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Design and Thermo Mechanical Analysis of High Pressure Vessels with Dish End

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ABSTRACT

In the present work design and finite element analysis of solid cylinder and multilayer cylinder with dish end are performed, due to which thermal stress have found using ANSYS software. Solid, multi cylinder and hemisphere dish end are designed according to ASME and results are compared with simulation software ANSYS and thermal analysis are performed according to design temperate and results are imported in to structural analysis to find out thermal stresses.

Introduction:

In thick walled cylinders subjected to internal pressure only, it can be seen from the equation of the hoop stress that the maximum stresses occur at the inside radius and this can be given. It can be shown that for large internal pressures in thick walled cylinders the wall thickness is required to be very large. This is shown schematically in figure.

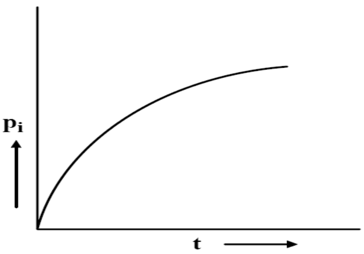

Fig: 1. internal pressures V/s thickness

This means that the material near the outer edge of the cylinder is not effectively used since the stresses near the outer edge gradually reduce. In order to make thick-walled cylinders that resist elastically large internal pressure and make effective use of material at the outer portion of the cylinder the following methods of prestressing are used:

• Shrinking a hollow cylinder over the main cylinder. (Compound cylinders)

• Multilayered or laminated cylinders.

An outer cylinder (jacket) with the internal diameter slightly smaller than the outer diameter of the main cylinder is heated and fitted onto the main cylinder. When the assembly cools down to room temperature, a compound cylinder is obtained. In this process the main cylinder is subjected to an external pressure leading to radial compressive stresses at the interface as shown in figure

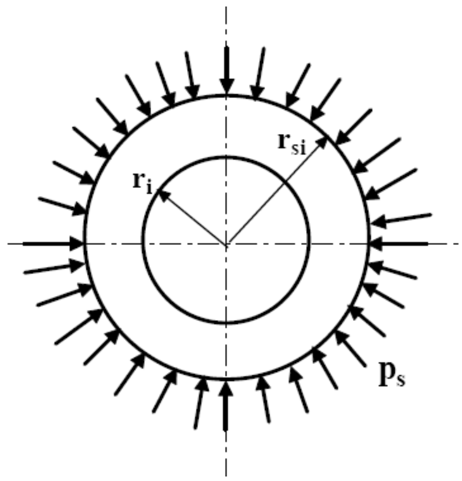

Fig: 2. internal cylinder

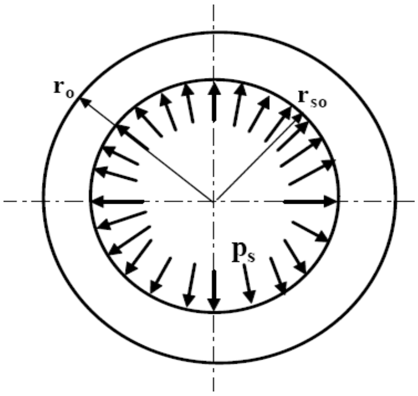

Fig: 3. External cylinder

The outer cylinder is subjected to an internal pressure leading to tensile circumferential Stresses at the interface as shown in figure. Under these conditions as the internal pressure increases, the compression in the internal cylinder is first released and then only the cylinder begins to act in tension.

Laminated cylinders:

The laminated cylinders are made by stretching the shells in tension and then welding along a longitudinal seam. This is shown in figure

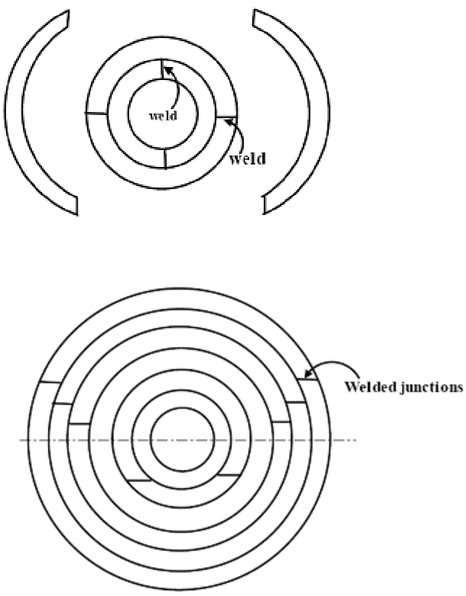

Fig: 4. Laminated cylinder

In that laminated cylinder tangential stresses, shrinkage stresses and warping stresses are developed due to which we can find stresses distribution along each layer of cylindrical shell.

Design of Thick Shell with Dish End:

A solid wall vessel consists of a single cylindrical shell, with closed ends. Due to high internal pressure and large thickness the shell is considered as a 'thick' cylinder design pressure has taken as 25 M.Pa, internal radius 1000mm , thickness has found 227 mm to carry specified pressure

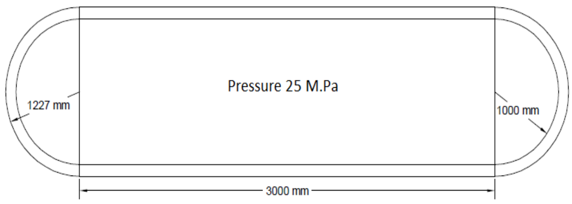

Fig: 5. Solid pressure vessel

Material of Construction:

Vessel SA 515 GR 70
Dished Ends SA 515 GR 70

Allowable Stress value:

Vessel & Dished Ends - 125 N/mm^2

The thickness of the Vessel is calculated from the equation

$$t = R_i \left[\sqrt{\frac{(SJ + P)}{(SJ - P)}} - 1\right] + C.A$$

$$t = 1000\left[\sqrt{\frac{(125 \times 1 + 25)}{(125 \times 1 - 25)}} - 1\right] + 3.0$$

$$= 227.74 \text{ mm}$$

Design of Hemispherical Dished End:

The thickness of the dished end is given by

$$t_d = \frac{P\ R_i}{2SJ - 0.2P} + C.A$$

$$t_d = \frac{25 \times 1000}{2 \times 125 \times 1.0 - 0.2 \times 25} + 3.0$$

$$= 105.04\text{mm}$$

(Adopted Thickness of the dished end is, t_d = 227 mm)

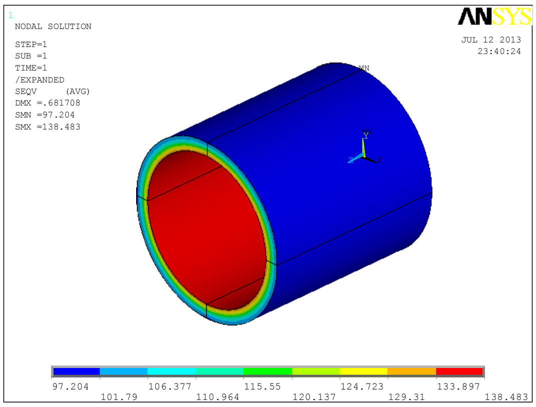

Fig: 6. Total stresses developed in cylindrical shell

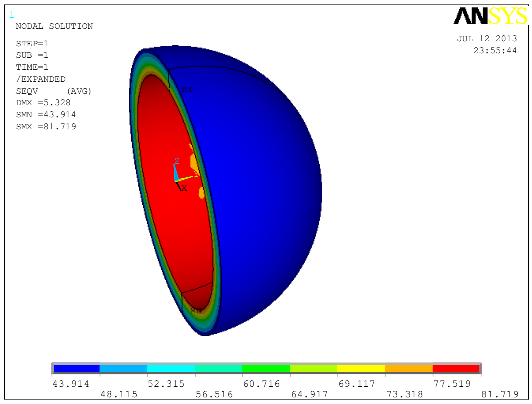

Fig: 9. Total Stresses developed in hemisphere end

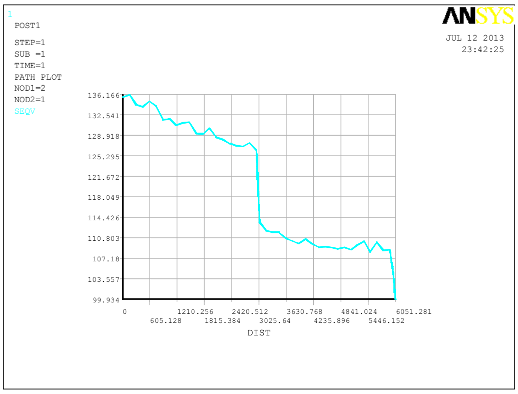

Fig: 7. Graph represents stresses developed along wall thickness from inside.

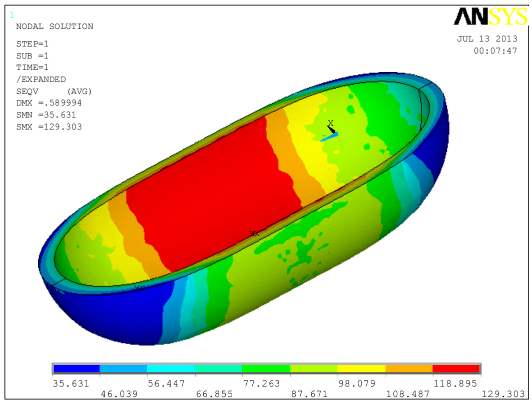

Fig: 10. Stresses developed in cylinder and Hemisphere ends (inside view)

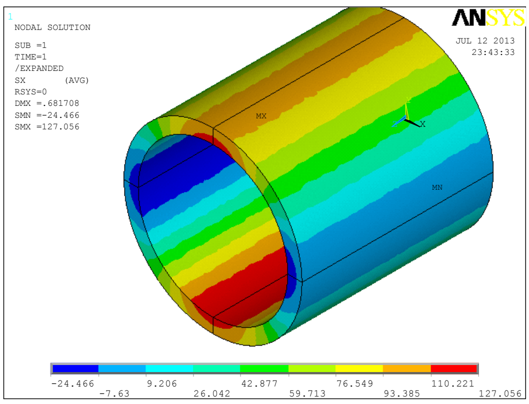

Fig: 8. x-directional stresses in cylindrical shell

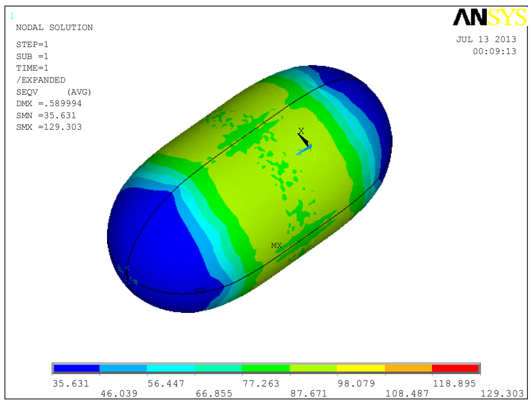

Fig: 11. Stresses developed in cylinder and Hemisphere ends (Outside view)

Table: 1.

	Theoretical M.Pa	Ansys M. Pa
Cylinder	125	127
Dish End	125	81 (For Adapted Thickness)
Cylinder + Dish End	129	

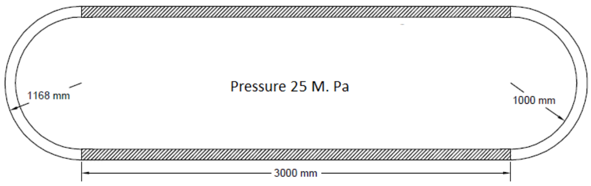

Fig: 12. Multi layer Pressure Vessel

The thickness of the shell is calculated from the ASME modified membrane theory equation as

$$t = \frac{P\ R_i}{S\,J - 0.6\,P} + C.A$$

$$= \frac{25 \text{ x } 1000}{165 \text{ x } 1 - 0.6 \text{ x } 25} + 3.0$$

= 169.66 mm

Provided thickness, t = 162 mm (12 mm Liner) + 27 layers of 6 mm thick)

The Thickness of Liner (core Tube)= 12 mm

The Thickness of Each Layer = 6 mm

Number of Layers = 27

The thickness of the dished end is given by

$$t_d = \frac{P\ R_i}{2\,S\,J - 0.2\,P} + C.A$$

$$t_d = \frac{25 \text{ x } 1000}{2 \text{ x } 125 \text{ x } 1.0 - 0.2 \text{ x } 25} + 3.0$$

= 105 mm

The adopted thickness of the dished end = 162 mm.

Tangential Stresses Due To Internal Pressure:

The tangential stress induced due to internal pressure in the multi layer shell at different layers is expressed by Seely,F.B., and Smith, A.O., as Tangential stress developed in n^{th} layer due to internal pressure

$$(S_i) = \frac{P\,R_i^2}{R_o^2 - R_i^2}\left(\frac{R_o^2}{X^2} + 1\right)$$

$$LINER = \frac{25\ x1000^2}{1168^2 - 1000^2}\left(\frac{1168^2}{1006^2} + 1\right) = 161.16\ M.Pa$$

Wrapping Stresses Due to Wrapping Pressure:

$$P_{i+1} = \frac{n\,K\,w\,E\,(R_{i+1}^2 - R_1^2)(R_{i+2}^2 - R_{i+1}^2)}{4\,\pi\,R_{i+1}^3\,(R_{i+2}^2 - R_1^2)}$$

The wrapping stress in the layer "27thi" due to wrapping pressure is given by the equation

$$S_i = \frac{P_{i+1}\ R_{i+1}}{t}$$

$$P = \frac{3 \text{ x } 0.1 \text{x } 10 \text{ x } 2.1e5\ (1162^2 - 1000^2)\ (1168^2 - 1162^2)}{4\ \pi\ 1162^3\ (1168^2 - 1000^2)}$$

= 0.429 N/mm^2

Wrapping Stress on 27th layer:

S = (0.429 * 1162) / 6 = **83.08 N/mm^2**

Shrinkage Stresses - Weld Shrinkage of Layers.

Stress in any layer due to welding other layers around it is given by the equation

$$S_x = -\left(1 + \frac{R_1^2}{X^2}\right)\sum_i^n \frac{P_{i+1}\ R_{i+1}^2}{R_{i+1}^2 - R_1^2}$$

Where X = ($R_{n-1} + R_{n-2}$)/2

$$S_x = \mathbf{0.00}\ \text{N/mm}^2$$

Shrinkage Stress on **27th** layer.

Shrinkage Stress on **20th** layer due to welding of 21th layer.

$$S_x = -\left(1 + \frac{1000^2}{1117^2}\right) * \left[\frac{0.456 \text{ x } 1120^2}{1120^2 - 1000^2} + 20.37\right] = -24.42\ N/mm^2$$

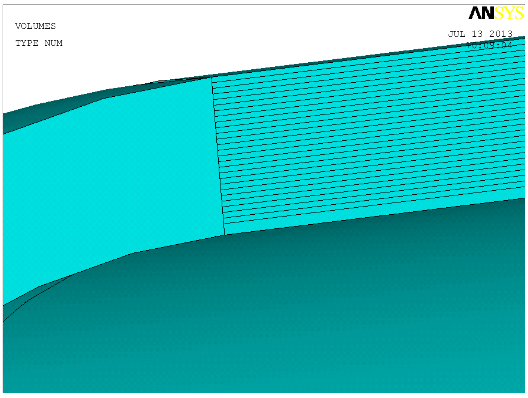

Fig: 13. Multi layer planning in ANSYS geometric model

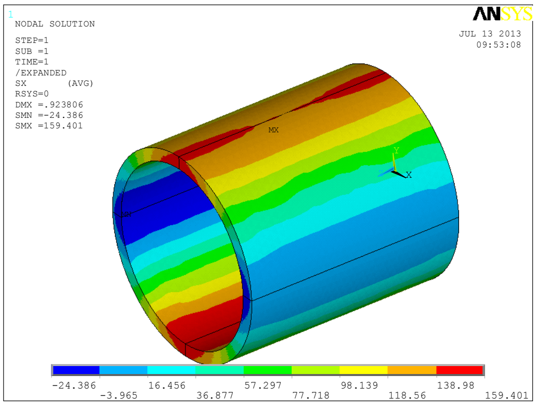

Fig: 14. x-directional stresses developed in multi layer cylinder

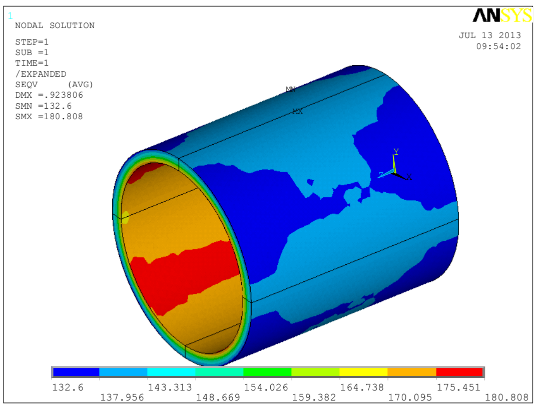

Fig: 15. Total stresses developed in multi layered for pressure cylinder

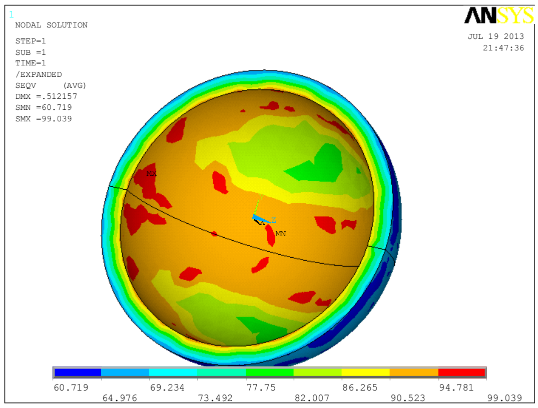

Fig: 16. Total stresses developed in hemisphere end multilayer vessel

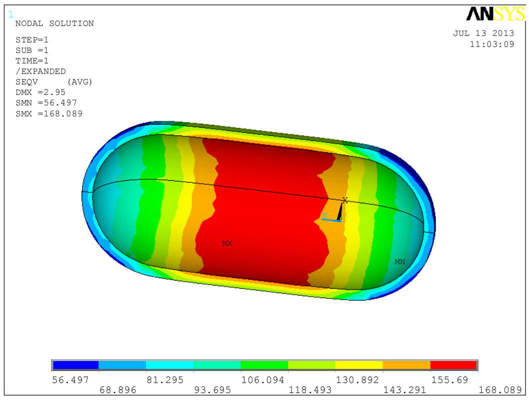

Fig: 17. Total stresses developed in multi layer cylinder and hemisphere ends (inside view)

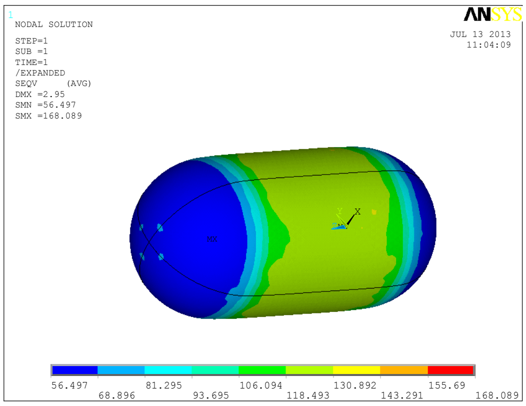

Fig: 18. Total stresses developed in multi layer cylinder and hemisphere ends (outside)

Table: 2.

	Theoretical M.Pa	**Ansys M.Pa**
Cylinder	165	168.401
Dish End	125	99 (For Adapted Thickness)
Cylinder+ Dish End	168	

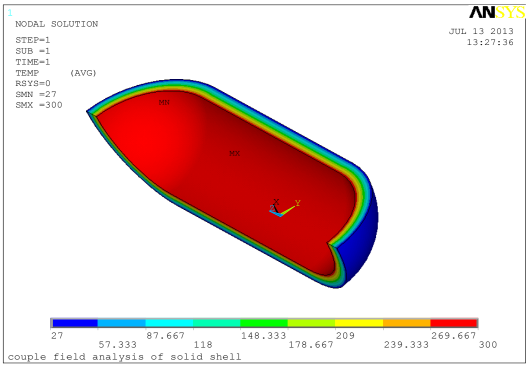

Fig: 19. Temperature distribution along solid cylinder and dish end

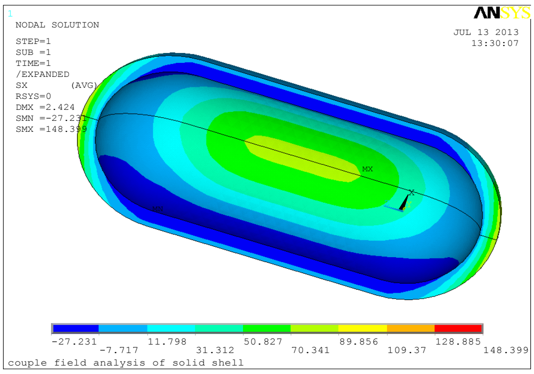

Fig: 20. x- directional Thermal stresses in solid cylinder hemisphere ends

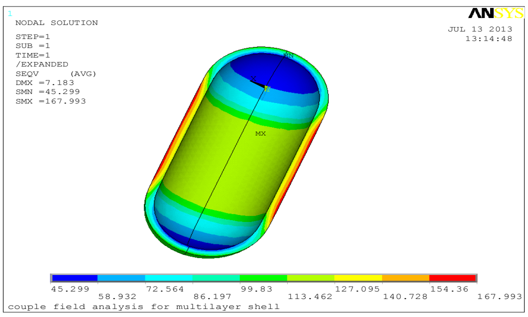

Fig: 21. Stresses in multi layer cylinder and hemisphere ends

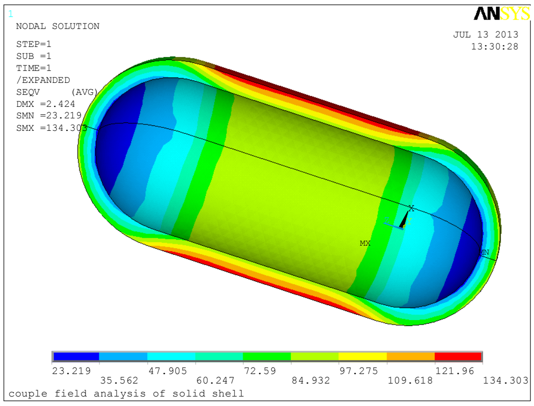

Fig: 22. Thermal stresses in solid cylinder and hemisphere ends

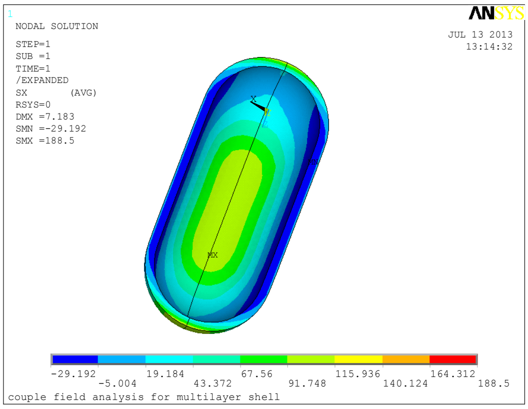

Fig: 23. X-directinal thermal stress in multilayer cylinder hemisphere ends

Conclusions:

1. Replacing of multi cylinder instead of solid cylinder to getting uniform stress distribution over inside to outside wall.
2. According to design 25.55% of thickness is reduced due to multi layer cylinder and dish end.
3. According to fabrication multi layer technique is an easy process compared with solid cylinder.
4. Analysis software is used to perform all analysis and compared with design results.
5. Deviation between analysis and design results is in minimum.
6. All stress are in allowable limit of used material.

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