ISSN 2249 5460

INTERNATIONAL JOURNAL OF MATHEMATICAL SCIENCES, TECHNOLOGY AND HUMANITIES

www.internationalejournals.com

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International eJournals

International Journal of Mathematical Sciences, Technology and Humanities 58 (2012) 635 – 646

Design and Analysis of LPG Cylinder using ANSYS Software

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ABSTRACT

This project aims at reduction of weight of Liquid petroleum gas(LPG). So, 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.

A number of cases are considered to study the stresses and deformations due to pressure loading inside the cylinder. First, the results of stresses and deformation for steel cylinders are compared with the analytical solution available in literature in order to validate the model and the software. The weight savings are also presented for steel, Glass Fiber Reinforced Plastic (GFRP) composites and Carbon Fiber Reinforced Plastic (CFRP) composite LPG cylinders. Variations of stresses and deformations throughout the cylinder made of steel, GFRP and CFRP are studied.

A complex orthotropic mechanics of FRP composites has been studied and discussed in brief to have some understanding of behavior of FRP composites. In addition to that an introductory Finite Element Method has also been presented on the basis of which the cylinder has been analyzed.

Key Words: LPG Steel Cylinder; (GFRP,CFRP) Composites; Design Analysis;

1. Introduction

LPG (propane or butane) is a colourless liquid which readily evaporates into a gas. It has no smell, although it will normally have an odour added to help detect leaks. When mixed with air, the gas can burn or explode when it meets a source of ignition. It is heavier than air, so it tends to sink towards the ground. Liquefied Petroleum (LP) Gas is composed predominantly a mixture of the following hydrocarbons: propane, propylene, butane or butylenes.

Liquefied Petroleum (LP) Gas 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 When gas is withdrawn, the pressure drops and the liquid reverts to gas.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 from liquid is 270:1 at atmospheric pressure. It is this expansion factor which makes LP-Gas more economical to transport and store large quantities of gaseous fuel in a small container in liquid state.

The LPG (Liquefied Petroleum Gas) Cylinders from past many years, are being manufactured in our country from the very conventional metallic material such as steel. The weight of the cylinder becomes more as density of steel is higher compared to other light weight materials. With the advancement of low-density materials like FRP (Fiber Reinforced Plastic) Composites, we can think of producing LPG cylinders with FRP to reduce its weight.

The present work deals with the Finite Element Analysis of LPG cylinders made of conventional material (such as steel) and different fiber reinforced plastic (FRP) composites. The performance of the steel cylinders has also been compared with FRP cylinders. This may be a technical proposal for the use of FRP composites in gas cylinders in our country.

2. FE Analysis, Results and Discussions

2.1 LPG Cylinder made of steel

Input Specifications

Empty gas cylinder weight = 15.9 kg (with frames and holders)

≅ 13.0 kg (without frames)

Gas weight =14.2kg

Volume of the Gas = 47.8 liters

Perimeter = 102cm

Assumptions: (1) End dome is hemispherical

(2) Cylinder has been modeled without end frames.

Thickness of the cylinder = 2.4mm~2.5mm

Material Properties

The material used is steel for which material properties are listed below.

Density, ρ = 7.8 gm/cc
Young's modulus, E = 207Gpa
Poisson ratio, ν = 0.3
UTS, σ = 800 MPa
Yield strength = 480 MPa

Results and Discussions

The maximum displacement is occurring at the extreme points in the x-direction. Maximum Longitudinal displacement = 0.0332 mm

The maximum stress is occurring at the mid plane at which the cylinder is constrained along the longitudinal direction (x-direction). Maximum Longitudinal stress = 43.48 MPa

The Maximum Vonmises stress =68.81 MPa and the yield strength of the steel is 480 MPa . so, the maximum stress occurring is within the limits and the design is safe.

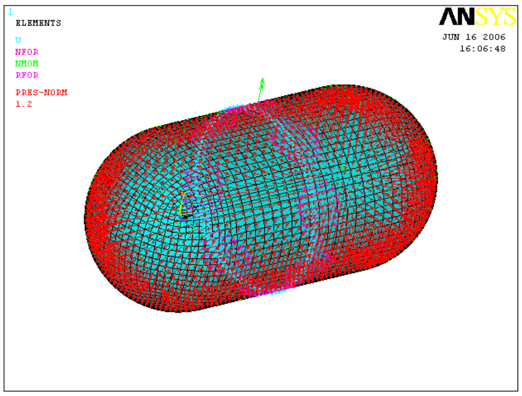


Fig1:Internal pressure applied on Steel cylinder

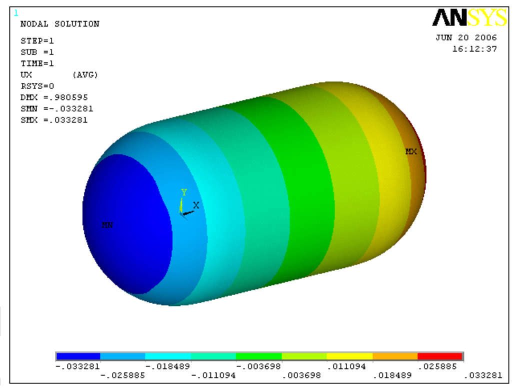


Fig2: Longitudinal Displacement plot for steel cylinder

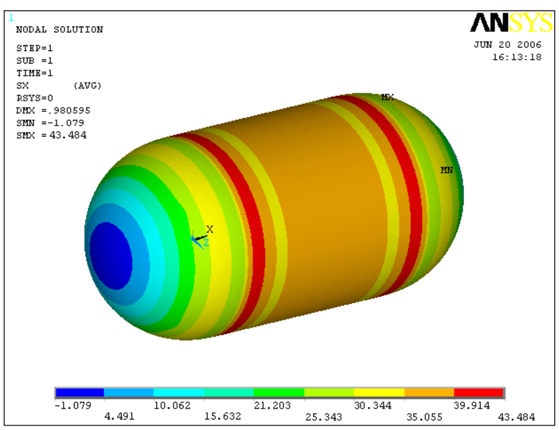


Fig3 : Longitudinal stress contour plot for steel cylinder

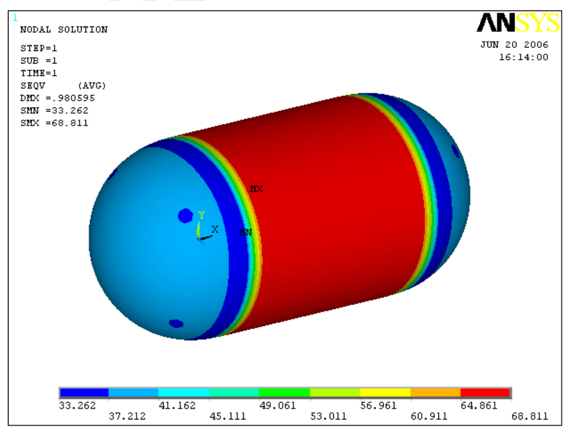


Fig4 : Von-mises stress contour plot for steel cylinder

The figure shows the nodes which are selected to draw the Longitudinal Displacement variation graph and the longitudinal Stress variation graph for Steel Cylinder.

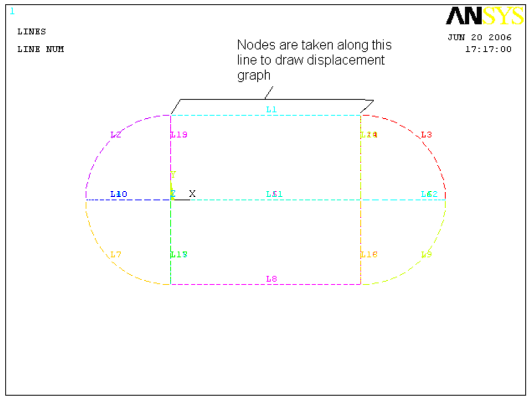


Fig5 : Nodes selected along the axis

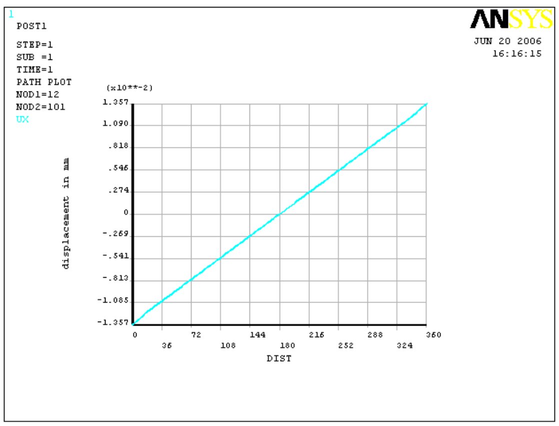


Fig6: Graph for the Longitudinal Displacement

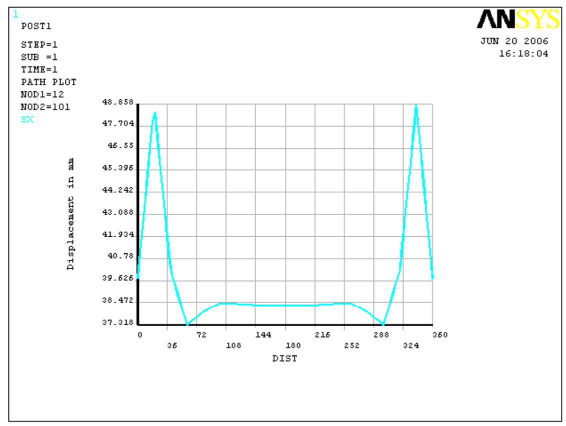


Fig7: Longitudinal Stress variation Graph for Steel Cylinder

Table 1: Comparison of results for steel

Sl.No.	RESULTS	FE METHOD	CLASSICAL METHOD
1	Longitudinal stress, MPa	43.48	38.4
2	Von-mises stress, MPa	68.81	66.5
3	Longitudinal Deformation, mm	0.033	0.050

2.2 LPG Cylinder made of GFRP

The GFRP cylinder has been modeled in ANSYS 9.0. The eight-noded linear layered shell element (SHELL99) with six degrees of freedom (u_x, u_y, u_z, rotx, roty, rotz) has been used to discretize the cylinder.

Material Properties

The material used is Glass Fiber Reinforced Plastic (GFRP) composites for which material properties are listed below.

MAT1 (PET)

Elastic Modulus, E = 1000 MPa

Poisson's Ratio, ν = 0.4

Tensile Strength, σ_T = 35 MPa

Density, ρ = 1.2 gm/cc

MAT2 (Uni-Directional S-Glass / Epoxy)

Table 2

Elastic Modulus	Poisson's Ratio	Shear Modulus
E_L = 34.4 GPa	ν_{LT} = 0.27	G_{LT} = 2.94 GPa
E_T = 9.67 GPa	$\nu_{LT'}$ = 0.27	$G_{LT'}$ = 2.94 GPa
$E_{T'}$ = 9.67GPa	$\nu_{TT'}$ = 0.42	$G_{TT'}$ = 3.4 GPa

Density, ρ = 1.8 gm/cc

Strength Properties

Longitudinal Tensile Strength, σ_{LT}= 530 MPa

Longitudinal Compressive Strength, σ_{LC}= 305 MPa

Transverse Tensile Strength, σ_{TT}= 530 MPa

Transverse Compressive Strength, σ_{TC}= 305 MPa

In-plane Shear Strength, τ = 72 MPa

Results and Discussions

The stress and deformation pattern is not systematic because of the anisotropic behavior of the material used.

Maximum Von-Mises stress = 65.00 MPa

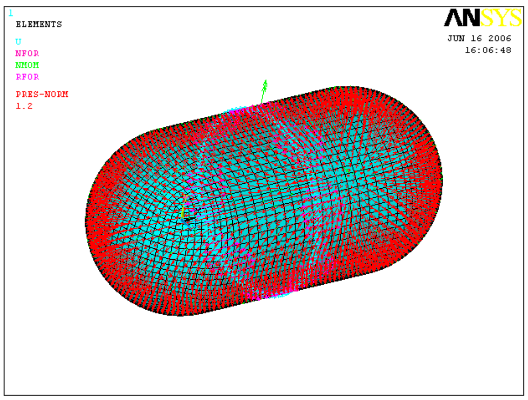
Maximum longitudinal deformation = 0.161 mm

Weight of the cylinder = 3.02 kg

Maximum Longitudinal displacement = 0.161 mm

The stress and deformation pattern is not systematic because of the orthotropic behavior of the material used. Maximum Longitudinal stress = 44.36 MPa

The figure showing the Vonmises stress plot for GFRP cylinder .For which the Maximum Vonmises stress =65.00 MPa. So, the maximum stress occurring is within the limits and the design is safe. Maximum Vonmises stress =65.00 MPa



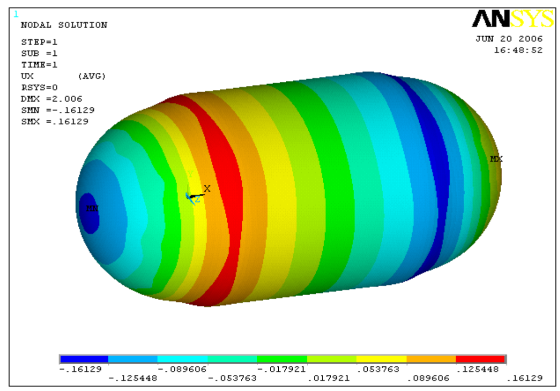
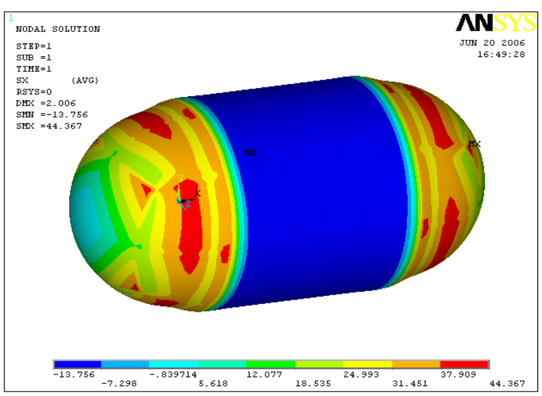


Fig8: Internal pressure applied on GFRP cylinder

Fig9: Longitudinal Displacement (mm) plot for GFRP cylinder



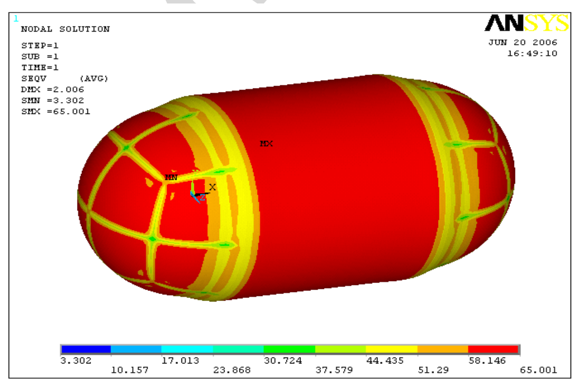


Fig10 : Longitudinal stress (MPa) for GFRP cylinder

Fig11: Von-mises stress (MPa) for GFRP cylinder

The figure shows the nodes which are selected to draw the Longitudinal Displacement variation graph and the Vonmises Stress variation graph for GFRP Cylinder.

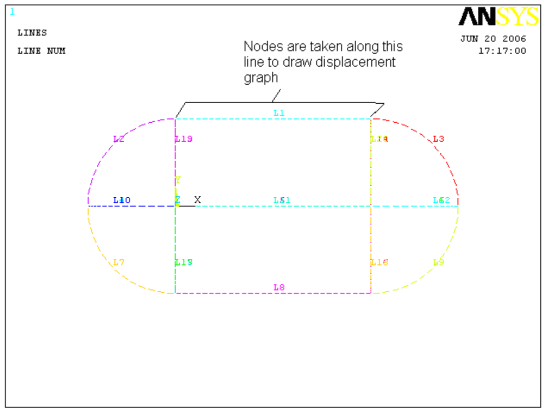
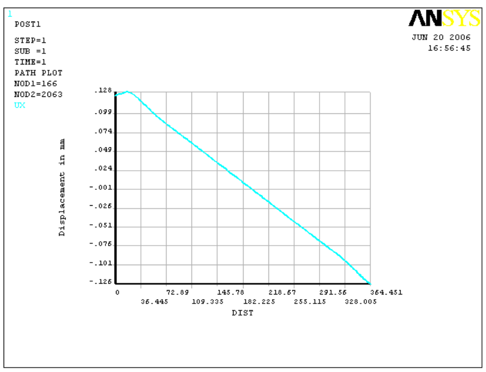


Fig 12 : Nodes selected along the axis



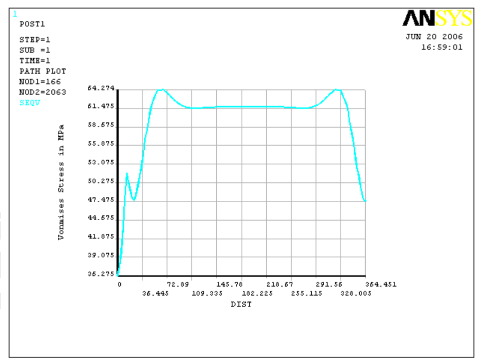


Fig13 : Graph showing the variation of Displacement

Fig14 : Graph showing the varaiation of Vonmises Stress

2.3 LPG Cylinder made of CFRP

Material Properties

The material used is Carbon Fiber Reinforced Plastic (CFRP) composites for which material properties are listed below.

MAT1 (PET)

Elastic Modulus, E = 1000 MPa
Poisson's Ratio, ν = 0.4
Tensile Strength, σ_T = 35 MPa
Density, ρ = 1.2 gm/cc

MAT2 (Uni-Directional Carbon / Epoxy)

Table 3

Elastic Modulus	Poisson's Ratio	Shear Modulus
E_L = 124 GPa E_T = 11.7 GPa $E_{T'}$ = 11.7GPa	ν_{LT} = 0.3 $\nu_{LT'}$ = 0.6 $\nu_{TT'}$ = 0.3	G_{LT} = 5.5 GPa $G_{LT'}$ = 2.75 GPa $G_{TT'}$ = 4.137 GPa

Density, ρ = 1.54 gm/cc

Strength Properties

Longitudinal Tensile Strength, σ_{LT}= 1520 MPa
Longitudinal Compressive Strength, σ_{LC}= 1590 MPa
Transverse Tensile Strength, σ_{TT}= 45 MPa
Transverse Compressive Strength, σ_{TC}= 252 MPa
In-plane Shear Strength, τ = 105 MPa

Results and Discussions

The detailed results of FE analysis for the cylinder are listed below.

Maximum Von-Mises stress = 109.09 MPa
Maximum longitudinal deformation = 0.135 mm
Weight of the cylinder = 2.62 kg

The figure showing the Longitudinal Displacement plot for CFRP cylinder .For which the maximum displacement is occuring in between cylindrical and hemispherical zones. Maximum Longitudinal displacement = 0.135 mm

The figure showing the Longitudinal stress plot for CFRP cylinder . The Maximum Longitudinal stress is occurring in the hemispherical dome zones. The stress and deformation pattern is not systematic because of the orthotropic behavior of the material used. Maximum Longitudinal stress = 54.30 MPa

The figure showing the Vonmises stress plot for CFRP cylinder .For which the Maximum Vonmises stress =109.97 MPa . so, the maximum stress occurring is within the limits and the design is safe. Maximum Vonmises stress =109.97 MPa

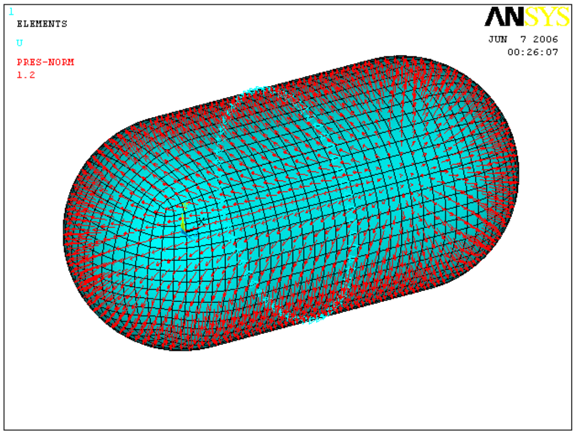


Fig15 : Internal pressure applied on CFRP cylinder

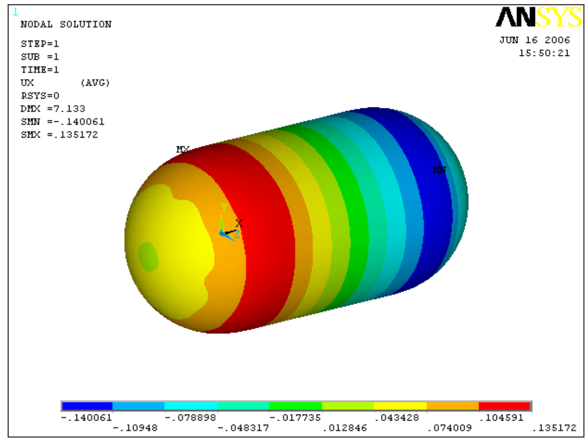


Fig16 : Longitudinal displacement (mm) plot for CFRP cylinder

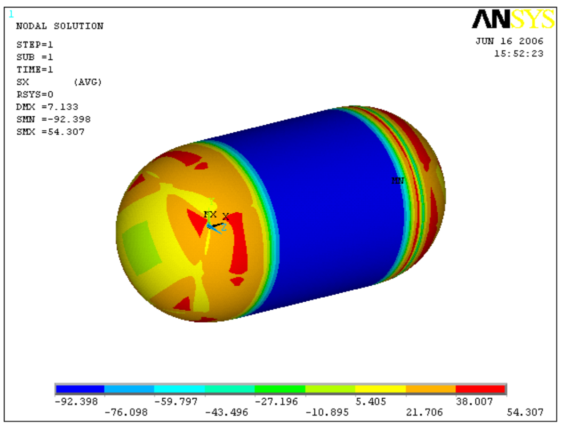


Fig17: Longitudinal stress (MPa) for CFRP cylinder

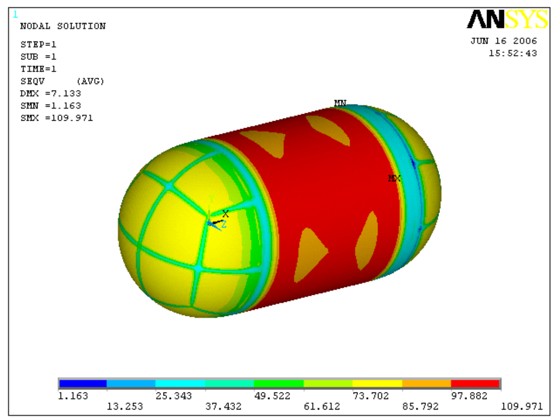


Fig18 : Von-mises stress (MPa) for CFRP cylinder

The figure is showing the line along which the nodes are selected to draw the Longitudinal Displacement variation graph and the Vonmises Stress variation graph for CFRP Cylinder.

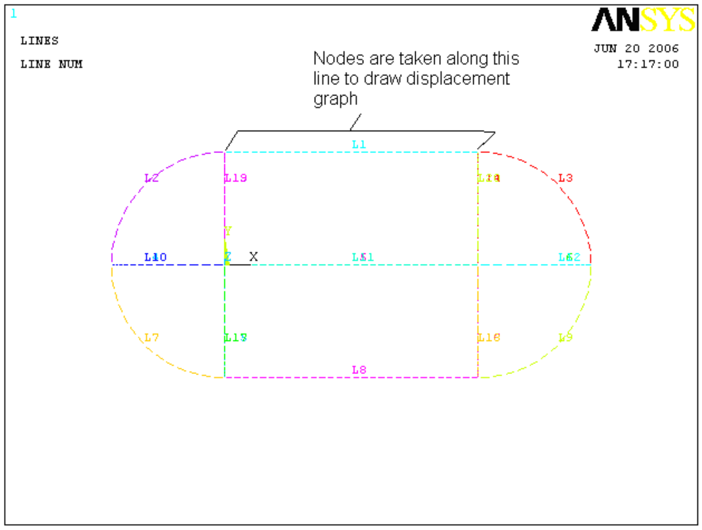
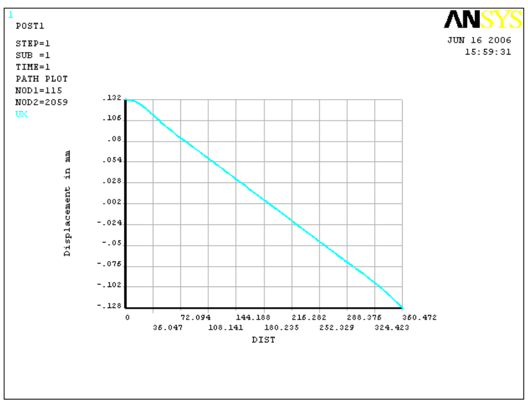


Fig19 : Nodes selected along the longitudinal axis



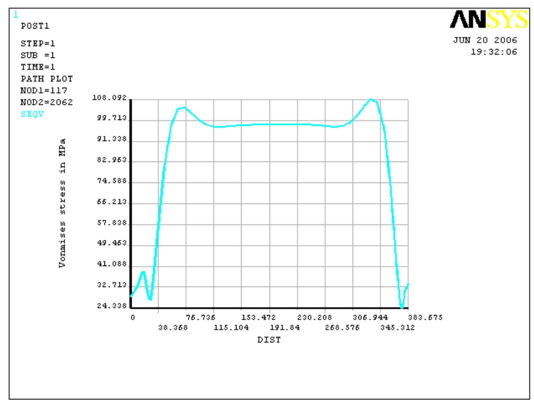


Fig20 : Longitudinal Displacement variation Graph

Fig21 :Vonmises Stress Variation Graph

<u>Table 4 : Comparisons of GFRP and CFRP</u>

	GFRP	CFRP
MaximumVonmises Stress in MPa	65	109.97
Maximum Longitudinal Stress in MPa	44.36	54.36
Maximum longitudinal deformation in mm	0.161	0.135

Conclusions

Based on the analysis of LPG cylinders made of different materials like steel, GFRP and CFRP, following salient conclusions have emerged out from the present investigations:

(1) The weight of LPG cylinder can be saved enormously by using FRP composites and the stress values are also well within the limit of capability of materials. This gives a clear justification for it's use in household applications.

Weight of the steel cylinder = 13.31 kg (without end frames)
Weight of the GFRP cylinder = 3.02 kg (without end frames)
Weight saving = 10.29 kg
Weight of the CFRP cylinder = 2.62 kg (without end frames)
Weight saving = 10.69 kg

(2) Apart from the weight savings, FRP composite LPG cylinders offer 'Leak before fail approach of design' which may be a design advantage in terms of safety and reliability.

(3) The cost of FRP raw materials is definitely more than conventional steel material, but the above two points justify it's use for household purpose.

Further Scope of Work

(1) Material properties evaluation of FRP composite laminate by coupon level testing.
The properties used for FE analysis are taken from available literatures, whereas the end properties of composites are highly dependent on process and laborer's skill.

(2) Optimization of winding angle in CNC filament winding process.
Fiber orientation is the decisive factor in the strength of the composites.

(3) Detailed design of FRP cylinders including end frames and its attachment with the cylinders.

(4) Burst Test of the LPG cylinders for its qualification as per ASME.

(5) Workout for the complete costing for FRP cylinders as well as existing steel cylinders, and to study its suitability in Indian scenario.

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