Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 9, No.1, September : 2024

STATIC ANALYSIS OF PRESSURE VESSEL THROUGH ANSYS

Deepak Prajapat, Harshita Soni, Emarti Kumari, Department of Mechanical Engineering, MBM University, Jodhpur, 324011, Rajasthan, India

Abstract
The main objective of this article to study the static characteristic of pipe modelled as pressure vessel using finite element based commercial software ANSYS. The pipe is modelled using SOLIDWORKS and structural analysis and thermal analysis would be performed through ANSYS workbench. The ratio of diameter to thickness (d/h) is greater than 20, here pipe considered as moderately thick structure. The pipe is open ended cylinder subjected radial internal pressure and thermal load: due to pressure radial and hoop stress are generated and for thermal analysis cylinder is subjected to thermal load. The primary focus is on calculating of hoop stress, radial stress, and shear stress to assess the structural integrity of the pipe under radial pressure.
Keywords: Pressure Vessel; *ANSYS*; Open Shell; Radial Stress, Hoop Stress; Thermal Stress.

1. Introduction

Pipes are integral components in various engineering applications such as pressure vessels, pipelines, heat exchangers, boilers, etc. [1-2]. These structures subjected to internal pressure due to the fluid transport. The bending behavior of these structures under radial pressure is crucial for ensuring safety and reliability in engineering designs [3]. A pressure vessel is composed of the following main types of components: shell, head and nozzles. The shell is the primary component that contains the pressure and forms a structure that has rotational axis. In this study, authors considered a pressure vessel to analyze the bending characteristics of a pipe using ANSYS and compared the numerical results with analytical results [4]. Here authors calculated the hoop stresses, which are crucial for evaluating the circumferential integrity of the pipe. Radial stresses were examined to understand the deformation in the radial direction, while shear stresses were investigated to assess material failure potential. ANSYS was chosen for its robust capabilities in simulating complex structural scenarios. The results obtained from the analysis provide valuable insights into the performance of the pipe under internal radial pressure. These findings contribute to the broader understanding of pressure vessel behavior, with potential applications in industries such as petrochemical, aerospace, and defense industries. This research emphasizes the significance of accurate stress analysis in ensuring the structural reliability of pipes functioning as pressure vessels. The presented methodology and results can serve as a foundation for further research in optimization, safe and reliable design of pressure vessels.

Thermal stress analysis plays a pivotal role in the design and assessment of pressure vessels. When subjected to thermal loads, pressure vessels experience temperature gradients that induce thermal stresses. These stresses arise due to the differential expansion or contraction of the vessel material, which can lead to significant deformations, fatigue, and, in severe cases, failure. [5] The study of thermal stress analysis in pressure vessels involves understanding the distribution and magnitude of stresses induced by temperature changes. In this paper, we focus on the thermal stress analysis of an open pressure vessel. Open pressure vessels, unlike closed ones, have openings that add complexity to the stress distribution and thermal response. The analysis involves both analytical and numerical methods, with finite element analysis (FEA) [6]. Recently, static and dynamic analysis of thin-walled structures has been carried by [7-15] under mechanical and thermal load. Thermal stress analysis has been carried out for pressure vessel with different temperature conditions.

2. Methodology:

2.1 Pressure Vessel Subjected Mechanical Load

A thick-walled cylinder, subjected to internal or external fluid pressure, has both radial and tangential stresses. The longitudinal stress may also be present, but this stress is insignificant in magnitude.

If external pressure is zero and $p_i$internal pressure is applied inside the vessel. Let R_o is outer diameter and $R_i$is internal diameter and r is the distance where stress is going to be calculate. $\sigma_r$and $\sigma_t$are radial stress and hoop stress respectively. Equations will be for calculating stresses:

$$\sigma_r = \frac{p_i R_i^2}{R_0^2 - R_i^2}\left(\frac{R_0^2}{r^2} - 1\right) \quad (1)$$

$$\sigma_t = \frac{p_i R_i^2}{R_0^2 - R_i^2}\left(\frac{R_0^2}{r^2} + 1\right) \quad (2)$$

In above equations, σ_t is positive when tensile and σ_r is positive when compressive. Further it should be noted that σ_t is tensile when $p_i > p_o$ or p_o is zero.

The hoop stress σ_t for thick vessel, subjected to p_i only, is maximum at the inner surface, and is:

$$(\sigma_t)_{\max} = p_i\left(\frac{R_0^2 + R_i^2}{R_0^2 - R_i^2}\right) \quad (3)$$

Maximum shear stress in the wall:

$$\tau_{\max} = \frac{p_i R_0^2}{R_0^2 - R_i^2} \quad (4)$$

The maximum shear stress theory gives $\tau = 0.5\sigma_t$, and we get

$$\sigma_{t_{\max}} = \frac{2 p_i R_0^2}{R_0^2 - R_i^2} \quad (5)$$

The above equation is based on the maximum shear stress theory and can be used for ductile material [1].

2.2 Pressure Vessel under Thermal Load

The basic equation for thermal stress is simple but become increasingly complex when subjected to variables such as thermal gradients, transient thermal gradients, logarithmic gradients and partial restraint. The basic equation is written as follows:

$$\sigma = -E\alpha(T_2 - T_1) \quad (6)$$

Where; T_1= Initial temperature; T_2= New temperature; α = thermal expansion coefficient; ν = Poisson's ratio.

If the temperature of a unit cube is changed from T_1 to T_2 and growth of the cube is restrained; Since, in thermal stress analysis, temperature T_2 is taken higher than T_1 i.e. $T_2 > T_1$, σ is compressive nature (expansion) [1].

Boundary condition: The shell is restricted only in one direction but free to expand in other direction: $u_r = u_\theta = w_z = 0$ at $z = 0$ or $L = 0$.

3. Material Description

Firstly, developed three-dimensional model of piston through SOLID WORKS as shown in Fig. 1 considering the following geometric properties:

- Outer diameter of vessel = 60mm
- Inner diameter of vessel = 40mm
- Length of vessel = 100mm

Fig. 1 Schematic representation of geometry of pressure vessel

Then after, developed SolidWorks model is imported to Ansys Workbench and after assigning material property as given Table 1. The material selected for analysis is structural steel.

Table 1 Material property of Structural steel

Density	7850 kg m^-3
Young's Modulus	200GPa
Poisson's Ratio	0.3
Tensile yield strength	250MPa
Coefficient of thermal expansion	1.2×10^{-5} /°C

To analyse the modelled pressure vessel discretised by using eight-node brick element having element size of 2 mm with 19750 elements and 92193 nods as shown in **Fig. 2.**

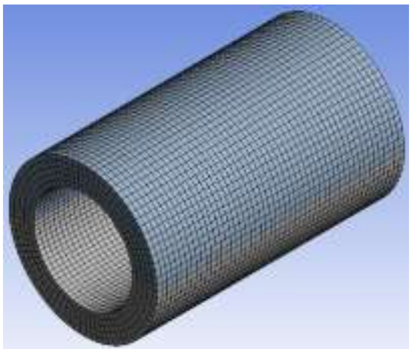


Fig. 2 Discretization of pressure vessel

4. Result and discussion

Boundary conditions are defined as load and for static structural analysis and thermal stress analysis, is shown in **Fig 3.** Study of static load conditions on vessel applied the radial pressure 30 MPa which act inside the surface of vessel and second one is the displacement boundary condition which is applied on both open sides of the vessel and study of thermal load on vessel are 100, 200, 300, 400℃ . Displacement support is applied in such a way that according to polar coordination system, change in behaviour of the vessel in the *y* and *z* direction is restricted and along the *x*-axis, changes of material's behaviour of vessel can be observed during loading condition. Direction deformation, radial stress, hoop stress, hoop and radial path stress maximum shear stress are identified for the vessel. These all values are presented in Fig. 3 for clear understating. Here, considered the clamped-clamed boundary conditions: $w_z = 0$ along *z*-axis at $L = 0, l$.

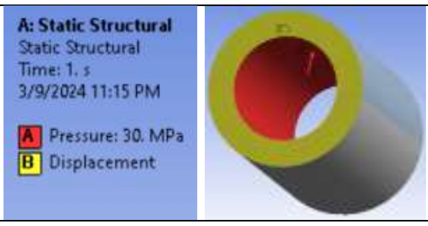
Mechanical Load	**Thermal Load**
	

Fig. 3

4.1 Directional deformation

The directional deformation is oriented on *x*-axis according to the polar coordination system. Maximum and minimum deformation of the vessel which values is given in **Table 2.** With red colour is presented the maximum value of deformation of the vessel and with the blue colour minimum directional deformation of the value as shown in **Fig. 4.**

Table 2.

Directional Deformation	
Orientation	*x*-axis
Minimum	6.5519e-003mm
Maximum	8.2681e-003mm

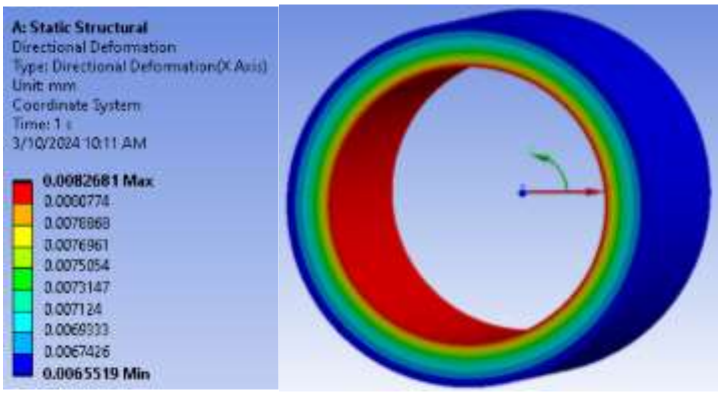


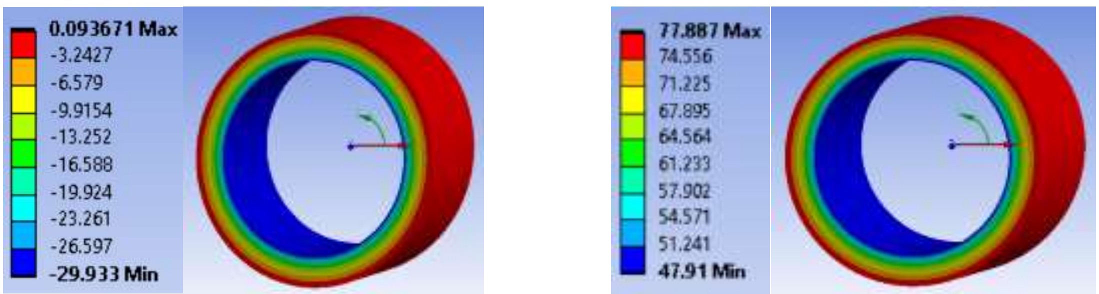
Fig. 5 Deformation of vessel under radial pressure

4.2 Radial and hoop stress:

Design pressure is applied on the inner walls of the vessel considering clamped-clamped boundary conditions. The minimum and maximum value of the radial and hoop stresses of the vessel according to the *x*-axis and *y*-axis orientation is given in **Table 3**; respectively. Schematic distribution of radial and hoop stresses is presented in **Fig. 6**. Present numerical results are compared with analytical or theoretical results as given in **Table** 4, it is observed that present results match well with percentage of error is less than 1%.

Table 3. Radial and Hoop stresses

	Radial stresses	Hoop stress
Geometry	All bodies	All bodies
Orientation	X-axis	Y-axis
Minimum	-29.933 MPa	47.91 MPa
Maximum	9.3671e-002 MPa	77.887 MPa
Average	-	60.432 MPa



(a) Radial stress distribution (b) Hoop stress distribution

Fig. 6 Distribution of radial and hoop stresses of pressure vessel under radial pressure

Table 4. Comparison of radial and hoop stress with analytical results and the percentage of error for the analytical and numerical results.

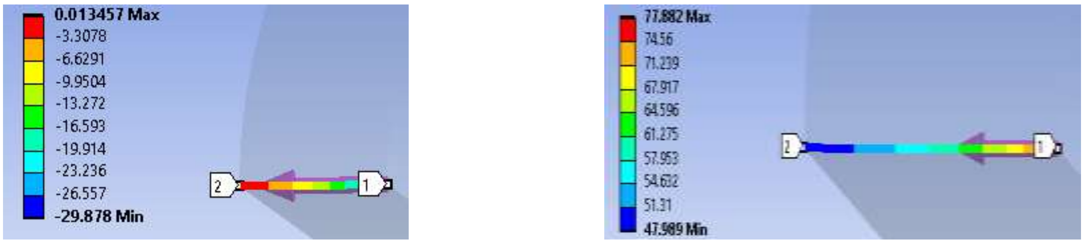
Stress		**Theoretical (MPa)**	**FEA (MPa)**	**% Error**
Radial Stress	Maximum	0	0.093671	
	Minimum	-30	-29.933	0.223
Hoop Stress	Maximum	78	77.887	0.144
	Minimum	48	47.91	0.185
Shear Stress	Maximum	54	53.905	0.175

4.3 Normal stresses (Scoping method – Path, *x*-axis and *y*-axis)

In the **Table 5**, there are presented the minimum and maximum values of normal stresses for chosen geometry of the pressure vessel cylindrical body. The scoping method is a selected path of the cylindrical body with *x*-axis and *y*-axis orientation. Variation of radial path, *x*-axis and *y*-axis from internal diameter to external diameter of the pressure vessel can be seen in **Fig. 7 and 8**. Mesh convergence is presented in **Table 6** for radial stress, hoop stress and maximum shear stress.

Table 5. Normal stresses using scoping method

	Normal Stress	
Geometry	Path	Path
Orientation	X- axis	Y-axis
Minimum	-29.878 MPa	47.989 MPa
Maximum	1.3457e-002 MPa	77.882 MPa



Normal stresses (Path, *x*-axis) Normal Stresses (Path, *y*-axis)

Fig. 7 Normal stresses using scoping method

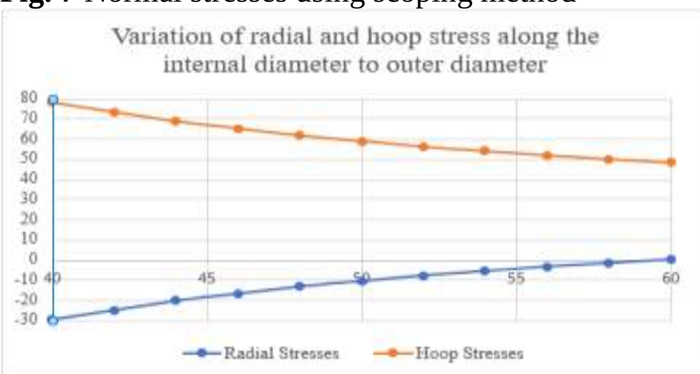


Fig. 8 Variation of radial and hoop stress along the internal diameter to outer diameter

Table 6. The effect of stresses while increasing the number of elements and order of the element

Element size (mm)	Statistical		Radial stress (MPa)		Hoop stress (MPa)		Maximum shear stress (MPa)
	Nodes	Element	Maximum	Minimum	Maximum	Minimum	
6	5070	884	0.7766	-30.346	77.934	47.256	54.099
4	15440	3000	0.31511	-30.049	77.891	47.696	53.937
2	92193	19750	0.093671	-29.933	77.887	47.91	53.905
1.5	216300	48307	0.049614	-29.974	77.947	47.953	53.957
1	675792	156000	0.022824	-29.98	77.968	47.978	53.973

4.4 Thermal stress

Material behaviour under different thermal load ΔT = 100°C, 200°C, 300°C, 400°C as presented in **Table 7**.

Table 7. Variation of stresses with change in thermal load condition.

<table>
<tr><th>Temperature (℃)</th><th>FEA Results</th></tr>
<tr><td>100</td><td>
</td></tr>
<tr><td>200</td><td>
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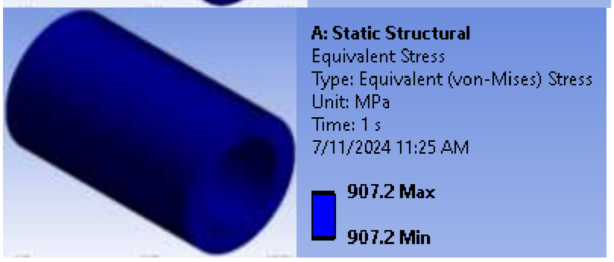
<tr><td>300</td><td>
</td></tr>
<tr><td>400</td><td>
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5. Conclusion

Here, studied the static characteristic of pipe modelled as pressure vessel using finite element based commercial software *ANSYS*. The ratio of diameter to thickness (*d/h*) is greater than 20, here pipe considered as moderately thick (d/h > 20). The pipe is taken open ended cylinder under radial internal pressure and thermal load; hoop stresses are generated due to pressure radial. Moreover, calculated the hoop stress, radial stress, and shear stress to assess the structural integrity of the pipe.

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