Design and Analysis of Composite LPG Cylinder

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Abstract-The objective of this study is to lighten the liquid petroleum gas (LPG) cylinder. As a result, an LPG cylinder made of steel and FRP composites was designed and subjected to a finite element analysis. Finite element analysis was used in this study to examine an LPG cylinder built from a mix of HDPE plastic, vinyl ester resins, and carbon fibres. The cylinder's liner and cover are both woven from continuous carbon fibre composite and vinyl ester polymer matrix, both of which are produced of HDPE plastics. The burst pressure of the cylinder was anticipated and tested. With a thickness of 2.5 mm and a variety of materials, such as low carbon steels, e-glass fibres, and carbon fibres. The advantages of these carbon fibre composite cylinders include their strength, low weight, and resistance to rust.

Keywords— **Finite element analysis, LPG cylinder, Composite, Pressure;**

1.INTRODUCTION

A mixture of butane and propane gases is stored under pressure as liquefied petroleum gas (LPG), typically in steel cylinders. LPG is odourless, non-toxic, and heavier than air. To help users find leaks, an odorant is added. Due to its high calorific value (13.8 kWh/kg, or 13.8 units of electricity per kilogramme), quick heat output, simplicity of ignition, clean burning, and portability, LPG is a safe, affordable, and practical fuel. It emits the least amount of toxic combustion products of all the frequently utilised fossil fuels, making it the most environmentally friendly. South Africa consumes over 280 million kg of LPG each year. LPG is frequently used for cooking, space and water heating, refrigeration, lighting, brazing, soldering, and welding, as well as in homes, restaurants, hospitals, small enterprises, and for leisure and entertainment. Stoves/ovens, grills/braais, heaters (portable and fixed), instantaneous water heaters, lamps (portable and fixed), welding equipment, and Bunsen burners are only a few examples of LPG appliances. Equipment are made to work at two different pressures: one controlled by a regulator fitted on the gas storage cylinder and the other controlled by an uncontrolled high pressure (for example, CADAC (or comparable) type camping appliances).Appliances for high and low pressures cannot be used interchangeably. Instead of a reticulated system of gas pipelines and fixed storage cylinders, most residences use gas appliances with a tiny dedicated gas cylinder. LPG storage cylinders are available in two types—household/industrial type and camping/hobby type—in a variety of standard sizes. The larger (9-48 kg) cylinders are tested at 30 pressures and are meant to work at 7 bars. When more than one cylinder, or a cylinder weighing more than 19 kg, is used on a household's premises, SABS087:1975, Part 1, code of practise for consumer LPG cylinder installation, applies to the storage of cylinders and gas pipework.The provision of adequate ventilation, preferably natural airflow, in the storage and appliance area is the most crucial installation consideration. Continuous fibres, discontinuous (chopped) fibres, and woven fabric shapes—which are typically combined with polymer matrix to create laminates—are the three most prevalent fibre configurations. The aligned, continuous fibre reinforcement produces the strongest material, but it is also the most anisotropic. Joints play a major role in composite material design. In addition to providing mechanisms for the incorporation of secondary structures like fittings, ribs, bosses, and dividers, joints also connect laminate portions together and connect composites to nearby structures made of metal, wood, ceramic, plastic, or other composites.The two most common joining techniques are mechanical and adhesive (more popular). In each joint, these are typically utilised separately, but they can be combined to create unique effects. The type of composite to be bonded, the application of the bonded composite, the service environment (temperature, solvent and moisture resistance, UV-light exposure, estimated service life, and the imposed loading), and cost typically determine which adhesive is best. Adhesives can be divided into several broad categories, including structural, hot melt, pressure sensitive, water-based, and radiation cured. When composites need to be joined, structural adhesives predominate in most cases. In the category of structural adhesives, epoxies, polyurethanes, acrylics, anaerobic, silicones, and phenolics are the most often used polymers.

2.DESIGN METHODOLOGY AND THOUGHTS

After experimenting with many design concepts, the concept shown in Fig2.1 (together with all the essential components) was ultimately chosen. The composite LPG cylinders will have three layers: a seamless polymer liner for gas containment to act as a gas barrier, a fibre structure to hold the burst pressure under extreme circumstances, and a fully integrated outer casing to help shield the valve/regulator and the pressure vessel from the environment.inner layer or liner made of HDPE-Blow Mouldable Grade plastic.The exterior liner is made up of carbon fibre filaments or strands.Plastics of the HDPE-Injection Mouldable Grade kind are used for the upper, middle, and lower coverings.A valve coupling is made of three materials: HDPE-Injection Mouldable Grade (Coupling-Case), Brass (Coupling-Insert), and Copper.Figure shows a close-up of the various components of the suggested design. The outer layer's vinyl-ester resin-infused filament strands will coil around the inner layer. Vinyl-ester resin is the ideal substance. The material that blocks UV rays and is semi-transparent best is vinyl-ester resin.

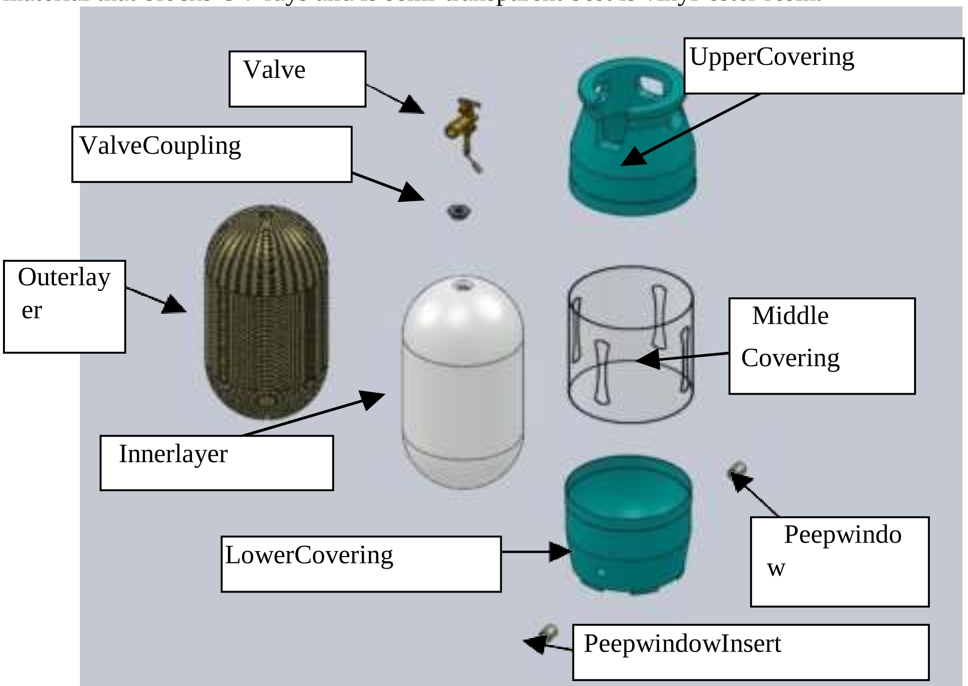

Fig 2.1 DesignedFRP LPGcylinder.Exploedviewofthe Components

The following production process is advised for the individual components:
There will be a blow-molded HDPE liner.The carbon fibre layer will be baked after being wound around a filament.Procedure for the pneumatic pressure test (3 MPa) and tightness test (1.8 MPa with helium).Once injection-molded, HDPE casing will be mechanically attached.
The following requirements must be met:
SANS 10019:2008 ISO 11119-3 SANS 1825 EN 12245All containers must be made and built in accordance with the applicable requirements of the following standards as well as the Pressure Equipment Regulations (PER) of the Occupational Health and Safety Act of 1993 (Act No. 85 of 1993):Fully wrapped composite cylinders up to 450 L, per EN 12245 (these containers shall have a lining as described in EN 12245 when manufactured for use in South Africa.)Fully wrapped, non-metallic, or non-load-sharing metal liners for an ISO 11119-3 fiber-reinforced composite gas cylinder.The certificate of manufacturing criteria must be met by adhering to the relevant production standards (i.e. SANS 10019 & EN 12257).LPG cylinders can all be regarded as pressure vessels since they are all portable gas containers. Any pressure vessel's contents are vulnerable to frequent phase changes (from liquid to gas or vice versa).Being heavier than air, LPG gas has the potential to produce pockets of oxygen-depleted air in low-lying areas. Scientific research has shown that LPG does not pose an ecological threat before the gas/air mixture is ignited.

3. FINITE ELEMENT MODELING AND ANALYSIS

The tables below include information on the characteristics of low carbon steels, carbon fibres, e-glass fibre, and vinyl-ester resin used to estimate composite properties.

Materials' characteristics

3.1Lowcarbonsteels

Table 3.1.1

E (Elastic modulus)	200 Gpa
G (Shear modulus)	76Gpa
σ (Tensile strength)	450Mpa
ρ (Density)	7850kg/m3

LPG cylinders made of low carbon steel are subjected to static structural analysis; the hole designated as fixed support and internal pressure are provided by concealing the lateral surface of the cylinder, respectively. Total deformation and von-mises stresses are chosen for analysis in the solution.

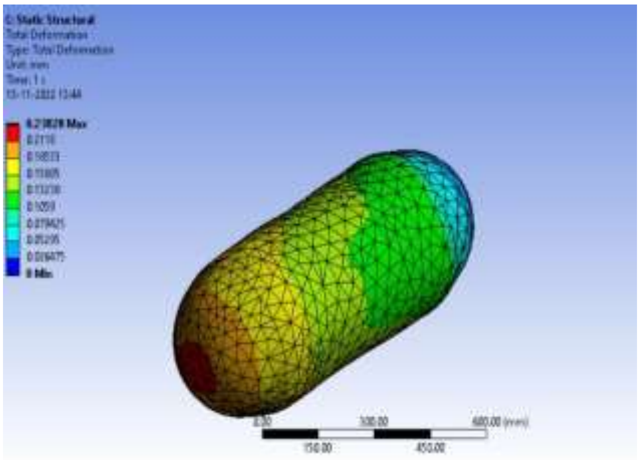

Fig.3.1.1 Total Deformation

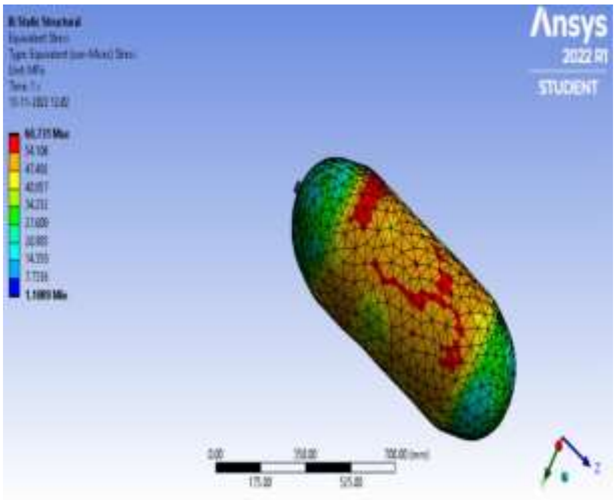

Fig.3.1.2 Stress(Von-mises)

3.2 E glass fibres+ vinyl ester matrix

The mixture rule formula was used to determine the properties.

Table 3.2.1

Properties	E-Glass continuousfiber	Cured VinylEster
E (Elastic modulus)	72 GPa	3.4 GPa
G (Shear modulus)	29.51 GPa	1.25 GPa
σ (Tensile strength)	345 MPa	338 MPa
ρ (Density)	2580 kg/m^3	1120 kg/m^3
V(volume fraction)	60%	40%

The Rule of Mixtures (RoM) idea is used to determine the E-glass/vinyl-ester composite's determined attributes.

Rule of mixture formula

$E_c=fE_f+(1-f)E_f$

Table 3.2.2

E (Elastic modulus)	44.4Gpa
G (Shear modulus)	5.86Gpa
σ (Tensile strength)	158.4Mpa
ρ (Density)	1695kg/m3

The static structural analysis is carried out on an LPG cylinder built of matrix-curved vinyl ester and E-glass fibres. Internal pressure is provided by concealing the cylinder's lateral surface and the hole is designated as a fixed support. Total deformation and von-mises stresses are chosen for study in the solution.

E-glass fibres(0/90 degrees)

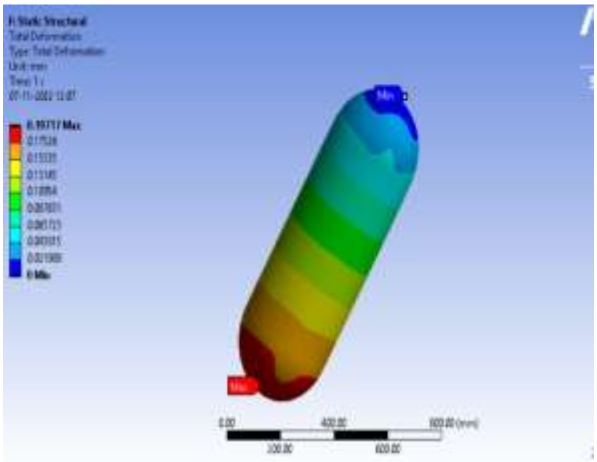

Fig.3.2.1 Total Deformation

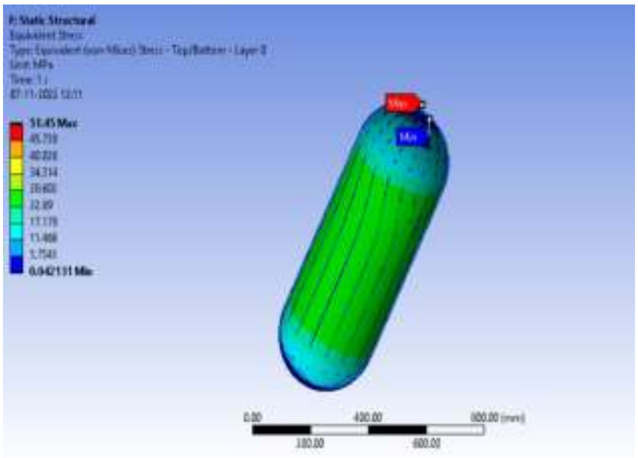

Fig.3.2.2 Stress(Von-mises)

E-glass fibres (45/-45 degrees)

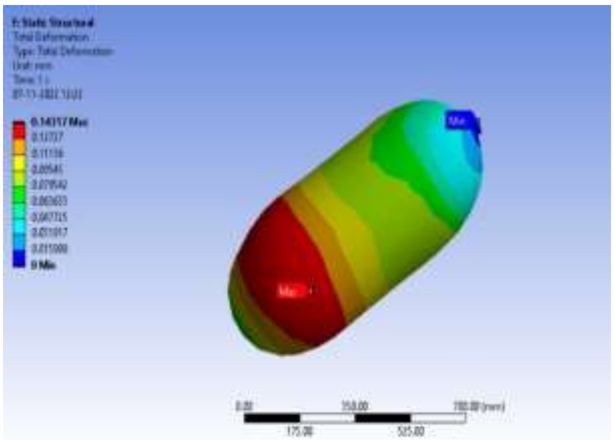

Fig.3.2.3 Total Deformation

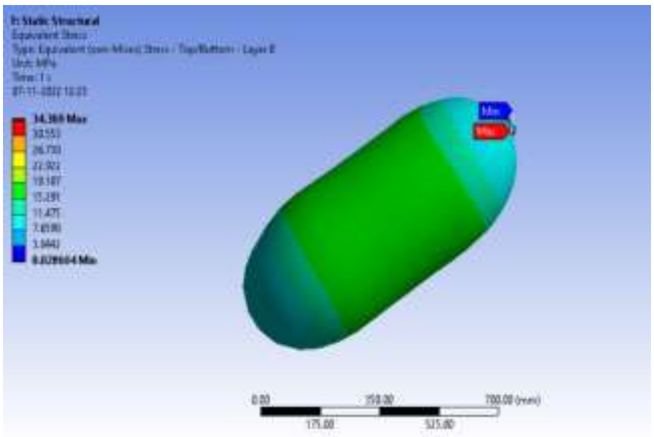

Fig.3.2.4 Stress(Von-mises)

3.3 Vinyl ester with carbon fibre matrix

The properties were determined using the mixture rule formula.

Table 3.3.1

Properties	**Carbon fibers**	**Cured VinylEster**
E (Elastic modulus)	250 GPa	3.4 GPa
G (Shear modulus)	12 GPa	1.25 GPa
σ (Tensile strength)	4.5MPa	338 MPa
ρ (Density)	1800 kg/m^3	1120 kg/m^3
V(volume fraction)	60%	40%

Rule of mixture formula

$E_c = fE_f + (1-f)E_f$

Table 3.3.2

E (Elastic modulus)	151.36 Gpa
G (Shear modulus)	7.68Gpa
σ (Tensile strength)	290.52Mpa
ρ (Density)	1521kg/m3

On an LPG cylinder made of carbon fibres and curved vinyl ester matrix, a static structural study is conducted. Internal pressure is provided by concealing the cylinder's lateral surface and the hole is designated as a fixed support. Total deformation and von-mises stresses are chosen for study in the solution.

Carbon fibres (0/90 degrees)

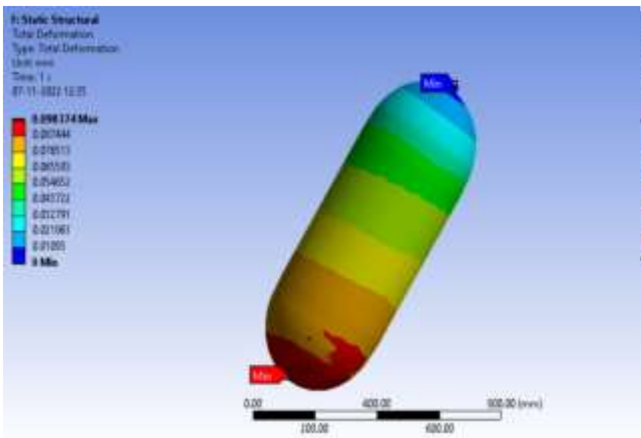

Fig.3.3.1 Total Deformation

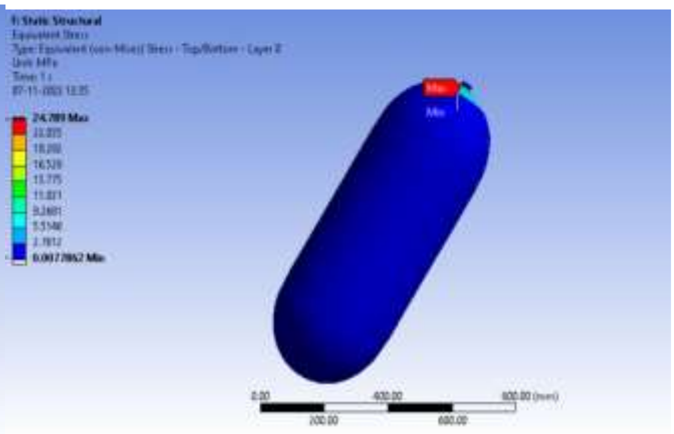

Fig.3.3.2 Stress (Von-mises)

Carbon fibres (45/-45 degrees)

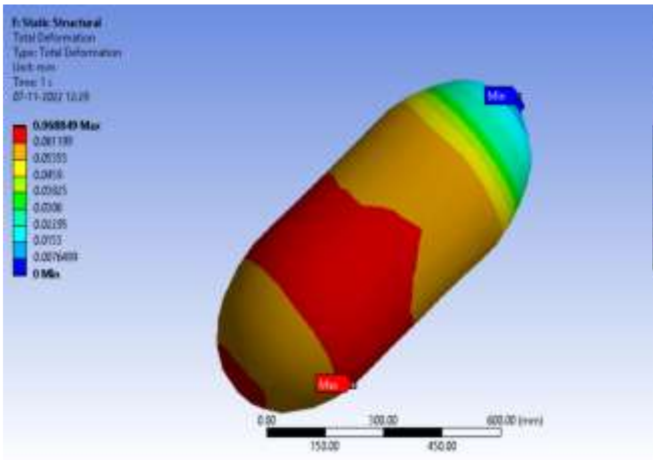

Fig.3.3.3 Total Deformation

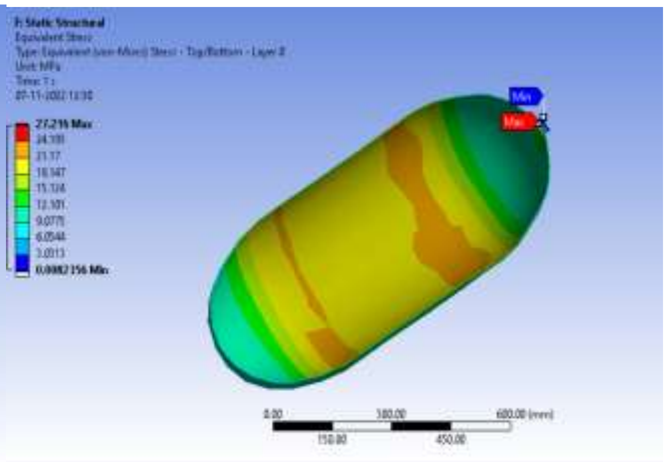

Fig.3.3.4 Stress (Von-mises)

4.Result

The following table provides the outcome of the analysis of various cylinders.

Table 4.1

MATERIAL	Deformation (mm)	Stress (MPa)	Strain
Low carbon steels	0.23828	60.731	0.00060599
E-glass fibres (0/90)	0.19717	51.45	0.00049203
E-glass fibres (45/-45)	0.14317	34.36	0.0009162
Carbon fibres (0/90)	0.098374	24.789	0.00038192
Carbon fibres (45/-45)	0.068849	27.216	0.00042227

5.Conclusion

The current investigations based on the analysis of LPG cylinders made of different materials, such as low carbon steels, E glass fibre, and carbon fibre composite materials, have produced the following findings:
1) An LPG cylinder's weight can be greatly reduced by using composites, and the stress values are well within the range allowed by the materials. This offers a compelling argument in favour of using it in household settings.2) Under the same pressure and cylinder thickness, carbon fibres bend relatively less as compared to low carbon steels and E glass fibres.3) By comparing the deformation results, we determine that the carbon fibre composite cylinder weights comparatively little. There could be a weight save of up to 72% for the steel cylinder and 15% for the E-glass composite cylinder.4) Carbon fibre composite LPG cylinders provide the Leak

before fail design method, which could be a benefit in terms of reliability and safety. In addition to weight loss, this occurs.5) The HDPE outer shell offers the cylinder a fashionable appearance while the inside liner protects the gas from leaks.6) The aforementioned factors promote the use of carbon fibre for domestic uses, despite the fact that its raw material costs are obviously higher than those of glass fibre and standard steel.7) The safety and dependability of designs are enhanced by the leak before fail design method.8) Low electrical conductivity and corrosion resistance.9) Visual appeal and soundproofing.

6.Future extension

Bright, lighter, and easier to handle cooking gas chambers will enter Indian kitchens in the upcoming years, eliminating the need for heavy and dangerous steel partitions. The composite gas chamber's primary benefit is risk reduction because there is no blast in the case of holes or fire hazards. This is due to the advanced carbon fibre technology used in the construction of the composite chambers. The new chamber would be transparent, letting customers to see how much gas is within and lowering the possibility of malfunction, as is typical with murky steel chambers.One of the key initiatives taken by the public authority to focus on the individual's satisfaction is the presentation of composite chambers. Although the Indian government has placed a lot of emphasis on showcasing the gas pipelines that will enable direct gas supply, it will take a very long time for this framework to start working. There are other considerations to keep in mind as pipes have drawbacks, such as support for the pipeline, inconvenience during installation (as streets would need to be cleared in order to install the gas pipeline), removal of already-used steel chambers, and so on. For isolated, underdeveloped areas with poor foundation, the gas pipeline would also not be practical. Due to the current inability to build pipelines, the public authority can benefit from the future scope of our project. The new composite chambers have additional benefits for storing because they can be used as backup gas sources during emergency situations once the pipelines have been installed. Regarding various concerns, it may also be widely used in businesses where weight is important, and these light-weight composite chambers can be effective for reducing costs.

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