Design and failure analysis of cylindrical shells due to explosive loads.

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Abstract. Metal cylindrical shells are widely used to store and transport highly hazardous chemicals and used as pressure vessels and pipelines. These structures can be subjected to explosive loads to accidents, terrorism, or military actions. The design of the cylindrical shell is to be done to resist the internal explosive pressures. This paper is viewed on the design of the cylindrical shell which can be used in real life applications to resist the internal pressure caused due to explosion of the fluid in it. The design process involves the determination of explosive loading, structural analysis, selection of appropriate material and the dimensions of the shell. The shell design is conducted in CATIA modelling software. The failure analysis of the cylindrical shell is conducted on the ANSYS 2021 R2 to determine the deformations and the stresses developed in the structure. By varying the shell geometry and load acting, the structural analysis is conducted.

Keywords: Cylindrical Shell, explosion pressure, explosive loading, structural analysis, CATIA, ANSYS 2022 r2, deformations and stresses.

1 Introduction

A cylindrical shell is a structural element that is used in a variety of applications including pressure vessels, storage tanks, pipelines, and columns. It consists of a long, hollow cylinder with closed ends and can be made from a variety of materials including metals and composites. When the cylindrical shell is subjected to explosions, there will have wide state of damage and destruction. In petrochemical field, pressure vessels often operate under high temperature and high pressure. In the event of sudden failure, the internal inflammable medium may explode. To resist the explosive, proper design characteristics are required.[1]

The design of the cylindrical shell involves determining the appropriate dimensions, material and the thickness of the shell required to withstand the loads and stresses. The loads and stresses that a cylindrical shell may experience include internal pressure, external pressure, bending, torsion and thermal expansion and contraction. One of the key considerations in the design is the material selection.[3] The material selection may be influenced by factors such as cost, availability, and environmental considerations. In addition to the material selection, another factor which influences the design is thickness of the shell.

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The thickness of the shell must be sufficient to withstand the loads and stresses, but not so thick as to be excessively heavy and expensive. Overall, the design of a cylindrical shell is a complex process that requires careful considerations of a wide range of factors.[2]

Wen-Sheng Mao[1], Ming-shou Zhong[2] et al. studied the dynamic response of the pressurized thin-walled cylindrical shell tube subjected to underwater explosion. They experimented the cylindrical tube with different internal pressures and wall thickness and carried out the numerical simulation in LS-DYNA finite element software. Steeve Chung Kim Yuen[1], Gerald N. Nurick[2] et al. presented a series of experimental and numerical results on cylindrical shells subjected to external blasts. The resulting impulse of the blast produce failure ranging from large inelastic deformation of the cylindrical shell to tearing of the structure and numerical simulations are carried out in ANSYS/AUTO DYN. Yan Li[1], Wen Wang[2] et al. made an innovative failure criterion considering the time effect is proposed for cylindrical metal shell under explosive loading. The results give the failure pressure equation of the shell subjected to explosive load. Huang Z[1], Yu x[1] et al. studied to analyse the explosive fracture process of the cylindrical shell at various detonation pressures. When the pressure decreases, the cylindrical shell fracture changes from pure shear to tensile shear.

Fig 1. Cylindrical Shell [6]

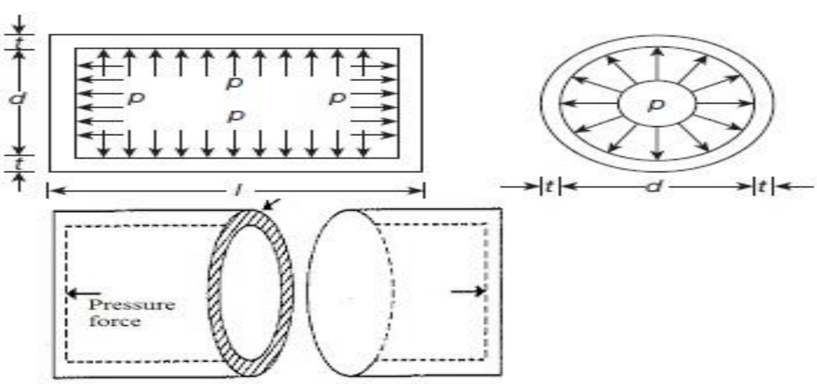

Fig 2. Stresses in cylinder subjected to internal pressure [7].

2 Methodology

The design of the cylindrical shell due to explosive loading involves several factors that are ensured to withstand the failure of the shell. The key factors that are considered in designing the cylindrical shell.[4]

- **a) Shape and size of the shell:** The shape and size of the shell are important factors in determining the strength and resistance to deformations.
- **b) Material properties:** The material properties of the shell, such as strength, toughness and ductility are essential in withstanding the explosive load.[4]
- **c) Explosive load:** The magnitude of the explosive force that the shell can withstand is the critical factor in determining the thickness.
- **d) Analysis:** The failure analysis on the cylindrical shell is conducted to determine the stress and deformation such that the maximum thickness it can be resisted is determined by applying the internal explosive load.[4]

2.1 Material selection

There are so many materials have been used in fabrication of cylindrical shells. The selection of the material will be based on the appropriate design standards. The selection of material which tells the ability of shell with maximum allowable stress. The material that is used for the fabrication of the cylindrical shell should contain the following properties.

- High tensile strength and yield strength
- High toughness
- Good corrosion resistant
- Good machinability
- Good weldability

In this project the material that is used in fabrication of the shell is Maraging steel. The composition of maraging steel is.[7]

Type	Yield strength (0.2% proof stress) MPa	% Alloy content				
		Ni	Co	Mo	Ti	Al
18Ni1400	1400	18	8.5	3	0.2	0.1
18Ni1700	1700	18	8	5	0.4	0.1
18Ni1900	1900	18	9	5	0.6	0.1
18Ni2400	2400	17.5	12.5	3.75	1.8	0.15
17Ni1600(cast)	1600	17	10	4.6	0.3	0.05

The specifications of the maraging steel [18Ni1700] are.

- Ultimate tensile strength = 2200MPa
- Nominal yield strength = 1700 MPa
- Young's modulus = 210 GPa
- Elongation at break = 15%
- Fracture toughness = 175 MPa
- Density = 8100 kg/m^3

2.2 Designing the shell:

The cylindrical shell is designed by using the modelling software CATIA. The shell was designed based on the required dimensions of length, diameter, and thickness of the cylinder and the structure of the cylinder.

The structure of the shell used in the design of the cylindrical shell is elliptical shaped cylindrical shell.

The specifications of the shell are.

Type	Elliptical shaped
Orientation	Horizontal
Shell length	4800 mm
Inside diameter	1400 mm
Shell thickness	54 mm
Nozzle diameter	205 mm
Nozzle thickness	12 mm

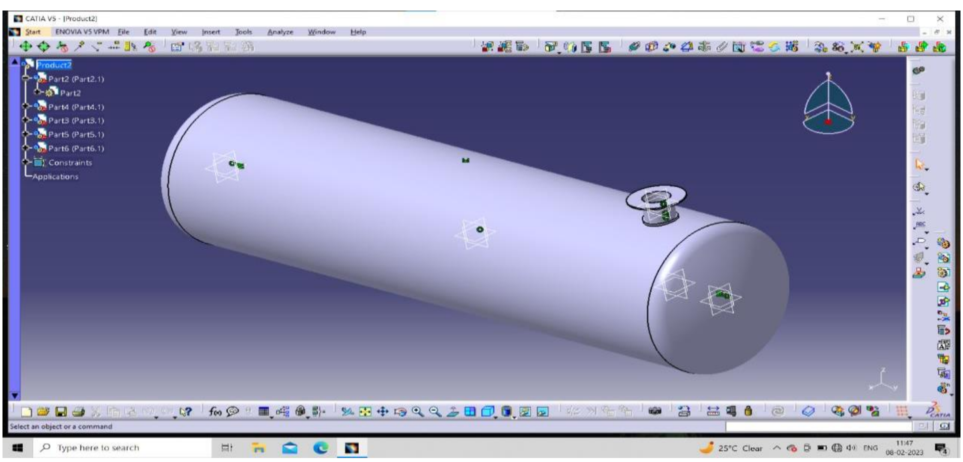

Fig 3. Cylindrical shell assembly

2.3 Theoretical Design characteristics

When the cylindrical shell is subjected to explosive loading (internal pressure), there will be development of stresses in three directions namely circumferential, longitudinal and radial direction. As we are designing the thin cylindrical shell, we neglect the stress developed in radial direction. And there will be some deformation in the structure of the shell and deformation can't be calculated by theoretical methods and it is analysed in ANSYS software.

Here are the formulas to find the stress induced in the shell when internal explosive pressure is acted.[4]

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1. In circumferential direction. (Hoop stress)

   $\sigma_c = p(r_1^2 + r_2^2)/(r_2^2 - r_1^2)$

2. In longitudinal direction.

   $\sigma_l = r_1^2\, p / (r_2^2 - r_1^2)$

where p= internal explosive load

r_1= Internal radius of the shell

r_2= External radius of the shell

Here we consider stress in circumferential direction because if the explosion occurs, impact will be more in circumferential direction. If the circumferential stress reaches the ultimate tensile strength of the material, the cylindrical shell will explode.

2.4 Loading and Boundary conditions

The analysis has been conducted on the cylindrical shell by applying explosive pressure inside it by fixing the two ends as fixed supports as boundary conditions. In this loading condition, the cylindrical shell is subjected to internal explosive pressure of 100 MPa. In fig 8, we can see the arrow is striking outside which means that pressure acting on the internal surface.

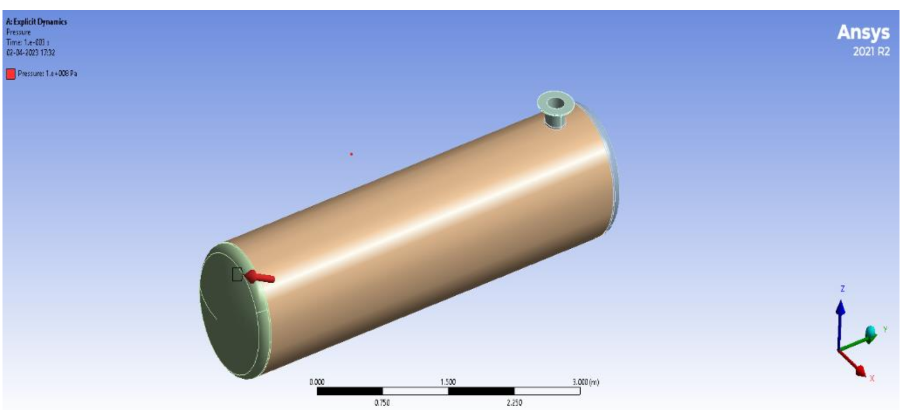

Fig 4. Shell subjected to internal pressure.

2.5 FEA Analysis

The analysis on the cylindrical shell is carried out in ANSYS 2021 R2 FEA software to determine the failure characteristics of the shell by adding the internal explosive pressure in the cylinder which determine the maximum stress and total deformation of the shell.

2.5.1 Total deformation of the shell

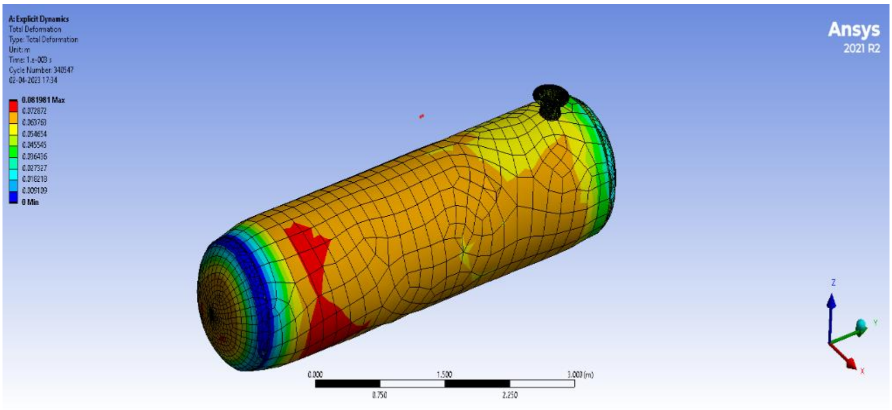

Fig 5. Deformation of the shell.

When the explosive pressure is subjected internally on the cylinder, the maximum deformation that the shell is exhibited is 0.0819 m. Here we can observe the deformation characteristics on the shell in the above figure 5.

2.5.2 Stress induced in the shell.

The maximum stress induced in the shell when the explosive pressure of 100 MPa applied is 1549 MPa. Here we can get the stress plot from the below figure 6.

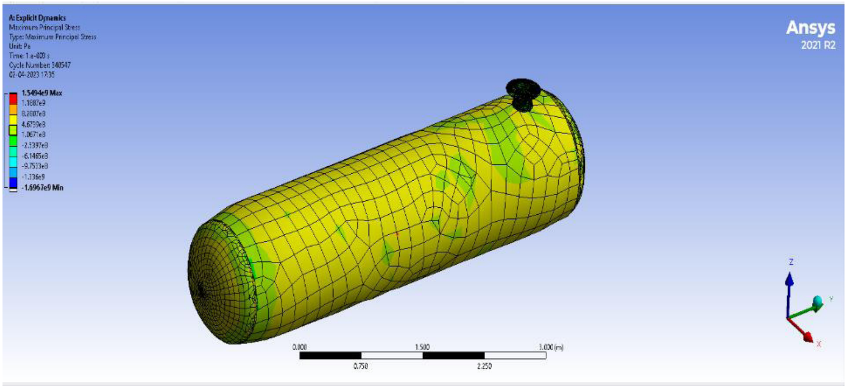

Fig 6. Stress plot of the shell.

3 Results of FEA analysis

When the cylindrical shell is subjected to internal explosive pressure with various pressure values, the stress plot of the shell is achieved, and they are noted down in the below table. And the stresses occurred when the solving the theoretical equations are noted down in the table. The respected deformation values of the shell when subjected to internal explosive pressure are noted down.

Table 1. Data of stress values at different explosive pressures

S.no	Explosive pressure (MPa)	Deformation (m)	Principle Stress (MPa)	Circumferential Stress (MPa)	Axial stress (MPa)
1	10	0.009	246	135	62
2	20	0.017	367	269	125
3	40	0.035	592	539	249
4	60	0.053	856	808	374
5	80	0.068	1178	1078	499
6	100	0.081	1549	1348	624
7	120	0.087	1652	1617	748
8	140	0.096	1893	1887	873
9	150	0.101	2034	2022	936
10	170	0.109	2293	2291	1060

From the above table we can conclude that the failure of the cylindrical shell which is made of maraging steel will occur at the pressure between the 170 MPa. Because the stress obtained by the FEA analysis and Theoretical calculation will result that they are exceeding the ultimate yield strength of the material i.e., 2200 MPa.

3.1 Comparison of FEA results with theoretical calculations

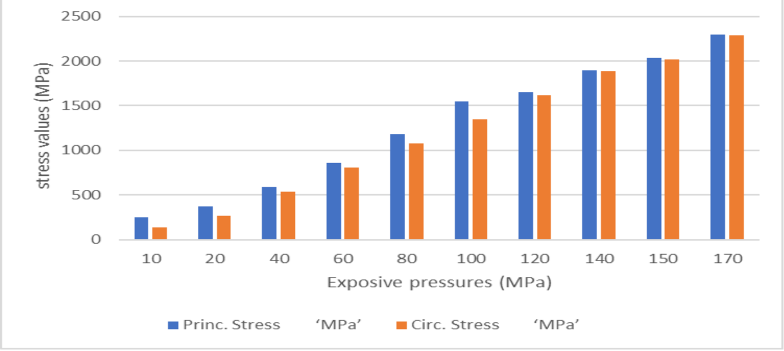

Fig 7. Comparison of FEA results with theoretical results

4 Conclusion

In this paper, the design and failure analysis of the cylindrical shell due to explosive loading was studied. Firstly, proper material is selected for the fabrication of the shell based on the requirements needed to resist the impact of the explosive load. Then the appropriate dimensions are determined. When the internal explosive pressure is applied on the shell, the deformation of the shell and the stress induced in the shell are determined by the FEA software called ANSYS 2021 R2 and they are compared with the theoretical calculations and the material properties. In this we have observed that the stress that are obtained from FEA analysis and theoretical calculation is less than the material nominal yield strength. So, we observed that the cylindrical shell with proposed parameters can withstand the designed explosive pressures up to 100 MPa. And we can observe that the failure of the cylindrical shell will occur if the explosive pressure load is more than 170 MPa as the principal stresses exceeds the ultimate tensile strength of the maraging steel. Overall, the design of the cylindrical shell under explosive loading is a multi-disciplinary approach and requires a deep understanding of principles of mechanics and material science. It is crucial to prioritize the safety and security in the design process to ensure the protection of public and infrastructure.

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