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DETERMINATION OF BURST PRESSURE OF VEHICLE LPG CYLINDER AND ITS OPTIMIZATION USING ANSYS APPROACH

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ABSTRACT

LPG is commonly used as an alternative fuel for automotive internal combustion engines. Now a day, a number of fire accidents are reported in news because of the failure of these cylinders. While in use pressure of the LPG in the cylinders is prone to increase, this is because of over filling of the gas tanks and also temperature is one of the factors for increase in pressure. On over filling, adds the gas molecules and collision of gas molecules takes place and hence which increases the gas pressure. This increase in the pressure of LPG in the cylinder, may lead to bursting of the cylinder resulting in the fire hazardous. A number of fire accidents have been reported in recent past. Hence in order to avoid bursting of LPG cylinder, radial and circumferential stiffeners are to be provided at the outer surface of the vehicle LPG cylinder. Experimental work has been carried out by various pioneers. The results of the experimental and FEM are compared for authentification in the present work, analysis is carried out to determine the burst pressure and burst failure location using FEM. To analyse the cylinder based on FEA, commercial finite element software ANSYS is used. Material non-linearity will be considered to estimate the burst pressure and burst failure location. Non-linear FEA analysis will be carried out for three different capacities of cylinder. Simulation results will be compared and matched to experimental results. Later, design iterations will be carried out to estimate the performance of cylinders under same capacity.

KEYWORDS :*Pressure, Non-linear, Converging, Diverging, Stiffener, Deformation.*

1.INTRODUCTION :

LPG is obtained from hydrocarbons produced during refining of crude oil and from heavier components of natural gas. It is petroleum derived colorless gas LPG consists of propane or butane or mixtures of both. Small quantities of ethane or pentane may also be present. LPG has high octane rating of 112 RON which enables higher compression ratio to be employed & hence gives higher thermal efficiency. Due to low maintenance cost, economic market price and environment friendly characteristics LPG is becoming popular. It is increasingly used as an aerospace propellant and a refrigerant replacing chlorofluorocarbons in a effort to reduce damage to the layer. When significantly used as a vehicle fuel it is often referred as an auto gas.

LITERATURE REVIEW

A Kaptan, Y. Kisioglu [6] this study address the determination of the burst pressure and burst failure locations of vehicle liquefied petroleum gas (LPG) fuel tanks using both experimental and finite element analysis (FEA).the experimental burst test investigations were carried out by hydrostatic test in which the cylinders were internally pressurized with water. Two non linear FEA models, plane and shell, were developed and evaluated under non uniform and axi symmetric boundary conditions. The required drawn shell properties including weld zone and shell thickness variations were investigated. The FEA burst pressure and the burst failure locations are compared to the experimental ones. The permanent volume expansions of the LPG tanks due to internal pressure were also examined based on the code regulations. A series of thin walled cylindrical LPG fuel tanks under internal pressure, to determine the burst pressure and burst failure location, was studied using both experimental and computer aided FEA approaches. The FEA models use 2D axisymmetric elements and simulate non-uniform geometry and non-homogeneous material property conditions on a nonlinear field. Based on the generated result, good agreement between the measured burst pressure in the experiments and the corresponding non-linear axisymmetric FEA model values was found for all of the tank models. Good experimental and FEA simulation agreement was also found for the burst failure location of the LPG tanks when considering non-uniform non-homogeneous axisymmetric FEA modelling conditions. In addition, the permanent volume expansion measurements obtained from both experiments and simulations verified each other and complied with the code definitions.

Laxmikant D. Rangari, P. M. Zode & P.G. Mehar [7] this paper analysed the burst pressure of the LPG cylinder using finite element analysis. The LPG gas cylinder is manufactured from low carbon steel. The LPG tanks are subjected to incremental internal uniform pressure in the FEA model. 2D nonlinear plane models are developed and evaluated under non-uniform and axis symmetric boundary conditions. For the analysis, the required actual shell properties including weld zone and thickness variation are investigated. Therefore the stress distribution has been analyzed using ANSYS 11 software for which maximum shear stress; equivalent shear stress at critical area has been calculated. Therefore 3D solid model has been chosen in order to predict the detailed stress. The burst pressure of LPG gas cylinder has been determined by use of finite element analysis. Max. And Min. equivalent stress, maximum shear stress and deformation at critical area have been calculated. The result of FEA analysis verified with hand calculation.

Siva Sankara Raju R, D.Ashok, Thimothy Pandi [8] this paper establishes the stress and deformation on LPG steel cylinder. LP-gas inside a container is in two states of matter, liquid and vapour. The liquid portion of container is in the bottom and the vapour is in the uppermost part of the vessel. 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. 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. A variation of stresses and deformations throughout the cylinder made of steel is studied. In this the cylinder is designed in Pro-E WILDFIRE to study the stresses and deformations of the cylinder. And it is converted to Pro-E model to ANSYS to know variations of the steel cylinder when it is under some conditions. Based on the analysis of LPG cylinder made of steel, the following salient conclusions have emerged out from the present investigations: By conducting analysis of LPG steel cylinders the stresses and deformations under pressure load of the cylinder are found. These results are compared with analytical solutions. Some variations of results of the LPG steel cylinder is generated while studying FE method and Analytical method.

David Heckman [9] this paper establishes the stress of the pressure vessel which have sharp corners. Pressure vessels are a commonly used device in marine engineering. Until recently the primary analysis method had been hand calculations and empirical curves. New computer advances have made finite element analysis (FEA) a practical tool in the study of pressure vessels, especially in determining stresses in local areas such as penetrations, O-ring grooves and other areas difficult to analyze by hand. This project set out to explore applicable methods using finite element analysis in pressure vessel analysis. Contact elements were tested to determine their usefulness in modelling the interaction between pressure vessel cylinder walls and end caps. When modelled correctly, contact elements proved to be useful, but the operator also needs to be able to interpret the results properly. Problems such as local stress risers, unrealistic displacements and understanding how to use such data become extremely important in this kind of analysis. This highlights the key to proper use of finite element analysis. The analyst should be able to approximate the solution using classical methodology in order to verify the solution.

Tested models were run with errors ranging from seven to nearly zero percent error and could be run in a relatively short time. Data must be verified with hand calculations to confirm that solutions are relatively accurate. For this pressure vessel, the model had a sharp corner, where in the actual pressure vessel there is a small radius which reduces the stress.

PROBLEM DEFINITION

Liquefied petroleum gas (LPG) is commonly used as an alternative fuel for internal combustion engines of vehicles in the world. The LPG is stored and transported based on the relevant standard of each country. In order to store LPG in vehicles, the LPG cylinders known as LPG fuel tanks are commonly used and approved by these regulations. The experimental burst test investigations were carried out by hydrostatic test in which the cylinders were internally pressurized with water. This study addresses the determination of the burst pressures (BP) and burst failure locations of vehicle liquefied petroleum gas (LPG) fuel tanks using finite element analysis (FEA). Using nonlinear FEA analysis, burst pressure will be determined and compared with experimental results.

OBJECTIVES

1.The primary objective of the current work is to estimate the burst pressure of vehicle LPG cylinders using non linear FEA analysis.
2.Determination of burst failure locations.
3.Design and optimization of vehicle LPG cylinder to avoid the hazardous situation.

METHODOLOGY

1.Review the design of LPG cylinders based on ASME code.
2.Generating the model of cylinder in solid works.
3.Import the geometry into ANSYS.
4.Mesh the model and preparation of boundary conditions.
5.Run a non-liner transient structural analysis.
6.Estimate the burst pressure using FE Approach.

7.Compare the results with literature.
8.Validate ANSYS burst pressure results with literature.
9.Design modifications for increasing the efficiency.

RESULTS AND DISCUSSIONS:

?Geometry of Cylinder with 6 Radial Stiffeners
• Six radial stiffeners of 2mm thick with a gap of 30mm are created on the outer surface of cylinder.
• This strengthens the cylinder and burst pressure capability increases.

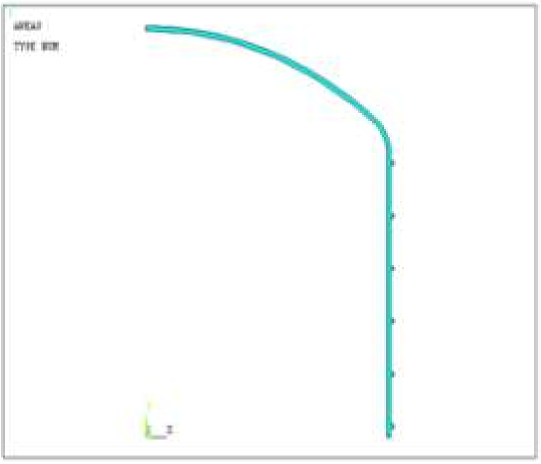


Figure: Geometry of Cylinder with Radial Stiffeners

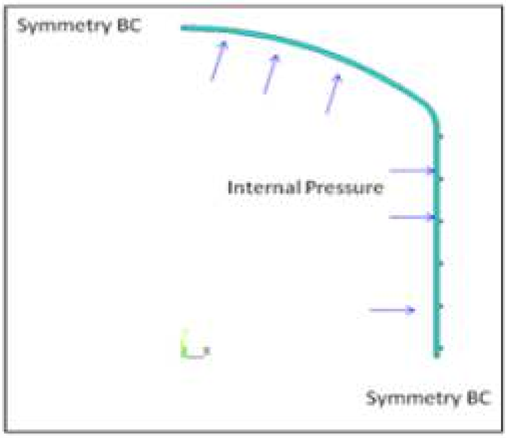


Figure: Boundary Conditions

Boundary Conditions

• The boundary conditions used for the analysis is shown in figure.
• By applying symmetry Boundary Conditions on both sides, a model is self constrained and no need to apply any more constraints.
• Internal pressure is applied as a transient load and will be increased in the simulation transiently.
• Initial value of initial pressure=1bar.

Results of "35 liter" Tank Analysis

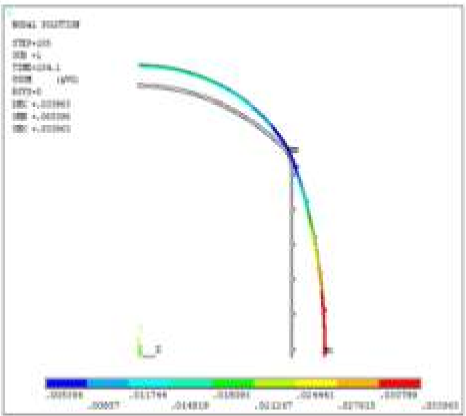
Understanding of Burst Pressure from Convergence Issue

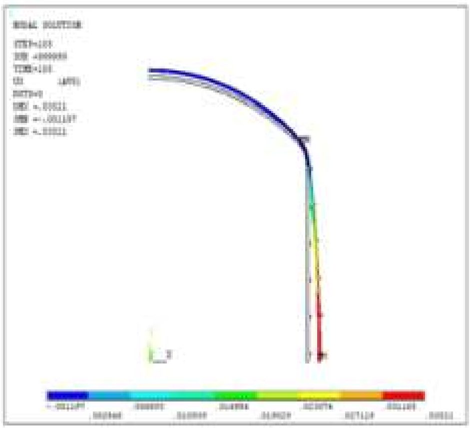
• It is important to note that the current analysis is trying to estimate the burst pressure.
• At the instant of burst pressure, solution in ANSYS is going to diverge. But, solution can be captured till the point of burst pressure.
• Convergence error in solution occurred at 105bar.Means Burst pressure is 105bar. from ANSYS
• Structural results at 104.1bar are given in the Table.
• Table: Structural Results at 104.1 bars

SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
134	101.00	101	7	855
135	101.10	102	1	856
136	101.20	102	2	863
137	101.30	102	3	864
138	101.45	102	4	865
139	101.67	102	5	866
140	102.00	102	6	867
141	102.10	103	1	868
142	102.20	103	2	879
143	102.30	103	3	880
144	102.45	103	4	883
145	102.60	103	5	887
146	102.82	103	6	888
147	103.00	103	7	889
148	103.10	104	1	890
149	103.20	104	2	902
150	103.30	104	3	903
151	103.45	104	4	904
152	103.67	104	5	905
153	104.00	104	6	917
154	104.10	105	1	918
155	105.00	105	999999	940

Deformation Plots at the Converged and Diverged Results

- Comparison of deformed plots between burst pressures of 104.1bar and 105bar is shown in Figure.
- At convergent result the maximum displacement is found to be 0.033963 m.
- At divergent result the maximum displacement is found to be 0.03521 m.





Converged result at 104.1bar Diverged result at 105bar,

Figure: Comparisons of Deformed Plots between Burst Pressures Of Converged and Diverged result

Von-Mises Stress Plot at 104.1sec (Converged Solution)

- At the time of 104.1sec, for the burst pressure of 104.1bar, Von-Mises contour is shown in Figure.
- Maximum stress is found to be 591MPa and is observed at the mid of tank.

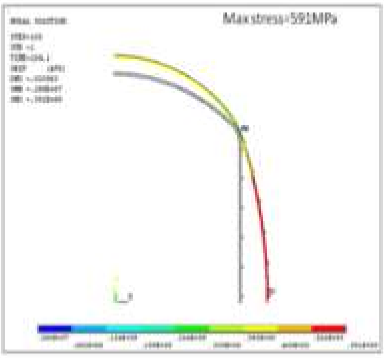


Figure Von Mises Stress

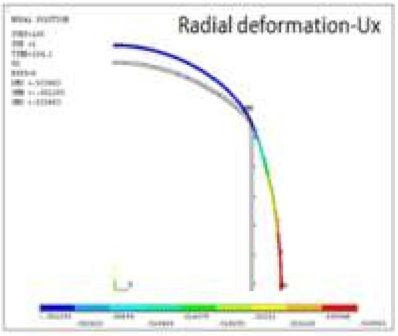


Figure Radial Deformation

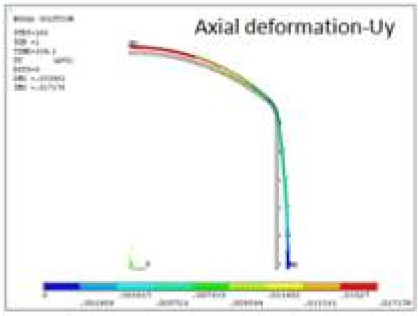


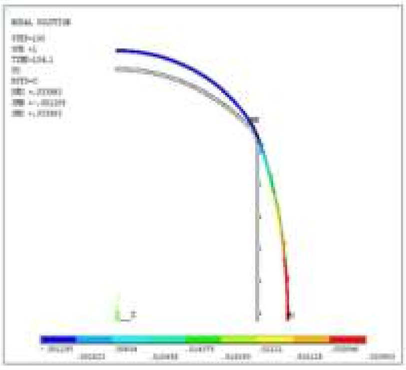
Figure Axial Deformation

Radial and Axial Deformation Plots at 104.1sec

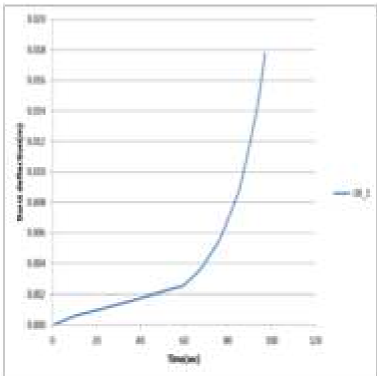
- The radial and axial deformation plots at the burst pressure of 104.1bar at 104.1sec is shown in Figure.
- The radial deformation is found to be 0.033963 m
- The axial deformation is found to be 0.033963 m

Radial Deformation Vs Displacement

- The radial deformation over time for the highlighted node is shown in Figure 5.32
- It can be observed that elastic behavior can be seen up to 60bar.
- After 60bar, huge increase in deformation can be noted for every 1bar increase in pressure because of the plasticity behavior.
- Highlighted location is going fail the component at 104.1bar.



Radial Deformation Vs Displacement



Burst Deflection Vs Time

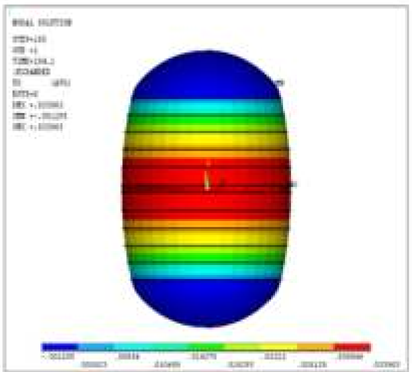


Figure Deformation Plot

Comparison of Failure Locations

- From the simulation result, it is seen that maximum deformation occurs at the midpoint of the cylinder which is sensible.
- After increasing the strength of cylinder also, failure location is not changed.

Iteration 2: “35 liters” Cylinder (with stiffeners)

Geometry of Cylinder with 12 Radial Stiffeners

- 12 radial stiffeners of 2mm thick with a gap of 12.75mm are created on the outer surface of cylinder.

•This strengthens the cylinder and burst pressure capability increases.

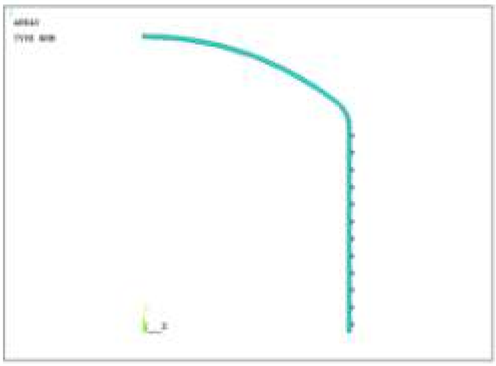


Figure: Geometry of Cylinder with Radial Stiffeners

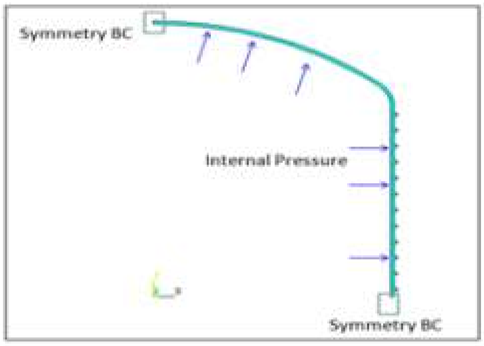


Figure: Boundary Conditions

Results of "35 liter" Tank Analysis

Understanding of Burst Pressure from Convergence Issue

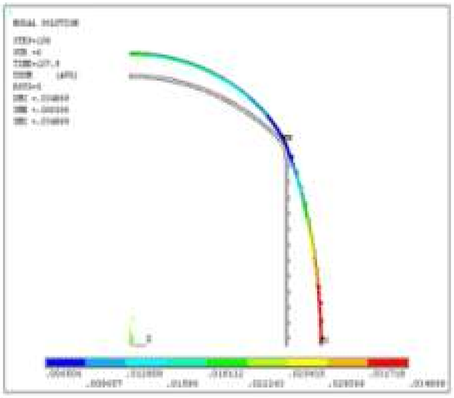
•It is important to note that the current analysis is trying to estimate the burst pressure.
•At the instant of burst pressure, solution in ANSYS is going to diverge. But, solution can be captured till the point of burst pressure.
•Convergence error in solution occurred at 108bar.Means Burst pressure is 108bar. from ANSYS
•A structural result at 107.9bar is given in the Table 5.6

Table: Structural Results at107.9 bars

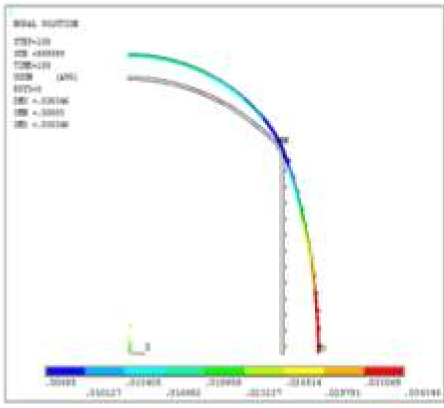
SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
470	104.30	105	3	882
471	104.45	105	4	883
472	104.67	105	5	884
473	105.00	105	6	885
474	105.10	106	1	886
475	105.20	106	2	897
476	105.30	106	3	898
477	105.45	106	4	902
478	105.60	106	5	907
479	105.82	106	6	908
480	106.00	106	7	909
481	106.10	107	1	910
482	106.20	107	2	917
483	106.30	107	3	920
484	106.45	107	4	921
485	106.67	107	5	922
486	107.00	107	6	931
487	107.10	107	1	932
488	107.20	108	2	952
489	10730	108	3	953
490	107.45	108	4	955
491	107.67	108	5	962
492	107.90	108	6	964
493	108.00	108	999999	986

5.11.2 Deformation Plots at the Converged and Diverged Results

•Figure 5.37 shows the Comparison of Deformed Plots between Burst Pressures of Converged and Diverged result.
•At convergent result the maximum displacement is found to be 0.034869 m.
•At divergent result the maximum displacement is found to be 0.036346 m.



Converged result at 107.9bar



Diverged result at 108bar
So, burst pressure=108bar

Von-Mises Stress Plot at 107sec (Converged Solution)

• At the time of 107sec, for the burst pressure of 107bar, Von-Mises contour is shown in Figure.
• Maximum stress is found to be 583MPa and is observed at the mid of tank.

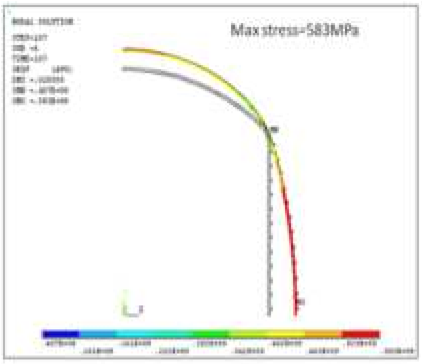


Figure: Von-Mises Stress

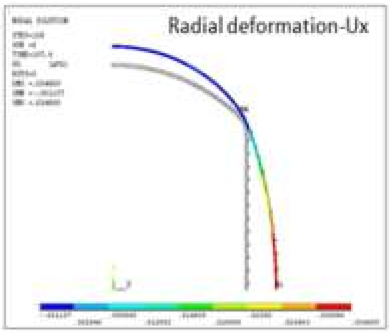


Figure: Radial Deformation

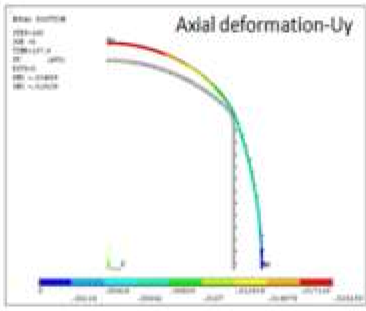


Figure: Axial Deformation

Radial and Axial Deformation Plots at 107.9sec

• The radial and axial deformation plots at the burst pressure of 107.9bar at 107.9sec.are shown in Figure.
• The radial deformation is found to be 0.034869 m
• The axial deformation is found to be 0.034869 m

Radial Deformation Vs Displacement

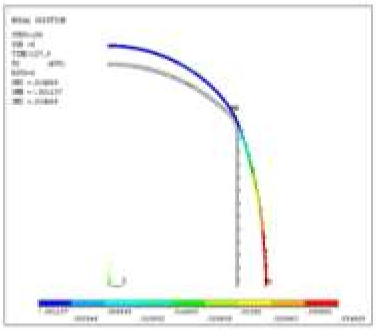
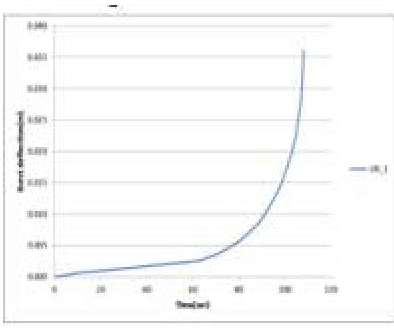
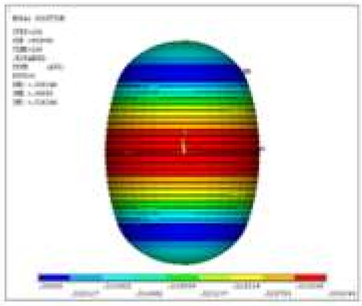




Figure: Radial Deformation vs Displacement/Figure: Burst Deflection Vs Time/ Figure: Deformation plot

•The radial deformation over time for the highlighted node is shown in Figure 5.42
•It can be observed that elastic behavior can be seen up to 60bar.
•After 60bar, huge increase in deformation can be noted for every 1bar increase in pressure because of the plasticity behavior.
•Highlighted location is going fail the component at 108bar.

Comparison of Failure Locations

•From the simulation result, it is seen that maximum deformation occurs at the midpoint of the cylinder which is sensible.
•After increasing the strength of cylinder also, failure location is not changed.

5.12 Iteration3: "35 liters" Cylinder (with stiffeners)

5.12.1Geometry of Cylinder with Circumferential Stiffeners

•Six circumferential stiffeners of 2mm thick over 360degrees are created on the outer surface of cylinder.
•This strengthens the cylinder and burst pressure capability increases.

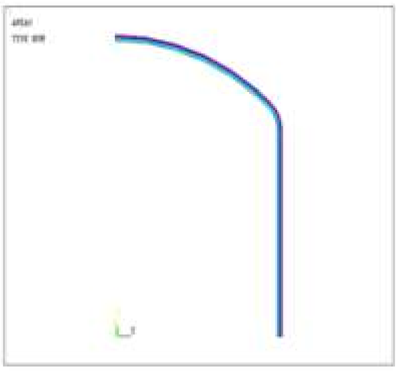


Figure: Geometry of Cylinder with Radial Stiffeners

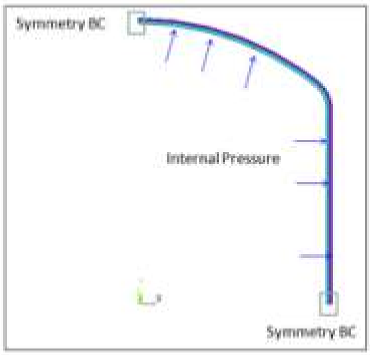


Figure: Boundary Conditions

Boundary Conditions

•The boundary conditions used for the analysis is shown in Figure 5.47
•By applying symmetry Boundary Conditions on both sides, models are self constrained and no need to apply any more constraints.

- Internal pressure is applied as a transient load and will be increased in the simulation transiently.
- Initial value of initial pressure=1bar

Results of "35 liter" Tank Analysis

Understanding of Burst Pressure from Convergence Issue

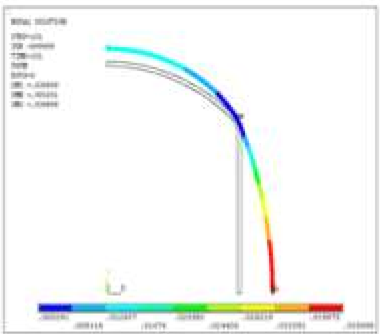
- Convergence error in solution occurred at 100.875bar.Means Burst pressure is 100.9bar. from ANSYS
- Structural results at 100.77bar are given in the Table.

Table 5.7 Structural Results at100.77 bars

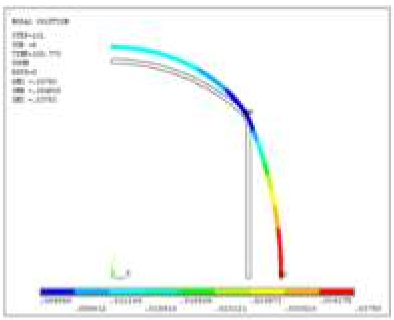
SET	TIME/FREQ	LOAD STEP	SUBSTEP	CUMULATIVE
440	97.300	98	3	942
441	97.450	98	4	943
442	97.675	98	5	944
443	98.000	98	6	945
444	98.100	99	1	946
445	98.200	99	2	955
446	98.300	99	3	956
447	98.450	99	4	957
448	98.675	99	5	958
449	99.000	99	6	959
450	99.100	100	1	960
451	99.200	100	2	972
452	99.300	100	3	973
453	99.450	100	4	974
454	99.675	100	5	975
455	100.00	100	6	976
456	100.10	101	1	977
457	100.20	101	2	995
458	100.30	101	3	996
459	100.45	101	4	998
460	100.67	101	5	1000
461	100.77	101	6	1046
462	101.00	101	999999	1068

Deformation Plots at the Converged and Diverged Results

- Figure 5.48 shows the Comparison of Deformed Plots between Burst Pressures of Converged and Diverged result.
- At convergent result the maximum displacement is found to be 0.039699 m
- At divergent result the maximum displacement is found to be 0.03783 m



Converged result at 100.9bar



Diverged result at 100.77bar
So, burst pressure=100.77bar

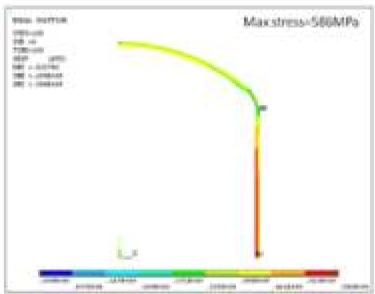


Figure: Von-Mises Stress

Figure: Comparisons of Deformed Plots between Burst Pressures Of Converged and Diverged result

Von-Mises Stress Plot at 100.7sec (Converged Solution)

- At the time of 100.7sec, for the burst pressure of 100.7bar, Figure 5.49 shows the Von-Mises contour.

• Maximum stress is found to be 586MPa and is observed at the mid of tank.

Radial and Axial Deformation Plots at 100.7sec

• The radial and axial deformation plots at the burst pressure of 85.925bar at 85.925sec.are shown in Figure.

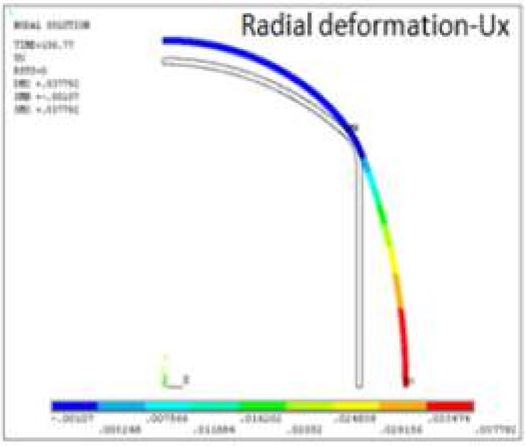


Fig: Radial Deformation

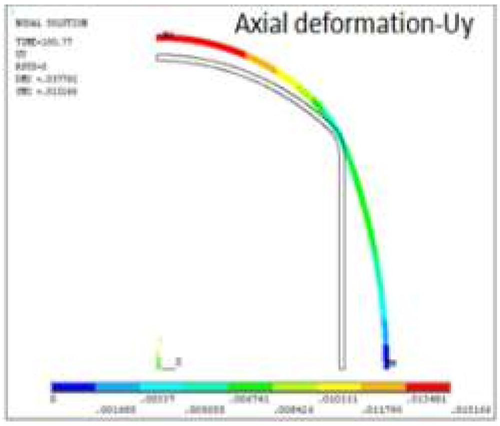
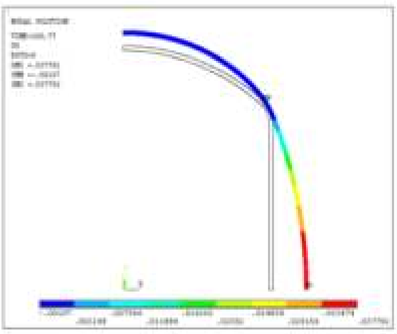
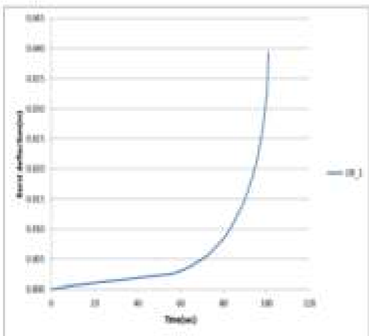


Figure: Axial Deformation

• The radial deformation is found to be 0.037792 m
• The axial deformation is found to be 0.037792 m

Radial Deformation Vs Displacement





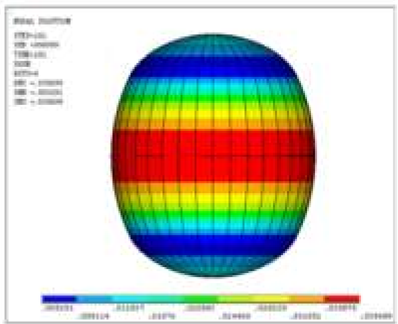


Figure: Radial Deformation vs Displacement/Figure: Burst Deflection Vs Time/ Figure: Deformation Plot

• The radial deformation over time for the highlighted node is shown in Figure 5.53
• It can be observed that elastic behavior can be seen up to 60bar.
• After 60bar, huge increase in deformation can be noted for every 1bar increase in pressure because of the plasticity behavior.
• Highlighted location is going fail the component at 100.9bar

Comparison of Failure Locations

• From the simulation result, it is seen that maximum deformation occurs at the midpoint of the

cylinder which is sensible.
•After increasing the strength of cylinder also, failure location is not changed.

CONCLUSION

•Comparison results are closely matching with the results obtained from the paper and the experimental results. Hence, the method adopted in this FE Analysis is correct and true.
•From the FEA analysis the fallowing conclusion can be made,
•Using nonlinear method (material properties) can gives the close results as that of experimental results. Hence, gives option for experimental analysis in the future analysis.
•Introducing the radial stiffeners with 6 numbers will increase the bursting pressure for the same thickness and capacity.
•Introducing the radial stiffeners with 12 numbers will further increase the bursting pressure for the same thickness and capacity.
•Design iteration with circumferential stiffeners also yields better results.
•Hence, these methods are best suited for twin application that is it can be used for low pressure and high pressure applications.

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