Stress Analysis of Pressure Vessel

Anushri S. Nikhate
Department of Mechanical Engineering
Shri Sai College of Engineering &Technology,
Bhadrawati, Chandrapur, India.

H.N. Sayankar
Department of Mechanical Engineering
Shri Sai College of Engineering &Technology,
Bhadrawati, Chandrapur, India.

Abstract: Tanks, vessel and pipelines that carry, store or receive fluids are called Pressure vessel. A pressure vessel is defined as a container with a pressure differential between inside and outside. The inside pressure is usually higher than outside. The fluid inside the vessel may undergo a change in state as in case of a steam boiler or may combine with other reagent as in the case of chemical reactor. Pressure vessel often has a combination of high pressure together with high temperature and in some case flammable fluids or highly radioactive material. Because of such hazards it is imperative that the design be such that no leakage can occur. In addition, vessel hat to be design carefully to cope with the operating temperature and pressure.

In this paper, the analysis on pressure vessel with variation of hole and outside temperature variation is carried out to find the stresses in pressure vessel. First, the finite element approach is used to evaluate the stresses in the closed pressure vessel and with varying material and outside temperature. Further the finite element approach is used to evaluate the stresses in the pressure vessel with holes on circumference and with varying material and outside temperature.

Keywords: Pressure Vessel, Fluid, Stresses, Circumference, Temperature, Material.

I. INTRODUCTION

Tanks, vessel and pipelines that carry, store or receive fluids are called Pressure vessel. A pressure vessel is defined as a container with a pressure differential between inside and outside. The inside pressure is usually higher than outside.

The fluid inside the vessel may undergo a change in state as in case of a steam boiler or may combine with other reagent as in the case of chemical reactor. Pressure vessel often has a combination of high pressure together with high temperature and in some case flammable fluids or highly radioactive material.

Pressure vessel are used in a number of industries; for example, the power generation industry for fossil and nuclear power, the petrochemical industry for storing and processing crude petroleum oil in tank farms as well as storing gasoline in service station, and the chemical industry.

I. OBJECTIVE

- Analytical design of pressure vessel having stress distribution over closed pressure vessel.
- To analyze the stress contour on pressure vessel with holes on cylinder and cover plate.

II. PROBLEM STATEMENT

- In this paper, the analysis on pressure vessel with variation of hole and outside temperature variation is carried out to find the stresses in pressure vessel.
- The various geometric ratios considered for analysis are follows,
  - Length of pressure vessel, L = 500 mm
  - Diameter of pressure vessel, D = 250 mm
  - Test pressure, p = 2 MPa
- The various material used for the analysis are:
  - Mild Steel
  - Stainless Steel
  - Aluminum
  - Copper
  - Gray Cast Iron
  - Titanium
- The finite element approach is used to evaluate the stresses in the closed pressure vessel and with varying material and outside temperature.
- Secondly, the finite element approach is used to evaluate the stresses in the pressure vessel with holes on circumference and with varying material and outside temperature.
- Variation of hole number on circumference: 1, 2, 3.
- Variation of diameter (mm): 10, 20, 30, 40.

IV. DESIGN CALCULATIONS OF A PRESSURE VESSEL

- Yield tensile stress, σ_y = 250 MPa
- Design tensile stress, σ_d = 0.8 σ_y = 196.8 MPa (For steel or ductile material)
- Standard thickness, t_b = 5mm

The hoop of circumferential stress is,
σ_h = \(\frac{P_T \times D}{2 \times t \times \eta}\)
= \(\frac{(2 \times 240)/(2 \times 5 \times 0.95)}{50.52 \text{ MPa}}\)

The Longitudinal stress is,
σ_l = \(\frac{P_T \times D}{4 \times t \times \eta}\)
= \(\frac{(2 \times 250)/(4 \times 5 \times 0.95)}{25.26 \text{ MPa}}\)

Maximum sheer stress,
\[ \Gamma_{\text{max}} = \frac{(\sigma_1 - \sigma_2)}{2} \]
\[ = \frac{(50.52-25.26)}{2} \]
\[ = 12.63 \text{ MPa} \]

The increase in diameter of the cylindrical shell due to an internal pressure is,
\[ \Delta d = \frac{Pr \times D^2}{2 \times t \times E \times (1 - \mu/2)} \]
\[ = \frac{(4 \times 250 \times 205)}{(2 \times 5 \times 200 \times 1000)} \times (1-0.3/2) \]
\[ = 0.106 \text{ mm} \]

Table 4.1: Analytical results for stresses on pressure vessel

| SR. NO. | Type of stress | Magnitude (MPa) |
|---------|----------------|----------------|
| 1       | Hoop Stress    | 50.52          |
| 2       | Longitudinal stress | 25.26       |

V. MODELING AND ANALYSIS OF PRESSURE VESSEL

The 3D model of pressure vessel is created using a CAD software Creo Parametric.

VI. STRESS ANALYSIS OF PRESSURE VESSEL WITH HOLES ON CYLINDER AND COVER PLATE

The finite element approach is used to evaluate the stresses in the pressure vessel with holes on circumference and with varying material and outside temperature.
- Variation of hole number on circumference: 1, 2, & 3.
- Variation of diameter (mm): 10, 20, 30, 40.

i. STRESS ANALYSIS OF PRESSURE VESSEL WITH ONE 10 MM DIAMETER HOLE

The stress analysis of pressure vessel with one hole of 10 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

Table 6.1. Stress Analysis of Pressure Vessel with One 10 mm Diameter Hole

| Material       | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|----------------|-------------------------|-------------------------|----------------------------|----------------------------|
| Aluminum       | 178.73                  | 2.63 e^13              | 159.88                     | 10.89                      |
| Copper         | 202.76                  | 6.89 e^13              | 161.13                     | 13.03                      |
| Gray Cast Iron | 155.4                   | 8.93 e^14              | 157.83                     | 8.52                       |

ii. STRESS ANALYSIS OF PRESSURE VESSEL WITH TWO 10 MM DIAMETER HOLE

The stress analysis of pressure vessel with two hole of 10 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

Table 6.2. Stress Analysis of Pressure Vessel with Two 10 mm Diameter Hole

| Material       | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|----------------|-------------------------|-------------------------|----------------------------|----------------------------|
| Aluminum       | 146.65                  | 2.55 e^13              | 158.7                      | 11.02                      |
| Copper         | 161.15                  | 2.54 e^14              | 159.47                     | 12.58                      |
| Gray Cast Iron | 146.74                  | 8.86 e^14              | 156.96                     | 8.97                       |
| Mild Steel     | 193.92                  | 1.02 e^13              | 159.07                     | 9.74                       |
| Stainless Steel| 246.31                  | 2.54 e^14              | 160.57                     | 12.58                      |
| Titanium       | 145.26                  | 3.68 e^14              | 158.43                     | 12.50                      |

iii. STRESS ANALYSIS OF PRESSURE VESSEL WITH THREE 10 MM DIAMETER HOLE

The stress analysis of pressure vessel with three hole of 10 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

Table 6.3. Stress Analysis of Pressure Vessel with Two 10 mm Diameter Hole

| Material       | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|----------------|-------------------------|-------------------------|----------------------------|----------------------------|
| Aluminum       | 177.33                  | 2.30 e^13              | 159.97                     | 9.92                       |
| Copper         | 201.77                  | 6.02 e^13              | 160.81                     | 11.04                      |
| Gray Cast Iron | 153.55                  | 7.80 e^14              | 158.19                     | 8.70                       |
| Mild Steel     | 239.57                  | 9.13 e^14              | 160.69                     | 11.69                      |
| Stainless Steel| 305.01                  | 2.26 e^14              | 163.34                     | 15.22                      |
| Titanium       | 146.41                  | 3.33 e^14              | 159.44                     | 11.22                      |

iv. STRESS ANALYSIS OF PRESSURE VESSEL WITH ONE 20 MM DIAMETER HOLE

The stress analysis of pressure vessel with one hole of 20 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.
The stress analysis of pressure vessel with three hole of 20 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

| Material  | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|-----------|-------------------------|-------------------------|-----------------------------|-----------------------------|
| Aluminum  | 168.35                  | 2.004e-13               | 180.41                      | 7.17                        |
| Copper    | 174.93                  | 5.26 e-13               | 181.35                      | 7.52                        |
| Gray Cast Iron | 168.03               | 6.84 e-14               | 178.86                      | 6.03                        |
| Mild Steel | 207.93                  | 7.95 e-14               | 181.71                      | 8.56                        |
| Stainless Steel | 263.74            | 1.98 e-14               | 183.8                       | 11.29                       |
| Titanium  | 166.6                   | 2.87 e-14               | 179.26                      | 6.37                        |

The stress analysis of pressure vessel with two hole of 20 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

| Material  | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|-----------|-------------------------|-------------------------|-----------------------------|-----------------------------|
| Aluminum  | 174.04                  | 2.60 e-13               | 185.3                       | 8.01                        |
| Copper    | 174.35                  | 6.89 e-13               | 185.93                      | 7.48                        |
| Gray Cast Iron | 173.94               | 8.86 e-14               | 183.82                      | 6.90                        |
| Mild Steel | 205.34                  | 1.03 e-13               | 185.46                      | 9.00                        |
| Stainless Steel | 259.8               | 2.58 e-14               | 186.61                      | 13.36                       |
| Titanium  | 173.02                  | 3.75 e-14               | 185.3                       | 9.02                        |

The stress analysis of pressure vessel with one hole of 20 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

| Material  | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|-----------|-------------------------|-------------------------|-----------------------------|-----------------------------|
| Aluminum  | 198.72                  | 2.57 e-13               | 211.85                      | 7.39                        |
| Copper    | 199.22                  | 6.93 e-13               | 212.55                      | 8.56                        |
| Gray Cast Iron | 198.68               | 8.80 e-14               | 210.86                      | 6.39                        |
| Mild Steel | 207.16                  | 1.02 e-13               | 213.18                      | 9.74                        |
| Stainless Steel | 261.59             | 2.61 e-14               | 214.89                      | 12.40                       |
| Titanium  | 196.7                   | 3.76 e-14               | 210.57                      | 7.35                        |

The stress analysis of pressure vessel with three hole of 30 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

| Material  | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|-----------|-------------------------|-------------------------|-----------------------------|-----------------------------|
| Aluminum  | 200.58                  | 2.58 e-13               | 212.11                      | 10.13                       |
| Copper    | 204.96                  | 6.80 e-13               | 212.45                      | 11.17                       |
| Gray Cast Iron | 200.77               | 9.00 e-13               | 211.43                      | 8.60                        |
| Mild Steel | 243                     | 1.02 e-13               | 212.5                       | 12.26                       |
| Stainless Steel | 308.41             | 2.54 e-14               | 213.26                      | 15.76                       |
| Titanium  | 199.62                  | 3.74 e-14               | 211.72                      | 8.64                        |

The stress analysis of pressure vessel with three hole of 30 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

| Material  | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|-----------|-------------------------|-------------------------|-----------------------------|-----------------------------|
| Aluminum  | 178.13                  | 2.60 e-13               | 189.58                      | 7.17                        |
| Copper    | 178.56                  | 6.78 e-13               | 190.3                       | 7.23                        |
| Gray Cast Iron | 177.77              | 8.63 e-14               | 187.95                      | 6.12                        |
| Mild Steel | 207.12                  | 1.00 e-13               | 189.89                      | 9.29                        |
| Stainless Steel | 261.03            | 2.57 e-14               | 191.31                      | 13.58                       |
| Titanium  | 177.03                  | 3.68 e-14               | 182.42                      | 8.95                        |

vii. STRESS ANALYSIS OF PRESSURE VESSEL WITH ONE 30 MM DIAMETER HOLE

The stress analysis of pressure vessel with one hole of 30 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

| Material  | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|-----------|-------------------------|-------------------------|-----------------------------|-----------------------------|
| Aluminum  | 198.72                  | 2.57 e-13               | 211.85                      | 7.39                        |
| Copper    | 199.22                  | 6.93 e-13               | 212.55                      | 8.56                        |
| Gray Cast Iron | 198.68              | 8.80 e-14               | 210.86                      | 6.39                        |
| Mild Steel | 207.16                  | 1.02 e-13               | 213.18                      | 9.74                        |
| Stainless Steel | 261.59             | 2.61 e-14               | 214.89                      | 12.40                       |
| Titanium  | 196.7                   | 3.76 e-14               | 210.57                      | 7.35                        |

viii. STRESS ANALYSIS OF PRESSURE VESSEL WITH TWO 30 MM DIAMETER HOLE

The stress analysis of pressure vessel with two hole of 30 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

| Material  | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|-----------|-------------------------|-------------------------|-----------------------------|-----------------------------|
| Aluminum  | 200.58                  | 2.58 e-13               | 212.11                      | 10.13                       |
| Copper    | 204.96                  | 6.80 e-13               | 212.45                      | 11.17                       |
| Gray Cast Iron | 200.77              | 9.00 e-13               | 211.43                      | 8.60                        |
| Mild Steel | 243                     | 1.02 e-13               | 212.5                       | 12.26                       |
| Stainless Steel | 308.41             | 2.54 e-14               | 213.26                      | 15.76                       |
| Titanium  | 199.62                  | 3.74 e-14               | 211.72                      | 8.64                        |

ix. STRESS ANALYSIS OF PRESSURE VESSEL WITH THREE 30 MM DIAMETER HOLE

The stress analysis of pressure vessel with three hole of 30 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.
Table 6.9. Stress Analysis of Pressure Vessel with Three 40 mm Diameter Hole

| Material      | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|---------------|-------------------------|-------------------------|----------------------------|----------------------------|
| Aluminum      | 225.45                  | 2.57 e-13               | 235.12                     | 6.04                       |
| Copper        | 229.11                  | 6.88 e-13               | 238.95                     | 11.62                      |
| Gray Cast Iron | 226.25                 | 9.11 e-14               | 235.04                     | 5.64                       |
| Mild Steel    | 230.53                  | 1.05 e-13               | 239.56                     | 12.51                      |
| Stainless Steel | 257.7               | 2.63 e-14               | 241.27                     | 14.22                      |
| Titanium      | 226.61                  | 3.70 e-14               | 236.94                     | 9.45                       |

x. STRESS ANALYSIS OF PRESSURE VESSEL WITH ONE 40 MM DIAMETER HOLE

The stress analysis of pressure vessel with one hole of 40 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

Table 6.10. Stress Analysis of Pressure Vessel with One 40 mm Diameter Hole

| Material      | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|---------------|-------------------------|-------------------------|----------------------------|----------------------------|
| Aluminum      | 239.69                  | 2.65 e-13               | 254.33                     | 9.08                       |
| Copper        | 240                    | 6.99 e-13               | 254.8                      | 10.47                      |
| Gray Cast Iron | 239.84                 | 9.11 e-14               | 253.66                     | 7.26                       |
| Mild Steel    | 241.27                  | 1.05 e-13               | 255.33                     | 10.75                      |
| Stainless Steel | 254.28             | 2.60 e-14               | 256.55                     | 13.74                      |
| Titanium      | 238.04                  | 3.78 e-14               | 253.29                     | 9.15                       |

xi. STRESS ANALYSIS OF PRESSURE VESSEL WITH TWO 40 MM DIAMETER HOLE

The stress analysis of pressure vessel with two hole of 40 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

Table 6.11. Stress Analysis of Pressure Vessel with Two 40 mm Diameter Hole

| Material      | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|---------------|-------------------------|-------------------------|----------------------------|----------------------------|
| Aluminum      | 233.7                  | 1.68 e-13               | 248.62                     | 8.98                       |
| Copper        | 233.8                  | 4.52 e-13               | 248.96                     | 9.78                       |
| Gray Cast Iron | 233.82                | 5.88 e-14               | 247.87                     | 7.24                       |
| Mild Steel    | 234.50                 | 6.79 e-14               | 248.99                     | 10.35                      |
| Stainless Steel | 235.18            | 1.71 e-14               | 249.79                     | 13.42                      |
| Titanium      | 232.94                 | 2.46 e-14               | 248.19                     | 8.55                       |

xii. STRESS ANALYSIS OF PRESSURE VESSEL WITH THREE 40 MM DIAMETER HOLE

The stress analysis of pressure vessel with three hole of 40 mm diameter is carried out for various material. The pressure vessel is subjected to structural and thermal load.

Table 6.12. Stress Analysis of Pressure Vessel with Three 40 mm Diameter Hole

| Material      | Von Misses Stress (MPa) | Total Heat Flux (W/mm²) | Max. Principle Stress (MPa) | Min. Principle Stress (MPa) |
|---------------|-------------------------|-------------------------|----------------------------|----------------------------|
| Aluminum      | 258.59                  | 1.75 e-13               | 274.91                     | 9.68                       |
| Copper        | 258.84                  | 4.65 e-13               | 275.33                     | 10.86                      |
| Gray Cast Iron | 259.26                 | 5.95 e-14               | 274.64                     | 7.87                       |
| Mild Steel    | 260.67                  | 6.95 e-14               | 276.37                     | 11.56                      |
| Stainless Steel | 261.81              | 1.72 e-14               | 277.68                     | 14.20                      |
| Titanium      | 256.44                  | 2.50 e-14               | 273.34                     | 7.94                       |

VII. CONCLUSION

- It is observed that stresses are increasing when the number of holes is increased & diameter kept constant. Minimum number of holes lower the stresses and maximize the number of holes increases the stresses.
- The analysis of pressure vessel is performed by changing the material. It is found that the von misses stress generated in the Titanium is lower than the material selected for the study. The von misses stress generated in the Stainless steel is maximum for the selected material. Below are the materials arranged in the increasing order of stress generated. Titanium > Gray Cast Iron > Aluminum > Copper > Mild Steel > Stainless steel
- The analysis of pressure vessel is conducted considering the thermal temperature. The heat flux generated in Titanium is lesser than the material considered for the study. The maximum heat flux is generated in Gray Cast Iron from the material considered for the study. Below materials are arranged in increasing order of Total Heat Flux generated.

Aluminum > Copper > Mild Steel > Stainless Steel > Titanium > Gray Cast Iron

REFERENCES

[1]. Vinod kumar, "Design of saddle support for horizontal pressure vessel" - World Academy of Science, Engineering and Technology, International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:8, No:12, 2014

[2]. Avinash Khart-"Stress concentration at openings in pressure vessels – a review", International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, No. 3, March 2013

[3]. Apurva Pendbhaje "Design and analysis of pressure vessel" - International Journal of Innovative Research in Technology & Science(IJI RTS), ISSN:2321-1156
[4]. S. G. Bhosale "FEA of cylindrical pressure vessels with different radius of openings", International Journal of Engineering Research & Technology (IJERT), Vol. 2 No. 10, October - 2013.

[5]. Amit Patil , "Finite element analysis; pressure vessel with angular leg supports" ,ISSN 2278 – 0149, Vol. 3, No. 3, July, 2014.

[6]. S. J. Kadam , "Study of different type reinforcement in cylindrical pressure vessel", International Journal of Advanced Engineering Research and Studies, Vol. I, No. II, January-March, 2012.

[7]. Buscioceanu Paraschina, "Study of stresses and stress concentrations in pressure vessels" - , Journal of Business Economics and Information Technology

[8]. Bhavik Desai , "Design automation nozzle reinforcement analysis for pressure vessel" -, International Journal of Innovative Research in Advanced Engineering (IJIRAE) ISSN: 2349-2163, Volume 1 No. 8 (September 2014)

[9]. Ch. Ramesh-"Optimization of location, size of opening hole in a pressure vessel cylinder", International Journal of Advanced Engineering and Technology, Vol. II, No. 3, May, 2016.

[10]. David Heckman "Finite element analysis of pressure vessels", MBARI 1998

[11]. Amarnath Zore "Design and optimization of saddle for horizontal pressure vessel " International Engineering Research Journal (IERJ) Special No. 2 Page 4201-4204, 2015.