

Stress Analysis Of An Open-Ended Thick-Walled Cylinder

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Abstract:

This study focuses on the stress analysis of open-ended, thick-walled cylindrical structures using ANSYS 18.1 finite element software. The analysis was conducted on cylinders with wall thicknesses of 50 mm, 60 mm, and 70 mm, each having a uniform length of 600 mm and an internal diameter of 330 mm. Internal pressures of 70 MPa, 80 MPa, 90 MPa, and 100 MPa were applied during the simulations. The materials selected for the analysis included aluminium alloys (Al), magnesium alloys (Mg), tungsten alloys (W), and stainless steel (SS). The simulation outcomes for both radial and hoop (circumferential) stresses were compared against theoretical calculations, with discrepancies found to be under 1%, confirming the model's accuracy. Results showed that as internal pressure increased, the induced stress within the cylinder walls also increased. Among the materials examined, stainless steel exhibited the minimum deformation under load, whereas tungsten alloys achieved the highest safety factor. The study concludes that ANSYS 18.1 is a reliable and efficient tool for evaluating stress in thick-walled pressure cylinders.

Keywords: Thick walled cylinder, internal pressure, Radial stress, circumferential stress, Safety factors.

1. INTRODUCTION

Cylinders are employed in a variety of applications such as pressure vessels, containers, and pipelines that carry liquids, vapours, or gases at high pressures, often exceeding 50 psi. Storage tanks, boilers, and heat exchangers are examples of pressure vessels used in the petroleum refining and chemical pressure industries. The fluid pressure that is exerted in these cylinders is distributed evenly in all directions [1]. Stresses are accumulating on specific portions of the pressure vessel wall as a result of internal loading. Titanium, nickel alloys, stainless steel, carbon steel, aluminium, and hastelloy are the best materials for making pressure vessels. Open end cylinders and closed end cylinders are the two types of cylinders based on their end structure. To build a simple cylinder with a piston and pipes, open end cylinders are utilised. A tank, on the other hand, is an example of a closed end cylinder. Circumferential stresses or hoop stresses are included in open ended tubes due to fluid pressure. In the case of closed-ended vessels, longitudinal strains are generated [2].

Cylinders are classified into two categories based on their dimensions: thin walled cylinders and thick walled cylinders. If the thickness of the cylinder's wall is less than one-twentieth of its internal diameter, it is referred to as a thin walled cylinder, and if it is greater than one-twentieth of its internal diameter, it is referred to as a thick walled cylinder. When internal pressure is high, thick walled vessels are utilised, and when internal pressure is low, thin walled vessels are employed [13]. Thin cylinders are used to make materials with high yield strength, whereas thick cylinders are used to make materials with low yield strength. Pressure vessels are used to hold both liquids and gases at varying pressures that can be applied internally or externally. Deformations and strains in all directions occurred as a result of the cylinder's

substance [4]. So, important aspect of thick walled cylinder is design withstand of applied to pressure to reduce the deformations and stress.

In this present study about open end thick walled cylinder stress induced by using with different kind material and wall thickness is analyse by using methods of simulation and theoretical. Obtained results are comparing and find to deviation between simulation and theoretical methods. Through simulations, investigate the deformations, stress distributions for various materials. Finally, to determine the optimise design and materials for thick walled cylinder by using different internal pressures.

2. LITERATURE REVIEW

L. A. N. Wibawa et al. [1] evaluated the stresses induced in a thick-walled cylinder for a rocket engine case when subjected to internal pressure. This study was carried out using the finite element technique and the ANSYS software, using varying thicknesses (6, 7, 8, 9, 10mm) and pressures (2, 4, 6, 8, 10MPa). Used dimension of thick walled cylinder is 300mm length and inner diameter is 122mm. For simulation, the cylinder stresses created with various materials such as Aluminium 6061, Carbon Fiber Reinforced Polymer (CFRP), and Glass Fiber Reinforced Polymer (GFRP) were compared. Analytical and modelling techniques were used to validate the thick-walled cylinder hoop and longitudinal stress results. According to the obtained data, the safety factor for 6061 and Carbon Fiber Reinforced Polymer (CFRP) is more than one for all variations of internal pressure and thickness. For all pressure variations, the safety factor of 10mm thick Glass Fiber Reinforced Polymer (GFRP) is more than one. The amount of error between analytical and modelling approaches is less than 1%.

Ahmed F. Mohamed [3] investigated the stresses produced by a thin-walled cylinder using a basic finite element approach. The hoop and longitudinal stress, as well as the stress distribution throughout the thickness of a thin walled cylinder, were examined in this study. The thickness of the thin cylinder is 2.5mm, the internal diameter is 750mm, the length is 250mm, and the pressure in the cylinder is 7MN/m². According to the derived model findings, the optimal stress distribution in both the hoop and the longitudinal stress under pressure of a closed thin cylinder. Finally, it was determined that using a pressurised closed thin wall cylinder end with a flat plate was not advised.

Q. S. Masikh et al. [4] used C++ software to optimise the analysis of thin and thick pressure vessels. The maximum normal stress theory for brittle materials and the maximum shear stress theory for ductile materials are used to optimise the thickness and internal pressure of pressure vessels. The open end and closed end states of pressure vessels are evaluated using maximum strain theory and Birnie's equation. Birnie's equation, in particular, has been used for very high pressure gas and oil pipelines. According to the results, raising the internal pressure of the fluid requires increasing the thickness of the pressure vessels for both ductile and brittle materials. In various designs, the thickness of ductile material is smaller than that of brittle material. In both thin and thick cylinders with varying material qualities, the current result is similar to the curve of standard results. It was projected that material will benefit from optimization.

Baaji et al. [5] used theoretical and modelling to evaluate the hoop and longitudinal stresses of a spherical vessel under varied pressure and temperature loads. ABAQUS simulation software was used for the finite element model. The Von-mises yield criteria are used to determine the stress distribution, and equations are generated as a function of temperature and wall radius. The obtained FEM findings for transient temperature, stress, and displacements were compared to theoretical findings, and there is satisfactory agreement.

G Raju et al. [7] predicted stress in a thick-walled cylinder with and without a hole using elastic and elastic-plastic analyses. The finite element approach was utilised in this work, and the tools utilised for modelling, meshing, and analysis were CATIA and ANSYS, in that order. To determine the fatigue life of a cylinder with radial perforations using a Finite element model. Theoretically, MATLAB has been used to anticipate the stress behaviour of a material. Maximum von mises stresses of cylinders with and without holes are compared with regard to varying internal pressures.

El-SayedHabib et al. [8] used mathematics to conduct the FGM (Functionally Graded Material) thick walled cylinder stress and strain study. Benchmarking has been completed and compared to recent work in the same sector. The Hoop stress and longitudinal stress of a cylinder were calculated theoretically under mechanical and thermal loading conditions. To determine the stresses, the ANSYS programme utilised the Finite element Method. The resulting ANSYS simulation results were compared to theoretical

findings. This study recommended that the efficiency of cylinder stress distribution and an optimised model be created. Although the design of FGM cylinders is theoretically sound.

Alikarami et al. [9] investigated the FGM cylinder subjected to the combined influence of pressure and thermal loads with radial graded material and the elastic-plastic complied behaviour. Using ABAQUS/implicit simulation software, researchers predicted the elastic and plastic zones of radial, circumferential, longitudinal, and effective stresses of a cylinder with combined loadings. Finally, the simulated findings were compared to the theoretical findings, demonstrating the correctness of the study.

3. MATERIALS AND METHODS

In this analysis, thick walled cylinder has used to find out stress developed, when applied internal pressure (P_i) only and external pressure (P_o) is zero. Here thick cylinder open ends. Commonly, there are three type of stress are generate in the thick walled cylinder in each direction of cylinder [11]. Figure 1 shows the geometry of thick cylinder which is designed in model generator of ANSYS software. Figure 2 shows the meshed geometry of thick walled cylinder as per that obtained number of nodes is 3828 and number of elements is 616 which was done by static structural- mechanical solver in ANSYS. Table 1 shows the parameters used for analysis of this research work.

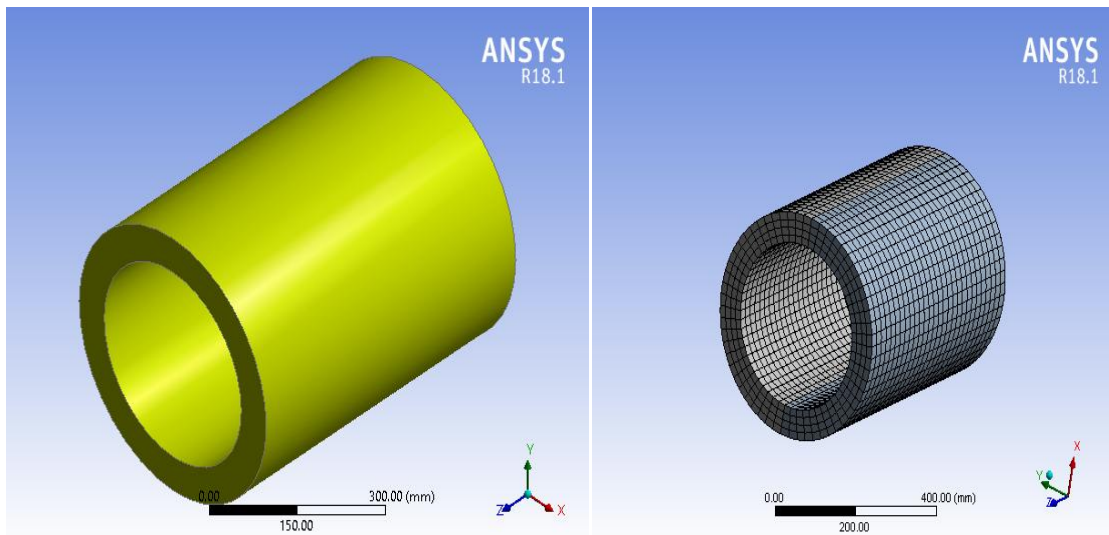


Fig. 1 Geometry of thick walled cylinder Fig. 2 Meshing of Geometry

Figure 4 shows the boundary conditions are applied by using ANSYS software. As per that displacement was employed both open end of cylinder faces and pressure is applied inner surface of cylinder [10]. For analysis displacement in X- axis free and both Y, Z-axis is zero are given values due to. Applied internal Pressure (P_i) is 70MPa.

In this analysis, for thick cylinder 4 types of materials used which structural steel, Aluminium alloy, Magnesium and Titanium alloys. Table 2 shows the materials properties using engineering data library in ANSYS workbench.

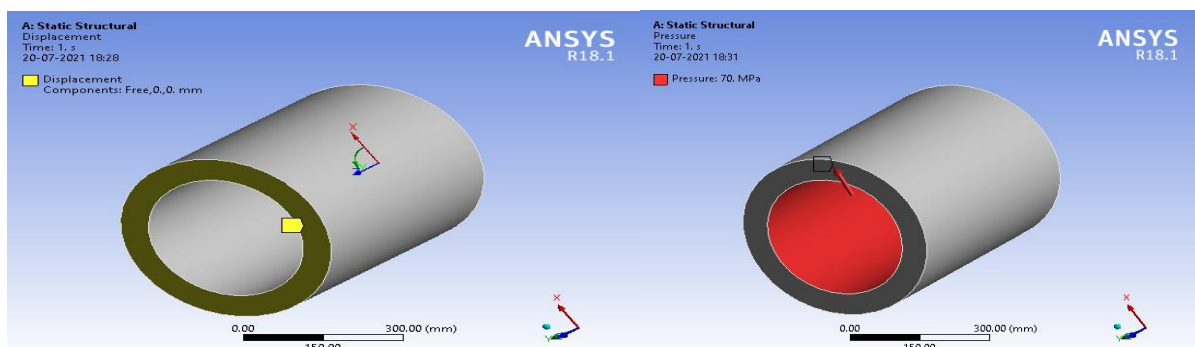


Fig.3 Boundary conditions applied using ANSYS software

Table.1 dimensions and specification of thick walled cylinder used

Parameters	Value
Inner Diameter (D _i)	330 mm
Thickness (t)	50, 60, 70mm
Length (L)	600 mm
Pressure (P _i)	70, 80, 90, 100MPa
No of Elements	6960, 6496, 6496
No of Nodes	33872, 31668, 31668

Table. 2 Material Properties

Material	Density	Poission Ratio	Young Modulus	Tensile Strength
Aluminium Alloys	2770 Kg/m ³	0.33	71000MPa	310 MPa
Magnesium Alloys	1800 Kg/m ³	0.35	45000MPa	255 MPa
Titanium Alloys	4620 Kg/m ³	0.36	96000 MPa	1070 MPa
Stainless Steel	7850 Kg/m ³	0.31	193000 MPa	586 MPa

3.1 Formulae used for theoretical Calculations

The following formulas, which are based on Lames' theorem of thick walled cylinder, are used for theoretical calculations. The stress in thick-walled cylinders has evolved in three directions: radial, circumferential, and longitudinal or axial stress. However, in this study, an open ended thick walled cylinder was utilised since longitudinal stress is negligible and only radial and circumferential stress exists [3]. And only inner pressure is applied throughout this work and outer pressure is zero.

Radial Stress

$$\sigma_r = \frac{p_i r_i^2}{r_o^2 - r_i^2} \left(1 - \frac{r_o^2}{r_i^2}\right)$$

Circumferential Stress

$$\sigma_c = \frac{p_i r_i^2}{r_o^2 - r_i^2} \left(1 + \frac{r_o^2}{r_i^2}\right)$$

Where,

p_i = internal pressure

r_i = internal radius of cylinder

r_o = outer radius of cylinder

4. RESULTS AND DISCUSSION

This section examined thick walled cylinder stresses, deformations, and safety factors using different wall thicknesses (50, 60, and 70mm) with varied internal pressures (70, 80, 90, and 100Mpa) in different materials (Aluminium, Stainless steel, Magnesium, and Titanium) using ANSYS 18.1 software. This section of the paper investigates radial, circumferential, and Von-Mises stresses. Also, the resulting simulated stress results were compared to theoretical stress findings.

4.1. Study of thick walled cylinder stresses

When using internal pressures, a thick-walled cylinder develops stresses such as radial, circumferential, and longitudinal stresses. However, in this work, an open end thick cylinder was chosen since the longitudinal tension (σ_l) is zero. In this study, only radial stress (σ_r) and circumferential stress (σ_c) are examined.

4.1.1. The effect of radial stress in a thick-walled cylinder

Figure 4-6 depicts the radial stress distribution of a thick-walled cylinder with varying thicknesses (50, 60, and 70mm) and internal pressures of 70, 80, 90, and 100MPa. According to the modelling results, the thickness of the wall is the same, but the internal pressure varies. When the internal pressure is raised, the hoop stresses increase [13]. Hoop stress has a negative sign since it occurs during compression of thick-

walled cylinders. As per the simulation outlines, the upper section of the cylinder has the most radial stress distribution while the inner portion has the least.

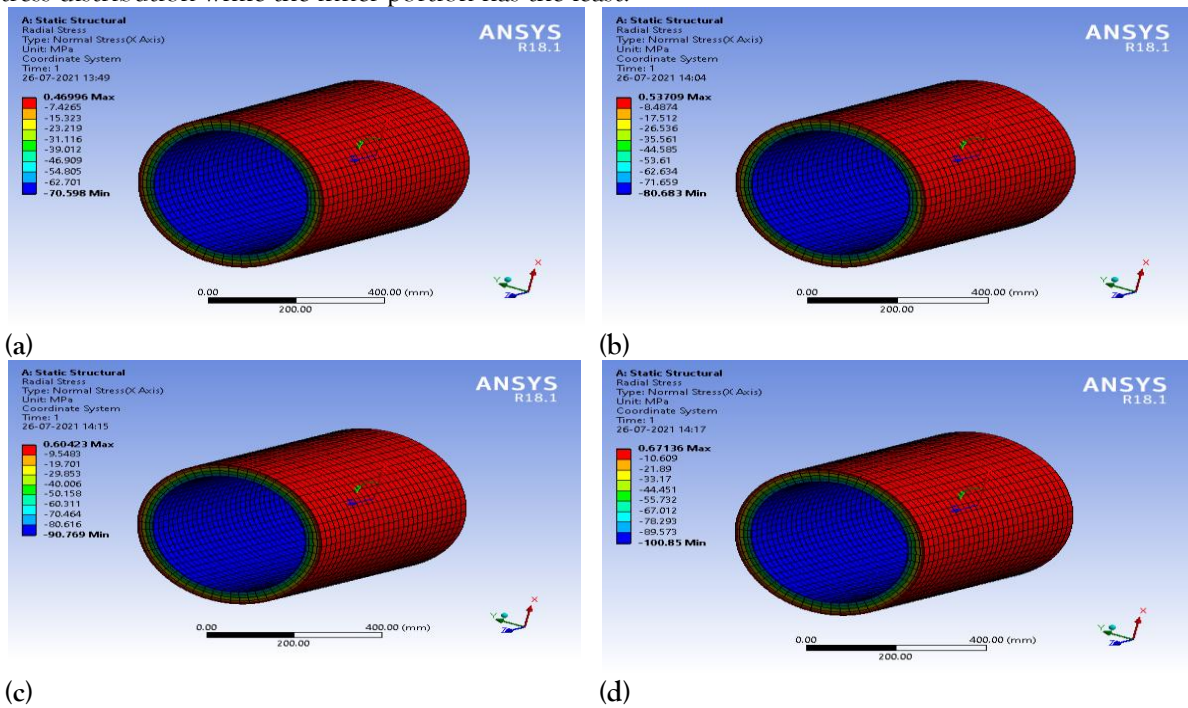


Fig. 4 Radial stress distributions of 50 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.

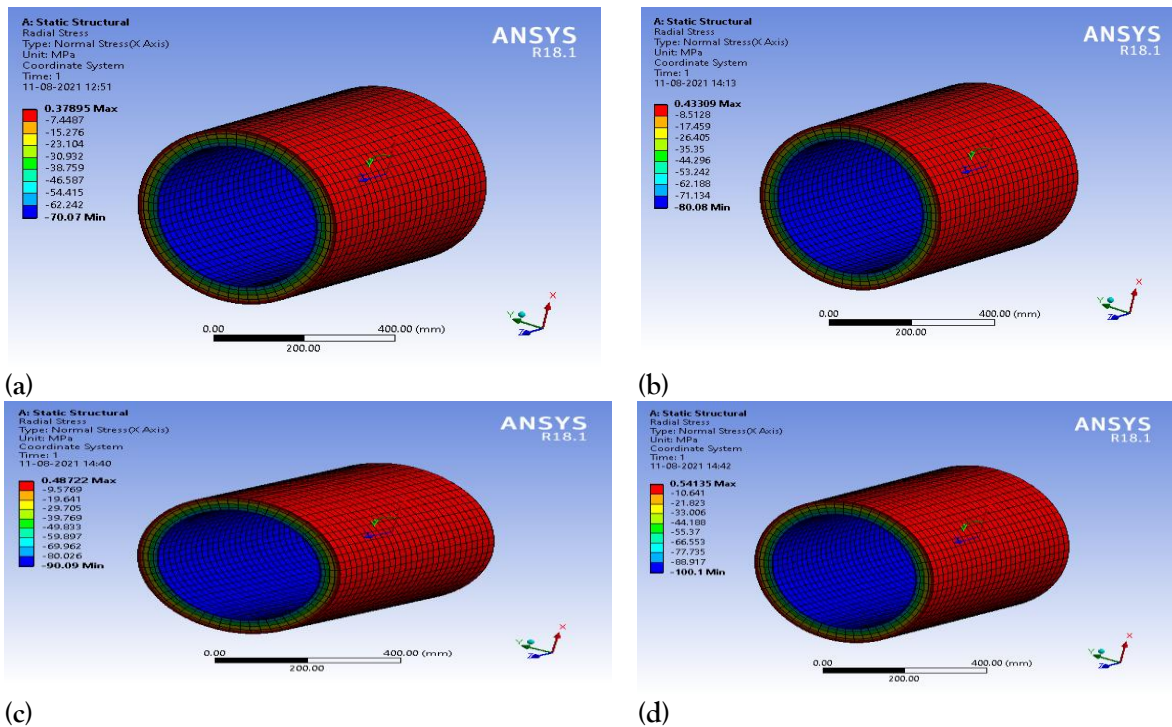


Fig. 5 Radial stress distributions of 60 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.

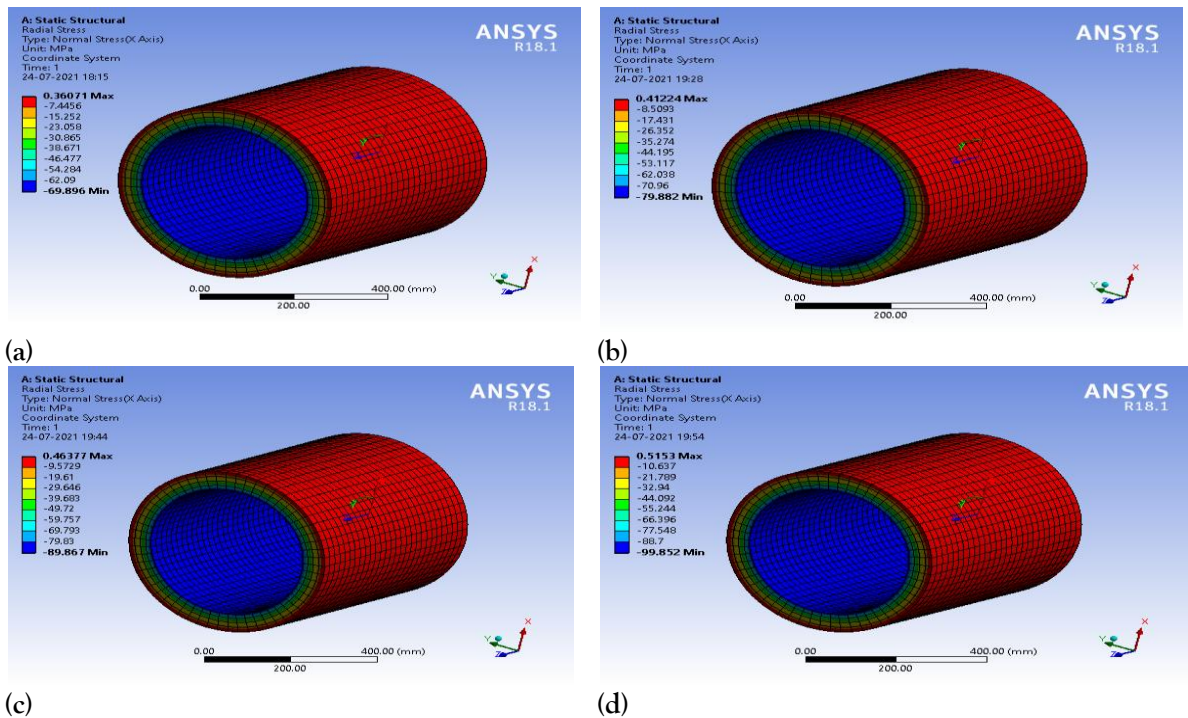


Fig. 6 Radial stress distributions of 70 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.

4.1.2. The influence of circumferential stress in a thick-walled cylinder

Figure 7-9 depicts the circumferential stress distribution of various thicknesses (50, 60, and 70mm) with simulated internal pressures of 70, 80, 90, and 100MPa. According to the simulation results, the stress distributions in circumferential directions are caused by tension when internal pressure is applied to the inside of the cylinder. So it is always positive sign value of stresses [8]. Maximum values of circumferential stress are consider to take analysis of thick walled cylinder. As per the simulated pictures displayed here, the stress distribution is lowest on the upper side and highest on the interior side of the cylinder. When raising internal pressure in the inner cylinder, stress increased across the thickness of the cylinder.

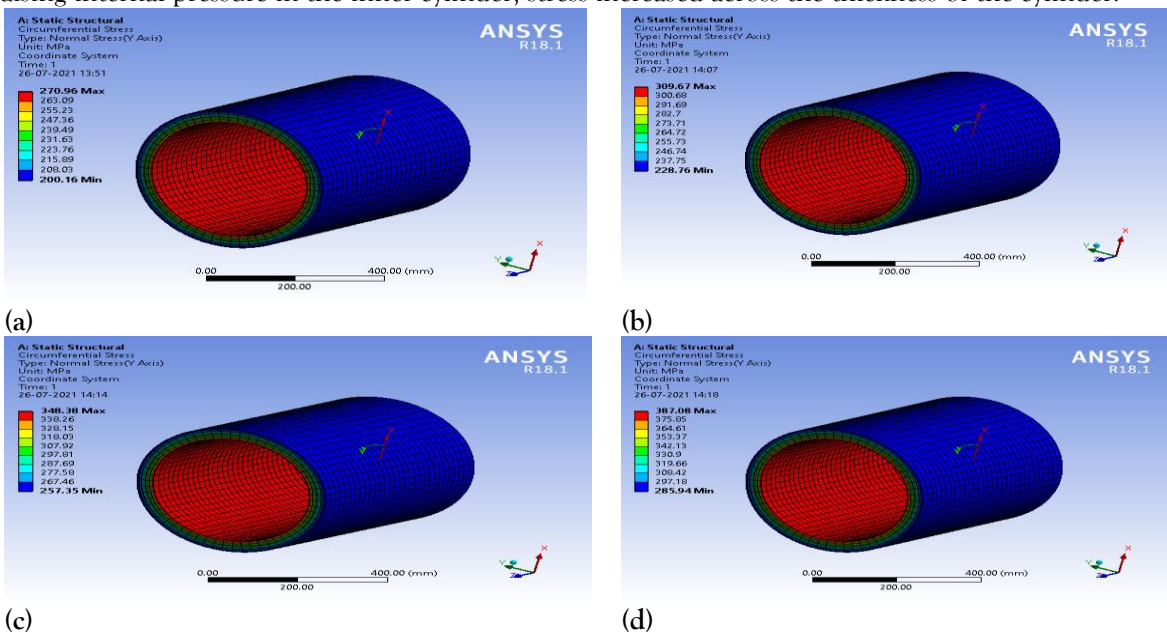


Fig. 7 Circumferential stress distributions of 50 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.

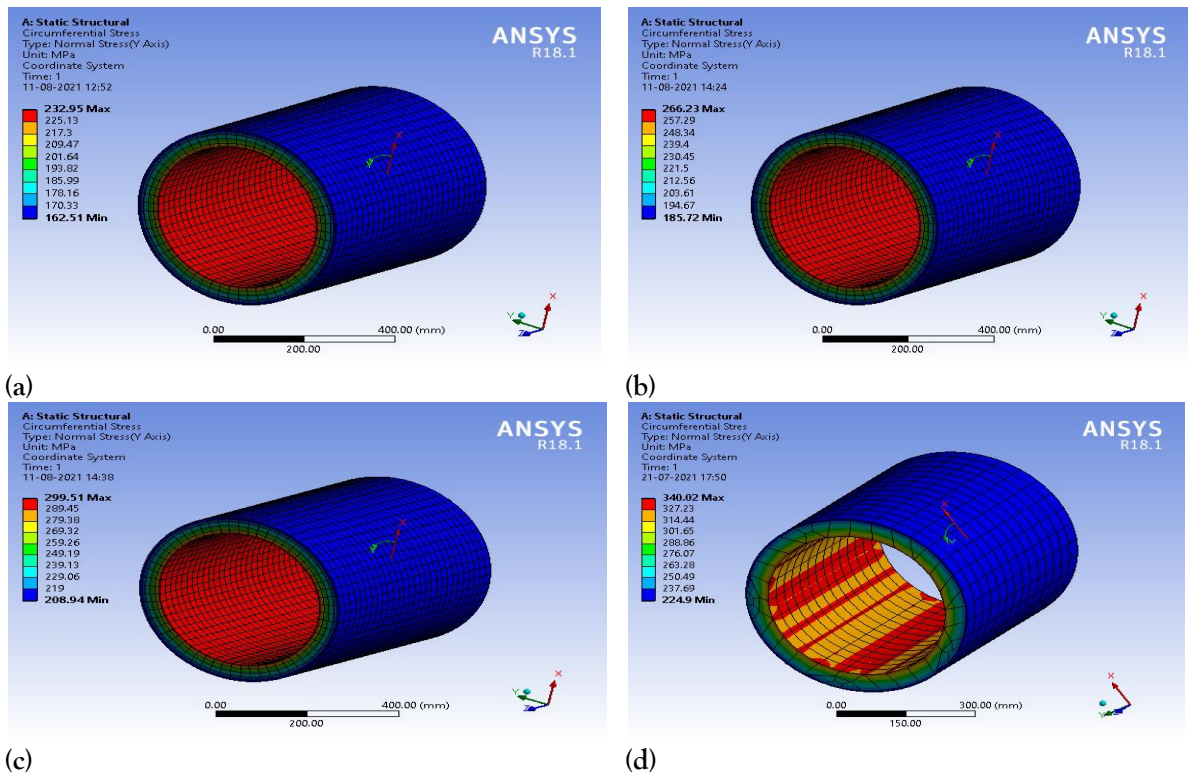


Fig. 8 Circumferential stress distributions of 60 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.

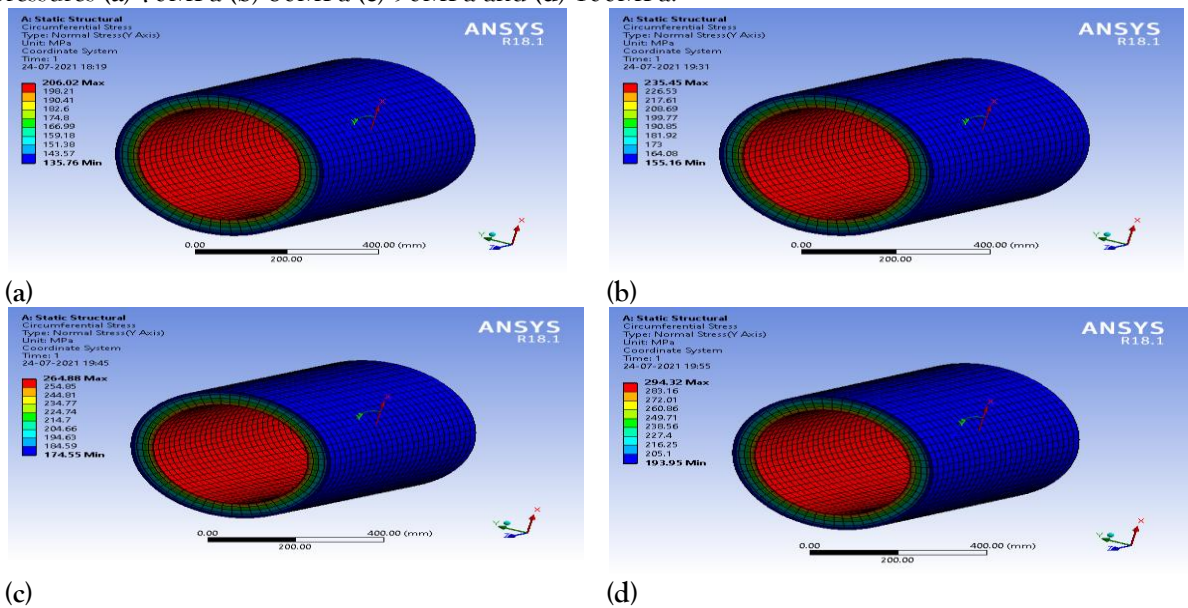


Fig. 9 Circumferential stress distributions of 70 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.

4.1.3. The effect of Von-Mises stress in a thick-walled cylinder

Figure 7-9 depicts the Von-Mises stress distribution of various thicknesses (50, 60, and 70mm) with simulated internal pressures of 70, 80, 90, and 100MPa. According to the obtained simulated results, increasing internal pressure increased stress. As a result, the internal pressures are proportional to the stresses. As per the simulation results, the von-mises stress distribution is greatest in the inner section of the cylinder and least in the outside portion. Maximum stress values are considered in this von-mises stress for study of a thick-walled cylinder [2].

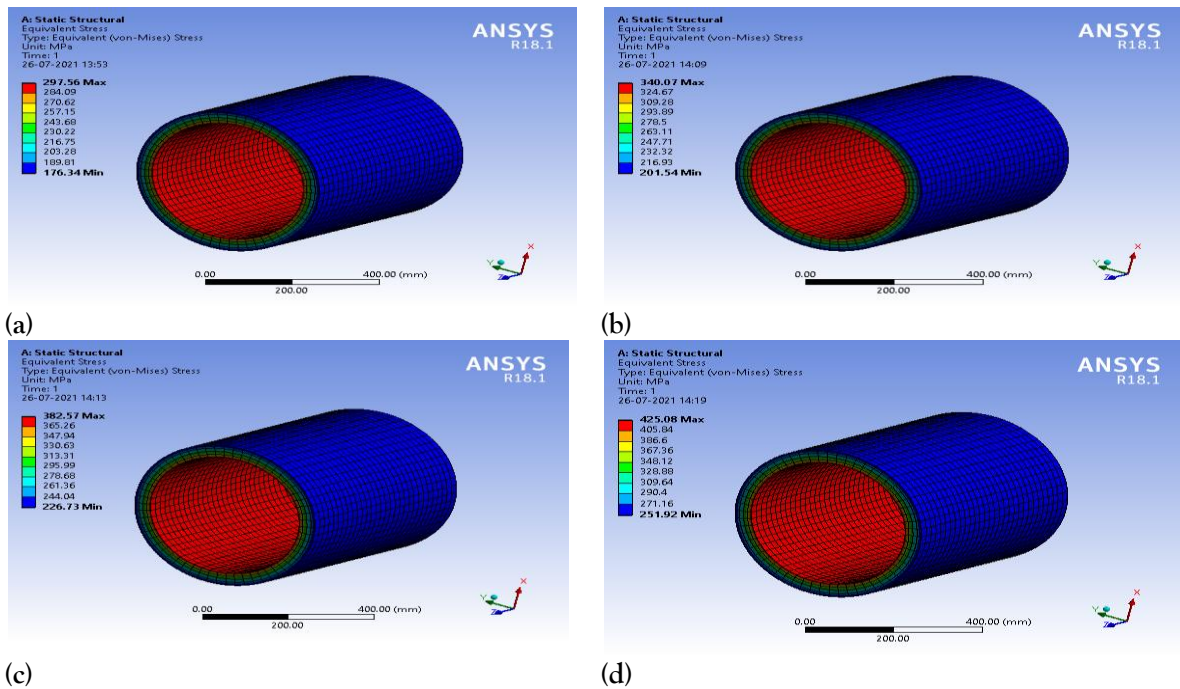


Fig.10 Von-Mises stress distributions of 50 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.

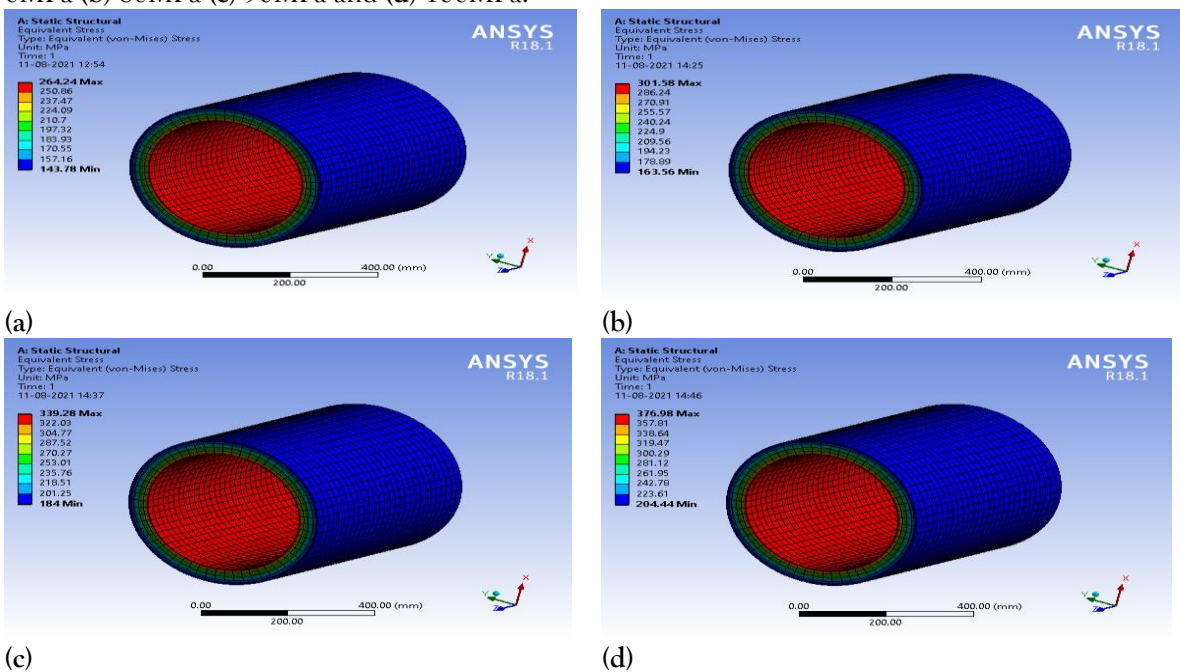
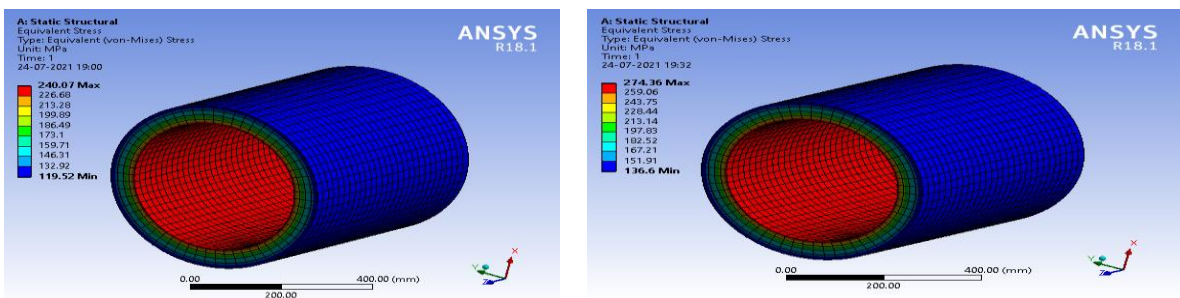


Fig.11 Von-Mises stress distributions of 60 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.



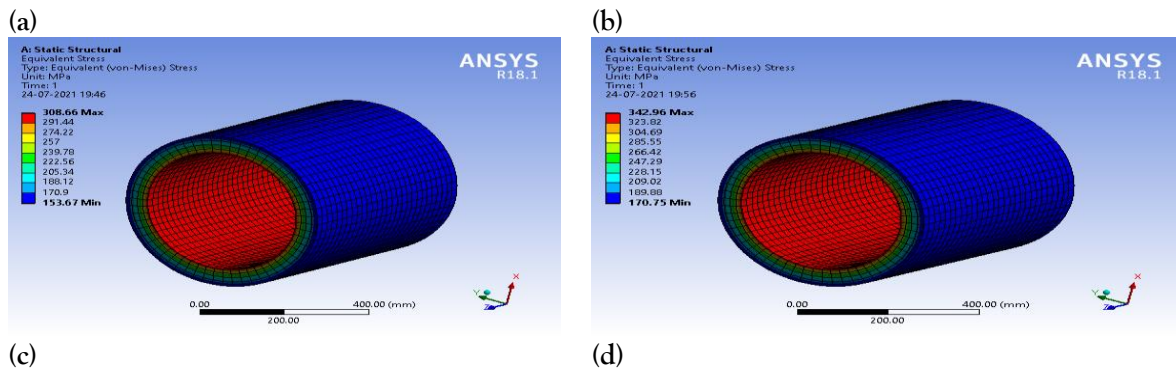


Fig. 12 Von-Mises stress distributions of 70 mm thick cylinder with applied different internal pressures (a) 70MPa (b) 80MPa (c) 90MPa and (d) 100MPa.

4.1.4. Comparison of simulated and theoretical results of stresses

The percentage error between simulated and theoretical radial and circumferential stresses is shown in Table 3. According to this, the simulated results were less than 1% of the theoretical values in all thickness and internal pressure circumstances [1]. Radial stress is compression caused by this minimum value of stress in this case. Similarly, circumferential stress is tension caused by the maximum value of stress. In all internal pressures at 50 mm thickness shows error percentage are high in both radial (0.85%) and circumferential (0.13%) stresses. Similarly, at 60mm thickness in all internal pressures, error percentages are low in both radial (0.10%) and circumferential (0.03%) stresses.

Table 3 Simulated and theoretical calculations of radial and circumferential stress comparisons

Internal Pressure (Mpa)	Thickness (mm)	Simulated (MPa)		Theoretical (MPa)		Error (%)	
		Radial Stress	Circumferential Stress	Radial Stress	Circumferential Stress	Radial Stress	Circumferential Stress
70	50	-70.60	270.96	-70	270.61	0.85	0.13
	60	-70.07	232.95	-70	232.88	0.10	0.03
	70	-69.90	206.02	-70	206.13	0.15	0.05
80	50	-80.68	309.67	-80	309.26	0.85	0.13
	60	-80.08	266.23	-80	266.15	0.10	0.03
	70	-79.88	235.45	-80	235.57	0.15	0.05
90	50	-90.77	348.38	-90	347.92	0.85	0.13
	60	-90.09	299.51	-90	299.42	0.10	0.03
	70	-89.87	264.88	-90	265.02	0.15	0.05
100	50	-100.85	387.08	-100	386.58	0.85	0.13
	60	-100.10	332.79	-100	332.69	0.10	0.03
	70	-99.85	294.32	-100	294.46	0.15	0.05

4.2. Investigation of the deformation of a thick-walled cylinder

Figure 13 depicts the directional deformations of thick wall cylinders with a thickness of 50mm when different internal pressures (70, 80, 90, and 100MPa) were applied in different materials (Aluminium alloys, Magnesium alloys, Tungsten alloys, and Stainless steel) using CFD simulations. When the internal pressure of a thick walled cylinder was raised, deformation increased in all thick walled cylinder materials [20]. In all internal pressure conditions, magnesium has the most deformation while stainless steel has the least distortion. Because magnesium alloys have a low density, young modulus, and tensile strength in comparison to other materials, maximal deformations occur [14, 21]. According to simulation data at 70MPa of internal pressure, deformation in aluminium alloys, tungsten alloys, and stainless steel is 36.30 %, 46.59 %, and 59.48% less than in magnesium alloys.

Figure 14 depicts the directional deformations of thick wall cylinders with a thickness of 60mm when different internal pressures (70, 80, 90, and 100MPa) were applied in different materials (Aluminium alloys, Magnesium alloys, Tungsten alloys, and Stainless steel) using CFD simulations [1]. In all pressure settings, high deformations were found in magnesium alloys and lower deformations in stainless steel [19]. Deformation in aluminium alloys, tungsten alloys, and stainless steel is 52.01 %, 66.52 %, and 85.04% less than in magnesium alloys, according to simulation data at 100MPa. Because of its high density and tensile strength, stainless steel exhibits less deformation in all conditions of internal pressures as compared to other materials of thick walled cylinders [10].

Figure 15 depicts the directional deformations of thick wall cylinders with a thickness of 70mm when different internal pressures (70, 80, 90, and 100MPa) were applied in different materials (Aluminium alloys, Magnesium alloys, Tungsten alloys, and Stainless steel) using CFD simulations. Figures 13 and 14 show the same scenario. In all internal pressure settings, low deformation in the stainless steel cylinder and high deformation in the magnesium alloys cylinder [18]. When compared to magnesium alloys and stainless steel cylinders, thick walled cylinders made of aluminium alloys and tungsten alloys exhibit reasonable deformation [8].

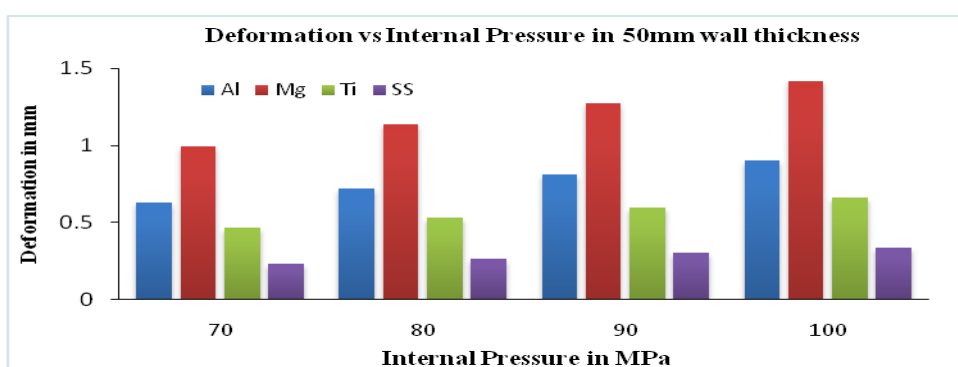


Fig. 13 Deformation in 50mm thickness with varying internal pressures

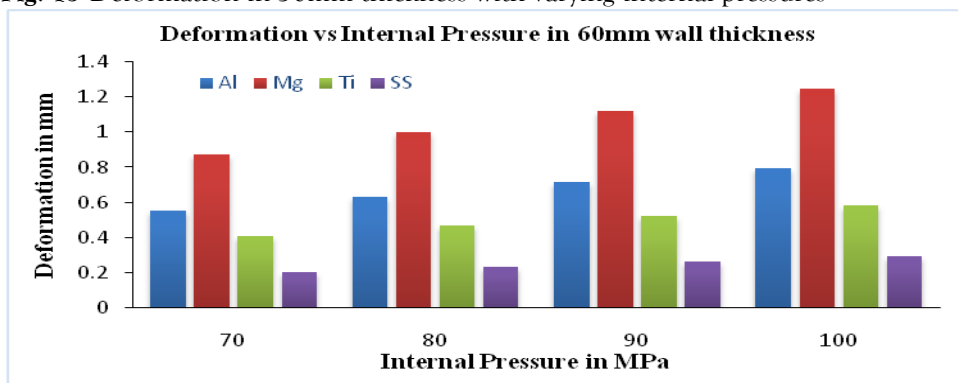


Fig. 14 Deformation in 60mm thickness with varying internal pressures

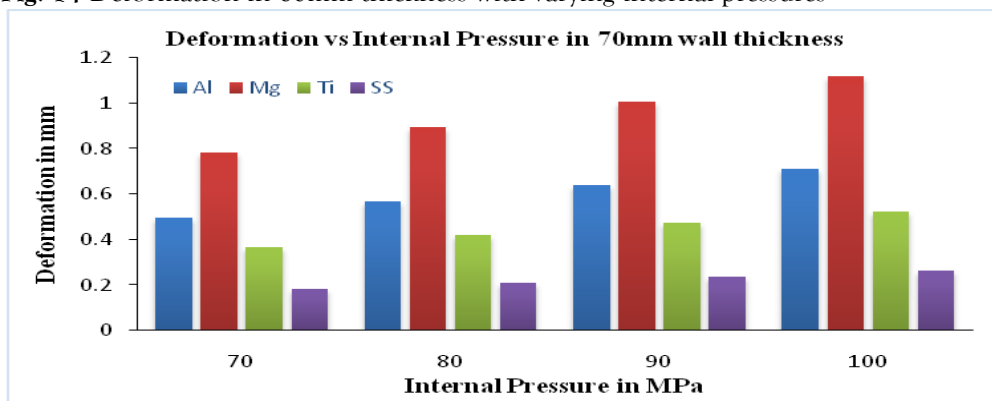


Fig. 15 Deformation in 70mm thickness with varying internal pressures

4.3. Study of safety factors

The safety factor is the ratio of maximum stress to allowable or working stress. The importance of safety factors in the choosing of thick walled cylinders cannot be overstated. Figure 16 depicts the safety factors of thick wall cylinders with a thickness of 50mm when different internal pressures (70, 80, 90, and 100MPa) were applied in different materials (Aluminium alloys, Magnesium alloys, Tungsten alloys, and Stainless steel) using CFD simulations. This work takes into account the maximum value of safety factors. Overall, tungsten alloy cylinders have a high safety factor under all internal pressure levels [6, 18]. Minimum safety factor (0.76) observed in the Magnesium alloy cylinder at 100MPa. Because magnesium cylinders are more prone to deformation than other cylinder materials. According to simulation results, safety factors lower than one are seen in cylinders of magnesium alloys and stainless steel at internal pressures of 90 and 100MPa.

Figure 17 depicts the safety factors of thick wall cylinders with a thickness of 60mm when different internal pressures (70, 80, 90, and 100MPa) were applied in different materials (Aluminium alloys, Magnesium alloys, Tungsten alloys, and Stainless steel) using CFD simulations [17]. In this thickness of cylinder, safety factor is greater than one for all conditions of internal pressure and materials of cylinders [11]. Overall, maximum (7.02) and minimum (1.02) safety factors were found in tungsten (70MPa) and magnesium (100MPa) cylinders, respectively. While raising internal pressures from 70 to 100MPa, the safety factor decreases in all cylinder materials [16].

Figure 18 depicts the safety factors of thick wall cylinders with a thickness of 70mm when different internal pressures (70, 80, 90, and 100MPa) were applied in different materials (Aluminium alloys, Magnesium alloys, Tungsten alloys, and Stainless steel) using CFD simulations. Maximum (7.82) and minimum (1.13) safety factors of thick walled in Tungsten alloys at 70MPa and magnesium alloys at 100MPa appear to exist. The safety factor decreases as internal pressure increases, according to the data [14]. In all cylinder materials, safety factors greater than one are attained in all conditions of internal pressures at 70mm thickness [15]. At 100MPa, the safety factor of tungsten alloys is 77.09 %, 79.02 %, and 70.01% higher than that of stainless steel, magnesium, and aluminium alloy cylinders, respectively.

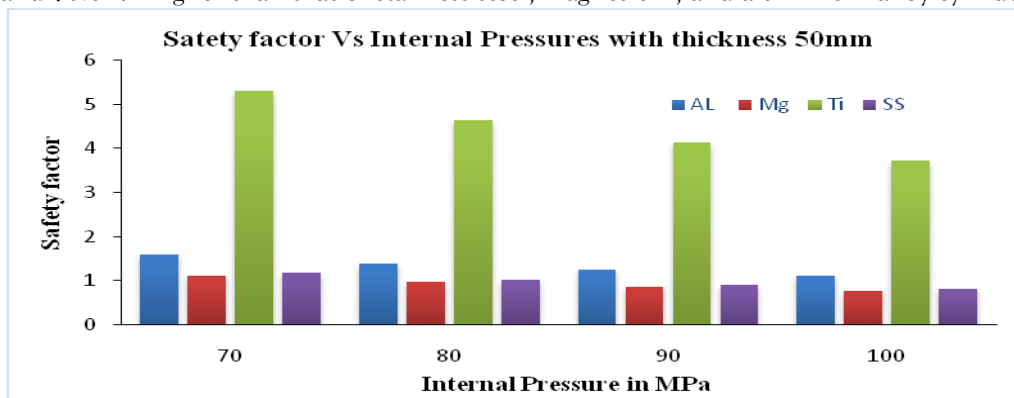


Fig. 16 Safety factor in 50mm thickness with varying internal pressures

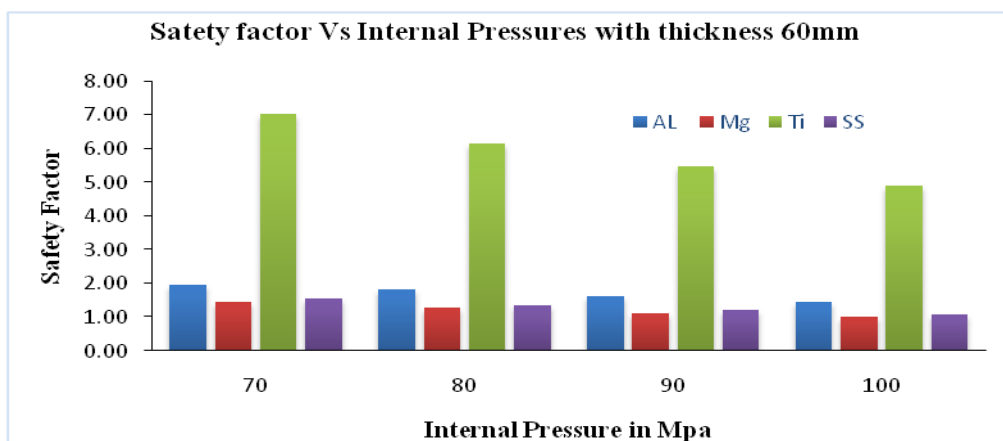


Fig. 17 Safety factor in 60mm thickness with varying internal pressures

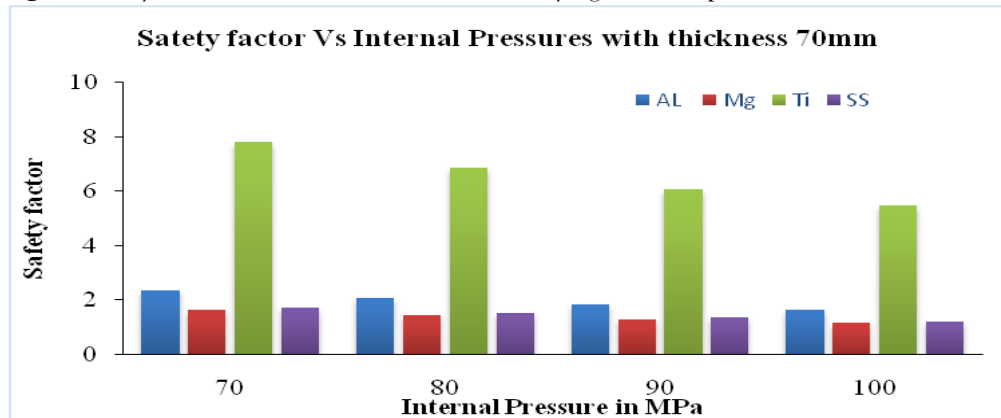


Fig. 18 Safety factor in 70mm thickness with varying internal pressures

5. CONCLUSIONS

The stress analysis of a thick walled cylinder was successfully completed in this research study utilising the ANSYS 18.1 software. Three wall thicknesses (50, 60, and 70mm) were utilised for simulation, with four variable internal pressures (70, 80, 90, and 100MPa) applied in four different materials (Aluminium alloys, Magnesium alloys, Tungsten alloys and stainless steel). Obtained results from simulation was radial stress, circumferential stress, Von-Mises stress, directional deformations and safety factors of different materials are compared. Deviations of theoretical and simulation results of stress was compared. As this following points are observed.

- Radial stress is greatest in the outside section and least in the interior portion of a thick-walled cylinder under internal pressure. Circumferential and Von-Mises stress are lowest in the outside section and highest in the interior region of a thick-walled cylinder.
- The percentage of errors in theoretical and simulation radial and circumferential stress values was less than one.
- Minimum and maximum deformation was found in cylinders of stainless steel and magnesium alloys under different internal pressure conditions.
- The maximum and minimum safety factors of thick cylinders under different internal pressures were in tungsten alloys and magnesium alloys.

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