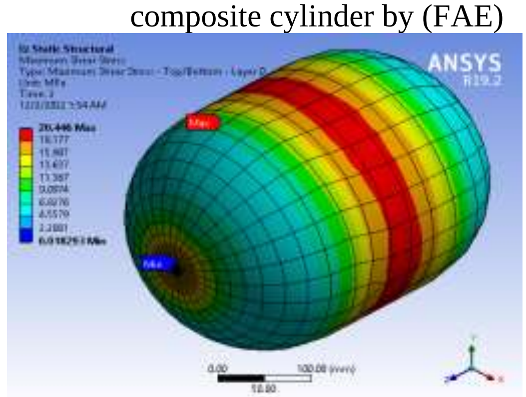


**Figure.16** Maximum Shear Stress of compoite cylinder by (FAE)

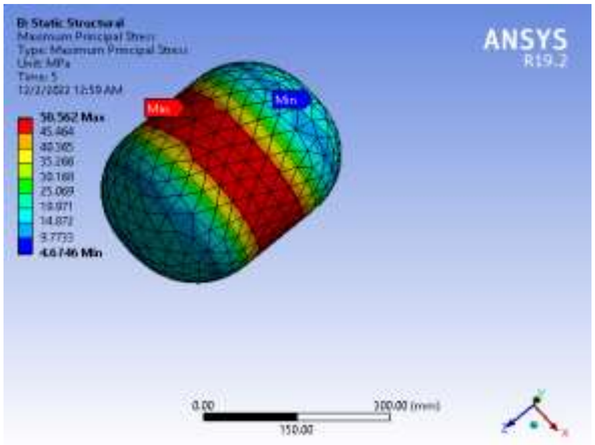


**Figure.11** Maximum Principal Stress of steel cylinder by (FAE)

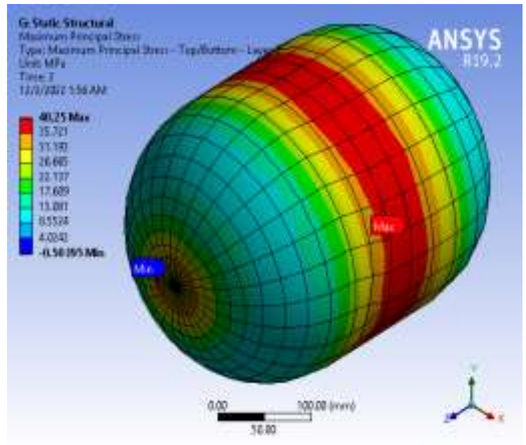


**Figure.17** Maximum Principal Stress of composite cylinder by (FAE)

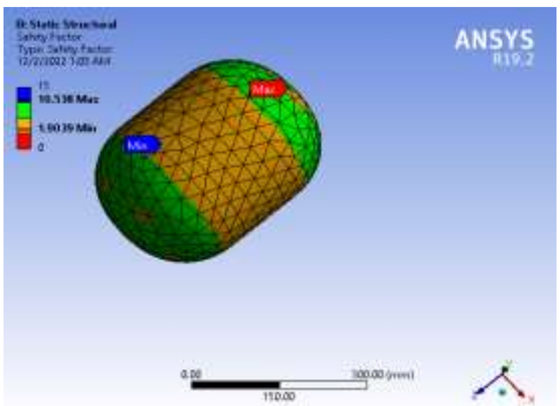


**Figure.12** Safety Factor of steel cylinder by (FAE)

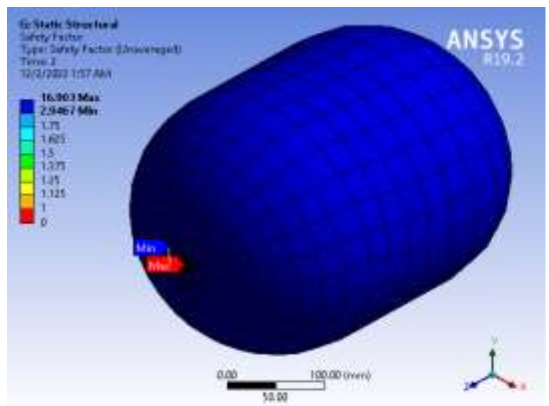


**Figure.18** Safety Factor of composite cylinder by (FAE)

## 6. Result and Discussion

**Table(3).** The results that obtain by ANSYS and that obtain theoretical

| Parameters | Theoretical | Ansys Workbench | Error,per cent% |
|---|---|---|---|
| Hoop stress $\sigma_h$( MPa) | 48.33333 Mpa | 49.4 MPa | 0.02 |
| Axial stress $\sigma_a$(MPa) | 24.2 Mpa | 25.9 MPa | 0.06 |

**Table(4).** The results obtained at internal pressure is 1MPa as shown in previous figures from figure(7) to figure(16) is:

| Property /internal pressure 1MPa | Steel gas cylinder ] Thickness=3mm | E-glass gas cylinder Thickness=3mm+5mm |
|---|---|---|
| Hoop stress(MPa) | **49.465** | **20.547** |
| Axial stress (MPa) | **25.975** | **9.167** |
| Max. shear stress (MPa) | **26.091** | **20.446** |
| Max. principle stress (MPa) | **50.562** | **40.25** |
| Direction deformation (mm) | **0.030488** | **0.12792** |
| Total deformation (mm) | **0.03147** | **0.52155** |
| Safety factor | **1.9039** | **2.94671** |
| Thickness (mm) | **3** | **5** |

**Table(5).** The results obtained at internal pressure is 2.5MPa

| Property /internal pressure 2.5MPa | Steel gas cylinder ] Thickness=3mm | E-glass gas cylinder Thickness=3mm+5mm |
|---|---|---|
| Hoop stress(MPa) | **64.938** | **51.367** |
| Axial stress (MPa) | **123.66** | **22.918** |
| Equivalent stress (MPa) | **45.276** | **37.737** |
| Safety factor | **0.76** | **1.17** |
| Thickness (mm) | **3** | **5** |

The results obtained from the stress analysis on E-glass gas material and steel gas material, illustrates that, when both materials subjected to the same internal pressure under the same operating conditions, the yield point or breaking point at E-glass gas cylinder appears to be much higher than steel. As a result, the composite cylinder has more stress carrying capacity than steel. In addition to that, the E-glass can stand higher stress by increasing the thickness of the cylinder as well as changing the angles of the layers.

## 7. Conclusion

From the comprehensive analysis of LNG cylinders crafted from diverse materials, the following conclusions have surfaced from our recent investigations:

- The innovative design employing the composite material E Glass Epoxy demonstrates heightened effectiveness in mitigating stresses induced by gas on the cylinder walls, despite a slight increase in wall thickness.

- The utilization of E Glass Epoxy significantly reduces the weight of the cylinder when compared to conventional plain carbon steel, showcasing an efficient plummet in weight.
- The newly designed cylinder not only enhances efficiency but also facilitates seamless transportation from industries to homes, promising a more convenient gas cylinder delivery system.
- These cylinders, with their innovative design, are poised to assist household wives by enabling easier movement, thereby reducing human efforts and addressing the challenges associated with handling traditional cylinders.
- The results showed that using E Glass Epoxy is better than steel at high pressure, considering that the weather in Libya is hot in summer, where the temperature reaches to $45C^0$ .

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