Finite Element Method For The Parametric Exploration Of Domestic Composite Liquid Petroleum Gas Cylinder With Steel

CH V K N S N Moorthy, V Srinivas, K Raghu Ram Mohan Reddy

Abstract*: Conventional Steel Cylinders used for LPG cylinder for domestic applications are not manufactured in a single joint but are welded. While composite cylinders are manufactured in a single joint, Composite components cannot be welded like the steel cylinder. Composite Cylinders are winded using Filament Winding technique. Compared to Steel Cylinders, Composite Cylinders are costlier. Composite cylinders are safer than steel cylinder. Composite Cylinders due to a rubber lining inside, they are 100% leak proof. If mass production of composite cylinders are done then the cost may get reduced. This paper summarizes the design and analysis of the manufacturing of Liquid petroleum gas (LPG) Cylinder using Glass Fibre Reinforced Plastic (GFRP) material. Further, the stresses and deformations that may develop due to internal pressure loading on the LPG Cylinder with GFRP material are to be analysed. Hence finite element analysis is applied with ANSYS software to simulate the corresponding analysis. Then the parametric comparative analysis of the LPG Cylinder with steel and GFRP material is also carried out assuming hemispherical end dome and considering cylinder without end frames. A significant saving in the weight of the LPG Cylinder, significant increase in the deformation and volumetric strain is observed with GFRP material against steel.

***Keywords:* Finite Element Method, GFRP, Liquefied Petroleum Gas (LPG), Pressure Vessel, Steel Vs GFRP.**

I. INTRODUCTION

Liquefied petroleum gas (LPG) is a mixture of butane and propane gases stored under pressure, usually in steel cylinders. LPG is heavier than air, non-toxic and odorless. A smelling agent is added to aid users to detect leaks. LPG is a safe, economical and convenient fuel as it has high calorific value (13.8 kWh/kg, which is equivalent to 13.8 units of electricity), provides instantaneous heat, is easy to ignite and clean-burning and is very portable.

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***** Correspondence Author

CH V K N S N Moorthy*, Department of Mechanical Engineering, Institute of Aeronautical Engineering, Dundigal, Hyderabad, Telangana State, India.

V Srinivas, Department of Mechanical Engineering, GITAM University, Vishakhapatnam, Andhra Pradesh, India.

K Raghu Ram Mohan Reddy, Department of Mechanical Engineering, Institute of Aeronautical Engineering, Dundigal, Hyderabad, Telangana State, India.

LPG is stored and handled as a liquid when under pressure inside a LP-Gas container. When compressed moderately at normal temperature, it becomes liquid. When gas is withdrawn, the pressure drops and the liquid reverts to gas. This means that it can be transported and stored as liquid and burnt as gas. The expansion ratio of gas liquid is 270:1 at atmospheric pressure. It is expansion factor which makes LP-Gas more economical to transport and store large quantities of gaseous fuel in a small container. LPG appliances include: stoves/ovens, grills, heaters (portable and fixed), instantaneous water heaters, lamps (portable and fixed), refrigeration and welding plant, and Bunsen burners. Appliances are designed to operate both at an unregulated high pressure (e.g. CADAC (or similar) type of camping appliances) and at a lower pressure controlled by a regulator mounted on the gas storage cylinder. High pressure and low-pressure appliances are not interchangeable. Most households use gas appliances with a small dedicated gas cylinder, rather than a reticulated system of gas piping and fixed storage cylinders. Many researchers have studied the analysis of LPG cylinder using composite materials using various commercial softwares [1-3] for the comparison of stress, strain and structure. It is shown that the stable angle of inclination of the fibres, where no strain-induced fibre rotations occur, deviates from the so-called 'ideal' fibre angle predicted by netting analysis by an amount that depends on the matrix-to-reinforcement-stiffness ratio [4]. But any pressure vessel made up of composite material like GFRP should be analysed for various parameters related to the manufacturing procedure of the cylinder unlike conventional steel cylinder [5]. Various researchers have published outcomes mentioning corrosion factors of the composites [21], the fibre orientations and their effect on the result of the composites [22] and Electro chemical corrosion effects of composites [25]. The modelling of composites and analysis aspects were published in detail [23] for the basic lead of this research, theoretical modelling was mentioned for Nano fluids [24] which was taken as a direction for the composites with sufficient improvisations. The concepts and features for coatings were also studied [26] before starting this research for understanding any similarities and possible inclusions in the proposed research. The analysis of LPG domestic cylinder was published using Classical lamination theory [19] and the calculations for various parameters like metallic boss, angle variation at dome and tip radius were explained in detail [20] for the initiation of this analysis.

Considering those research outcomes published in the mentioned literature, this paper deals with various simulation analysis results of GFRP cylinder in comparison with that of steel.

II. MATERIAL PROPERTIES

Table- I: Cured Composite – E-Glass Fiber (1200Tex)/Epoxy LY556

S. No.	Parameters	Value
1.	Longitudinal modulus, E1	44GPa
2.	Transverse modulus, E2	10GPa
3.	Shear modulus, G12	8GPa
4.	Poison's ratio,v12	0.24
5.	Longitudinal tensile strength, T1	800MPa
6.	Transverse tensile strength, T2	18MPa
7.	Longitudinal compressive strength, C1	400MPa
8.	Transverse compressive strength, C2	85MPa
9.	In-plane shear strength, S12	44MPa
10.	Density	2100 kg/m^3
11.	Fiber volume fraction, Vf	0.6

III. PARAMETRIC ANALYSIS OF GFRP CYLINDER WITH STEEL WHEN USED FOR THE LPG DOMESTIC GAS CYLINDER

A comparative parametric analysis is done between the steel and GFRP materials for the domestic LPG gas cylinder assuming hemispherical end dome and considering cylinder without end frames. The material and design input data are tabulated in table 4.

Hoop stress, $$\sigma_H = \frac{PD}{2t} \quad (1)$$

Longitudinal Stress, $$\sigma_L = \frac{PD}{4t} \quad (2)$$

Table- II: Various design requirements and Material properties of steel and GFRP LPG

S.No.	Name of the parameter with notation	Steel	GFRP
1	Density	7.8 kg/mm^3	1.8 kg/mm^3
2	Youngs Modulus/Elastic Modulus	200 GPa	26 GPa
3	Poison's Ratio	0.3	0.28
4	Yield strength	240 MPa	125 MPa
5	Ultimate Strength	420 MPa	530 MPa
6	Perimeter of the cylinder	102 cm	102 cm
7	Thickness of the cylinder	2.5 mm	2.5 mm
8	Hoop Stress	76.8 MPa	76.8 MPa
9	Longitudinal Stress	38.4 MPa	38.4 MPa

The following equations are used in calculating the parameters to be compared in deciding the utilization of GFRP to steel

Material volume required = volume of outer pressure vessel – volume of inner pressure vessel

= (Volume of Cylinder + Volume of sphere)-(Volume of Cylinder+ Volume of sphere)

$$V_R = V_o - V_i = (V_c + V_s)_o - (V_c + V_s)_i \quad (3)$$

Mass of the LPG Cylinder

$$m = \rho v \quad (4)$$

Longitudinal Deformation

$$LD = \frac{pdL(0.5-\nu)}{2tE} \quad (5)$$

Change in diameter

$$\Delta D = \frac{pd^2(1-0.5\nu)}{2tE} \quad (6)$$

Volumetric strain

$$\varepsilon_v = 2(\frac{\delta d}{d} + \frac{\delta l}{l}) \quad (7)$$

Change in volume = Volumetric strain × volume of pressure vessel

$$\Delta V = \varepsilon_v \times V \quad (8)$$

IV. RESULTS AND DISCUSSIONS

A. Results of FEA using ANSYS

Modeled the parts like Polar Metallic boss(Brass material), Rubber liner(blow moulding process), Nozzle (machined from brass rods), Cylinder (fabricated using GFRP by filament winding process) and Cylinder casing as well as assembly and the finite element analysis is carried out using ANSYS software. The various stages of modelling and analysis are shown in the figures 1 to 12

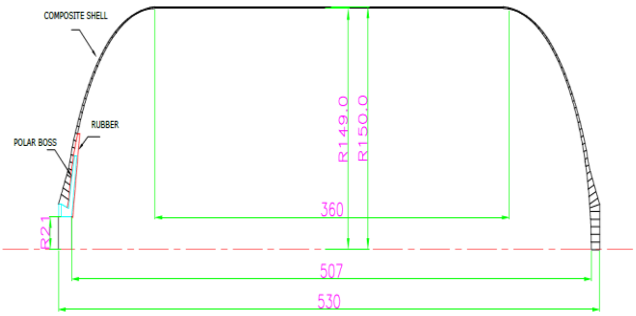

Fig. 1.The dimensional drawing of the proposed LPG Cylinder

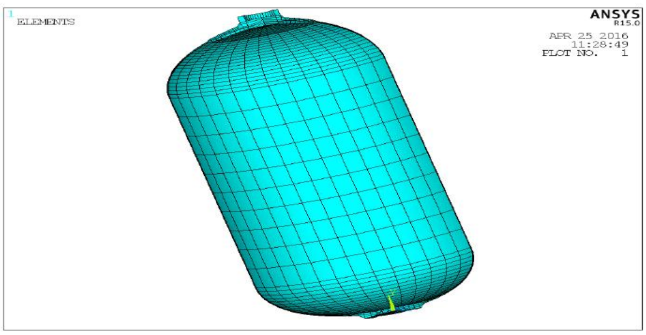

Fig. 2. Meshing of the model

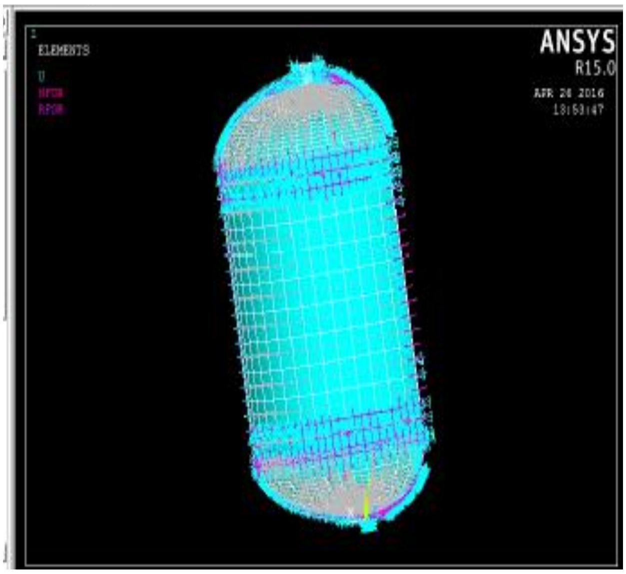

Fig. 3. Application of loads

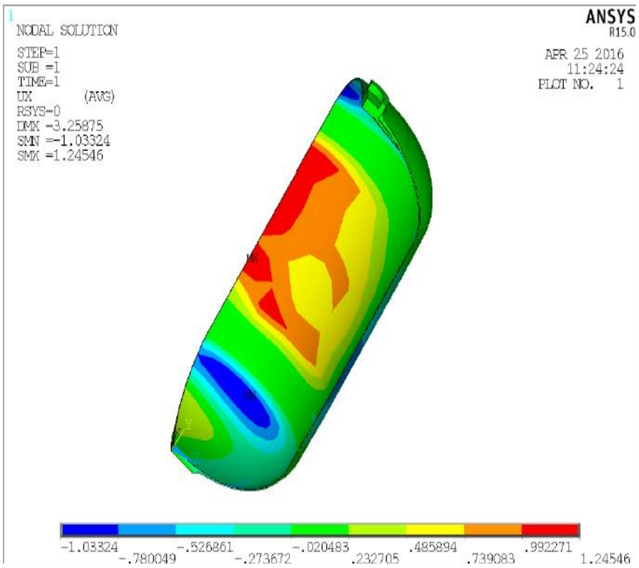

Fig. 6.Displacement contours along Y direction

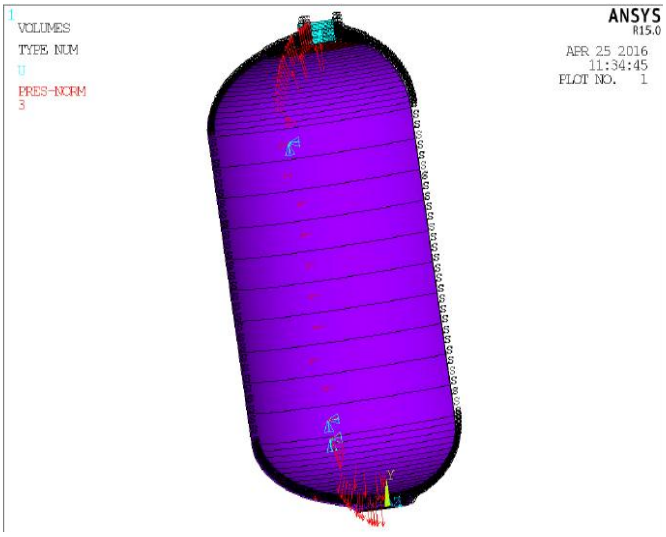

Fig. 4.Application of the Boundary Conditions

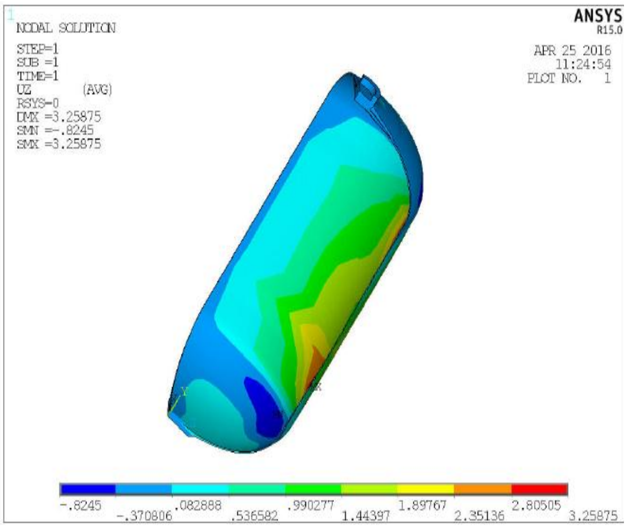

Fig. 7.Displacement contours along Z direction

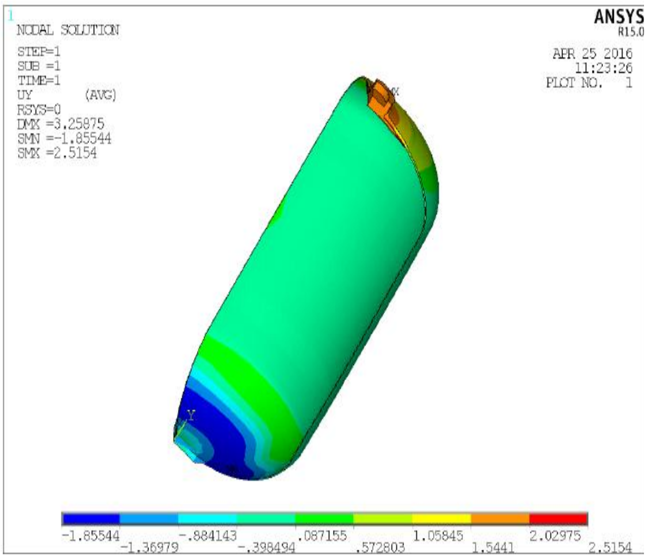

Fig. 5. Displacement contours along X direction

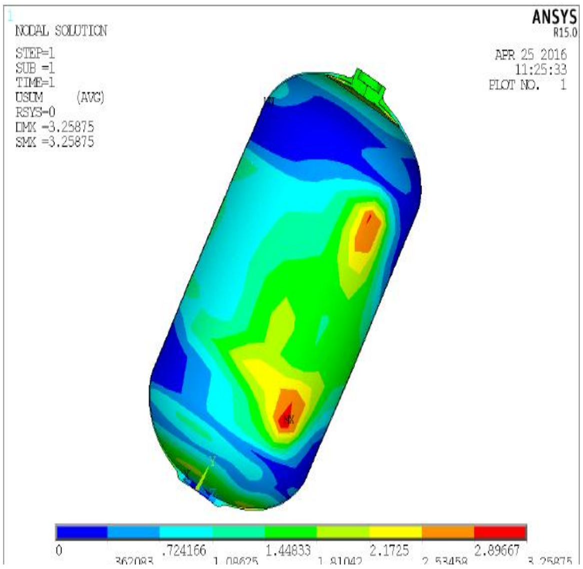

Fig. 8.Displacement contours along Vector Sum

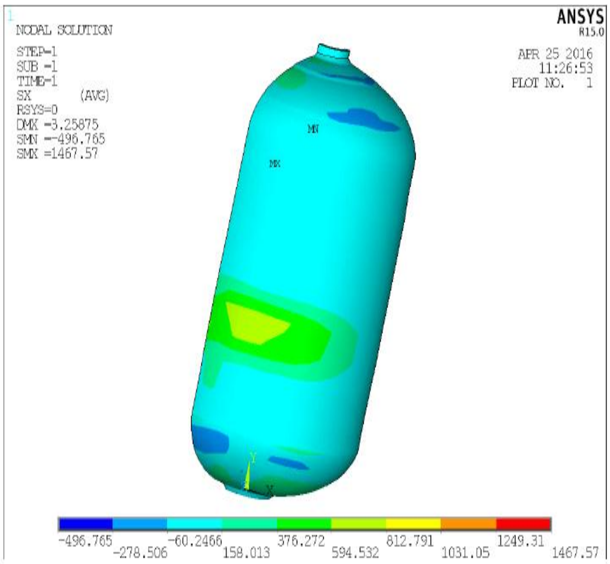

Fig. 9.Stress contours along X direction

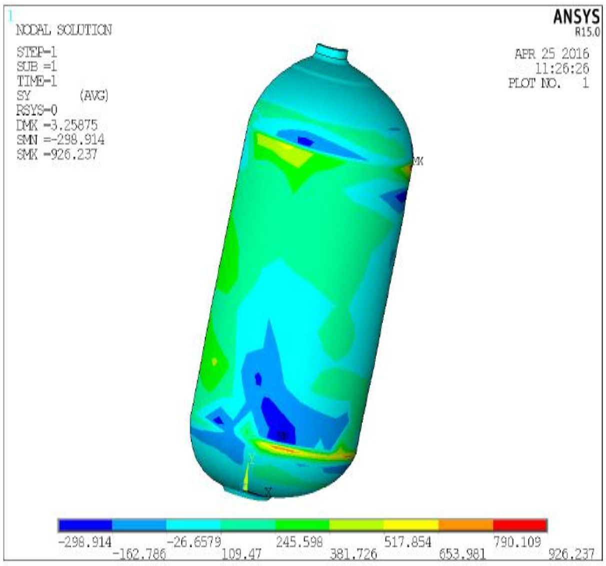

Fig. 10. Stress contours along Y direction

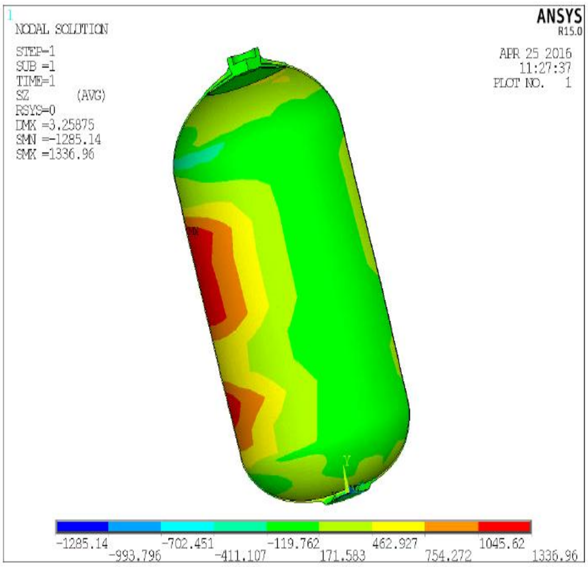

Fig. 11. Stress contours along Z direction

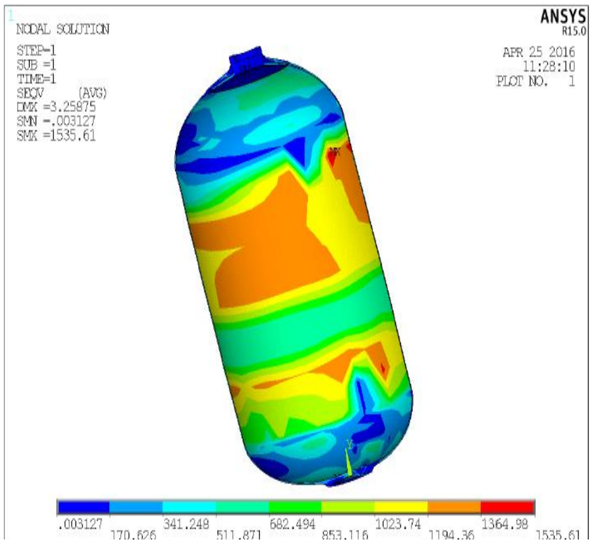

Fig. 12. Stress contours along Vonmises Stresses

B. Comparative Results of GFRP Cylinder with Steel when used for the LPG domestic gas cylinder

A comparative analysis is done between the steel and GFRP materials for the domestic LPG gas cylinder assuming hemispherical end dome and considering cylinder without end frames. The results are tabulated in table III

Table- III: Comparative results of the mechanical properties of steel and GFRP LPG domestic gas cylinder

S.No.	Name of the design output parameter with notation	Steel	GFRP	% Change
1	Requirement of the Material Volume	1.7 X $10^{-3}m^3$	1.7 X $10^{-3}m^3$	NA
2	Mass of the Cylinder	13.26 Kg	3.06 Kg	-76.92
3	Longitudinal deformation	0.052 mm	0.442 mm	+750.00
4	Change in diameter	0.104 mm	0.81 mm	+678.85
5	Volumetric Strain	7.29 X 10^{-4}	5.71 X 10^{-3}	+683.26
6	Change in volume	39866.52 mm^3	312393.94 mm^3	+683.60

V. CONCLUSIONS

The analysis of LPG cylinder using GFRP composite material and its comparison with that of steel metallic material is carried out using netting analysis, classical lamination theory and finite element analysis. The following conclusions have been drawn

1. The composite LPG cylinder designed is meeting the expected stipulated maximum operating pressure.
2. The new method proposed for analysis of filament wound composite cylinder is worked out to be efficient in accurately predicting the structural response.
3. The FE results and analytical results are in close agreement.
4. The design stresses are within safe limits.

Based on structural analysis, fibre stresses are within safe limits and weight saving can be achieved by 75% against the metallic cylinder. In future LPG composite cylinders can be fabricated and test can be performed to see the design margins.

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It is optional. The preferred spelling of the word "acknowledgment" in American English is without an "e" after the "g." Use the singular heading even if you have many acknowledgments. Avoid expressions such as "One of us (S.B.A.) would like to thank ... ." Instead, write "F. A. Author thanks " *Sponsor and financial support acknowledgments are placed in the unnumbered footnote on the first page*.

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AUTHORS PROFILE

Dr CH V K N S N Moorthy is presently working as Professor of Mechanical Engineering at Institute of Aeronautical Engineering an Autonomous Institution, Hyderabad, India. Dr Moorthy published more than 50 research articles including various research articles and book chapters. He is a life Fellow member of Institution of Engineers (India) and a life member of ISTE and ASME. He has been working in active research for more than 9 years involving more than 250 K USD projects funded by various organizations such as Ministry of Science and Technology and Department of Science and Technology established by Government of India. His thrust areas of research are Nano technology, nano coolants for automotive, nano lubricants, nano composites, renewable energy resources, Solar energy and Computational Fluid Dyanamics.

Dr V Srinivas is presently working as Professor of Mechanical Engineering at GITAM University, Vishakhapatnam, India. Dr Srinivas published more than 75 research articles including various research articles, book chapters and books. He is a life Fellow member of Institution of Engineers (India) and a life member of ISTE and ASME. He has been working in active research for more than 15 years involving more than 300 K USD projects funded by various organizations established by Government of India. His thrust areas of research are Nano technology, nano coolants for automotive, nano lubricants, nano composites, renewable energy resources and Solar energy

Dr K Raghu Ram Mohan Reddy is presently working as Professor of Mechanical Engineering at Institution of Aeronautical Engineering, Hyderabad, India. Dr Reddy published more than 25 research articles. He is a life member of Institution of Engineers (India) and ISTE. He has been working in active research for more than 8 years involving more than 50 K USD projects funded by various organizations. His thrust areas of research are Nano technology and nano composites.