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Design Parameters of Multilayer High Pressure Vessel

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Abstract : *This paper analyses multilayer high pressure vessel and also focuses on design parameters of multilayer high pressure vessel. The work in this paper includes the theoretical and software analysis of stress distribution. The stresses developed in solid wall pressure vessel and multilayer pressure vessel was analyzed by using ANSYS. Theoretical calculation of stress using failure theory is done and same is compared with ANSYS results. The study has revealed that multi layering technique has reduced the overall cost as well as properties have improved.*

Keywords: *Multilayer High Pressure Vessel, ANSYS, Stress*

I. Introduction

The pressure vessels are used to store fluids under pressure. The fluid being stored may undergo a change of state inside the pressure vessels as in case of steam boilers or it may combine with other reagents as in chemical plants. This pressure may be obtained from an external source or by the application of heat from a direct or indirect source.

The limitations of single wall cylindrical shaped metallic vessels for restricting large volumes of high internal pressures has been recognized in process industries like chemical and petroleum industries. In process engineering as the pressure of the working liquid increases, increase in the thickness of the vessel planned to hold that liquid is an automatic decision. The addition in the thickness beyond a certain point has fabrication challenges as well as requests stronger material for the vessel development. Multilayer Pressure Vessels have extended the art of pressure vessel development and gave the process designer a reliable bit of equipment valuable in an extensive variety of working conditions for the issues created by the storage of hydrogen and hydrogenation.

Bandarupalli Praneeth, T.B.S.Rao [1] Theoretical calculated values by using Different formulas are very close to that of the values obtained from ANSYS analysis is suitable for multilayer pressure vessels. Owing to the advantages of the multi layered pressure vessels over the conventional mono block pressure vessels, it is concluded that multi layered pressure vessels are superior for high pressures and high temperature operating conditions. Spence et al[2] He discussed the various important events occurred over the years in the development of technology of pressure vessels. They recognized the various milestones which stimulate the manufacturing, operation, analysis methods and new equipments regarding pressure vessels depending on many individuals' work. They traced the evolution of codes and standards since industrial revolution. Jaroslav Mackerle[3] had worked on bibliographical review of finite element method(FEMs) applied for the analysis of pressure vessel structural/components and piping from the theoretical as well as practical points of view. J.P.Balicevic, D Kozak, D. Karlievic[4] presented work on ANALYTICAL and NUMERICAL solution of internal forces by cylindrical pressure vessel with semi elliptical heads, in this paper the solution for internal forces and displacement in the thin-walled cylindrical pressure vessel with ellipsoidal head using general theory of thin walled shell of resolution have been proposed. L. B.S.Thakkar and S.A.Thakkar [5] did a case study and put efforts to design the pressure vessel using ASME codes & standards to legalize the design. The performance of a pressure vessel under pressure can be determined by conducting a series of tests to the relevant ASME standard in future scope. Siva Krishna Raparla ,T.Seshaiah[6]There is a percentage saving in material of 26.02% by using multilayered vessels in the place of solid walled vessel**.** This decreases not only the overall weight of the component but also the cost of the material required to manufacture the pressure vessel. Jahed and Dubey[7] This study employs the method for prediction of the residual stresses induced by auto frettage process. This method is capable of considering real material behaviour and, hence, providing a closer estimation of the residual stresses. In this study, both shrink fitting and auto frettage are combined and the optimum values of the layer thicknesses, shrink-fitting pressures, and auto-frettage percentages are determined with a proper sequence of steps to achieve maximum fatigue life of a three layer vessel.

DATA OF THE VESSEL

A. For Single LayerVessel

Material	SA516 Gr70
UTS	460 MPa
Yield Stress	250 MPa
Inside diameter Di	30 mm
Outside diameter Do	50 mm
Young's modulus E	210 GPa
Internal pressure P_i	50 MPa

B. For Multilayer Vessel

Material	SA516 Gr70
UTS	460 MPa
Yield Stress	250 MPa
Inside diameter Di	30 mm
Outside diameter Do	50 mm
Young's modulus E	210 GPa
Internal pressure P_i	50 MPa

II. DESIGN SCHEME

DESIGN PARAMETER OF PRESSURE VESSEL

The following are design parameters of pressure vessel

1. Design Pressure
2. Allowable stress
3. Corrosion Allowance

Design Pressure

In the pressure vessels, three terms related to pressure are commonly used

1. Maximum Working pressure is the maximum pressure to which the pressure vessel is subjected.
2. Design pressure is the pressure for which the pressure vessel designed.
3. Hydrostatic test pressure is the pressure at which the vessel is tested. The pressure vessel is finally tested by the hydrostatic test before it is put into operation.
4. The design pressure and the hydrostatic test pressure are obtained as follows:

Design pressure = 1.05 (Maximum working pressure)*

Hydrostatic test pressure = 1.3 (Design pressure)*

Allowable Stress

As per the IS Code and ASME Code, the allowable stress is based on the ultimate tensile strength with a factor of safety of 3 and 4 respectively.

Therefore,

Allowable stress, σ= Sut/3 or σ= Syt/ (1.5)

Where, σ = allowable tensile stress for the pressure vessel, N/mm²

Sut = ultimate tensile strength for the pressure vessel material, N/mm²

Syt = yield strength for pressure vessel material, N/mm²

Corrosion Allowance

The walls of the pressure vessel are subjected to thinning due to corrosion which reduces the life of the pressure vessel. The corrosion in pressure vessel is due to the following reasons:

1. Chemical attack by reagents on the inner wall surface of the vessel.
2. Rusting due to atmospheric air and moisture.
3. High temperature oxidation.
4. Erosion due to flow of reagent over the wall surface at high velocities.

TABLE I
MATERIAL ATTRIBUTES

Material	P	E	σ_Y	ν
SA516 Gr70	7750	192	260	0.3

III. ANALYTICAL

For designing the multilayer pressure vessel, first analytical analysis is carried out by using different mathematical equations. In analytical calculations hoop stresses developed in the pressure vessel is carried out.

Thickness (t) and outer diameter d_2 of single layer thick pressure vessel is given by equations below,

$$thickness = t = r_i\left[\sqrt{\frac{\sigma_t + p_i}{\sigma_t - p_i}} - 1\right]$$

$$outer\ diameter(d_2) = d_i + (t \times 2)$$

Hoops stress in single layer vessel is given by,

$$\sigma_\theta = \frac{p_i(r_2^2 + r_1^2)}{(r_2^2 - r_1^2)}$$

$$\sigma_\theta = \frac{50(25^2 + 15^2)}{(25^2 - 15^2)}$$

σ_θ = 106.25 MPa.

IV. ANSYS ANALYSIS

The modelling of pressure vessel is carried out in SOLIDWORKS and the same model is imported in ANSYS Workbench where stress analysis is carried out on model of pressure vessel. A solid element can be utilized to model thick layered composites but it requires that the mesh divisions in thickness directions must be the same as the number of material layers. SHELL 99 is a linear layered structure shell element. Very thin to moderately thick layers can be modelled with this element. The finite element model has been plotted and meshed model is shown in Fig 2.

The pressure is applied on the inside area of vessel. The pressure applied is 50MPa. Material used is SA516Gr70.

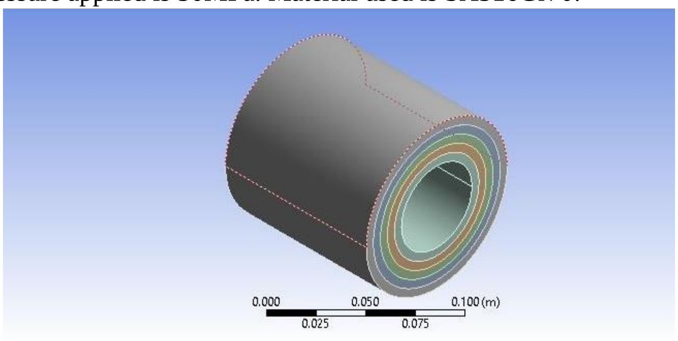

Fig. 1 Geometry of Multilayer Pressure Vessel

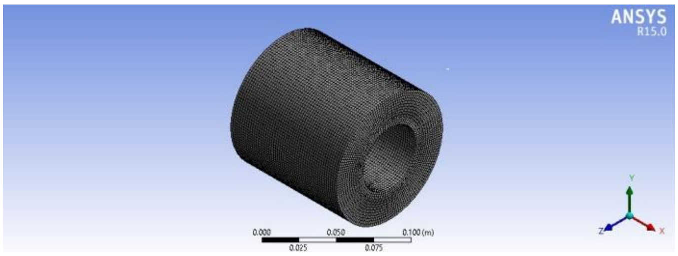

Fig. 2 Meshed Model

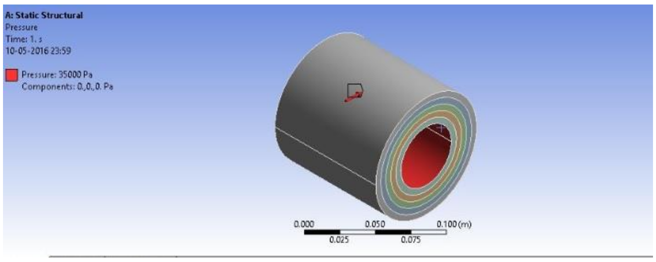

Fig. 3 Loading Of Multi 5- Layer SA516Gr70

V. Result Analysis

It involves determination of maximum stress calculation. Analysis is done for single,3 and 5 layers.The Von-Mises stress distribution is shown in Fig. 4,5 and 6.

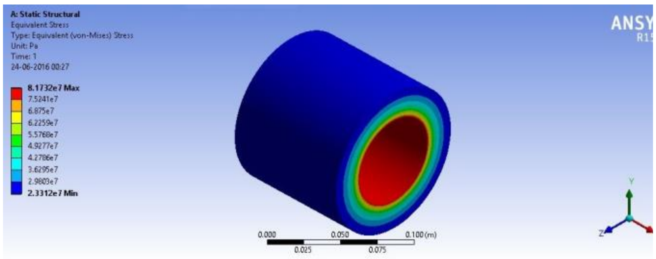

Fig. 4 Von-Mises Stress Of Single Layer SA516Gr70

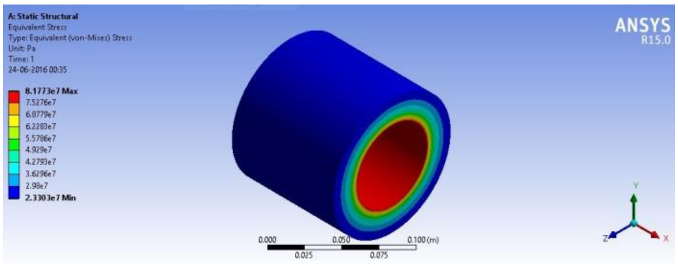

Fig. 5 Von-Mises Stress Of 3-Layer SA516Gr70

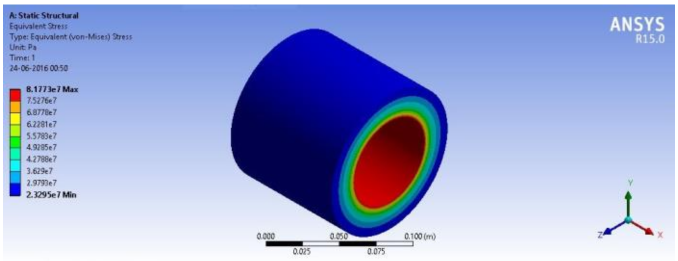

Fig. 6 Von-Mises Stress Of 5-Layer SA516Gr70

TABLE II
Comparison of Allowable and Max. Stresses

Sr. No.	LAYERS	Ansys Stress (max)	Ansys Stress (min)	Max. allowable Stress
1	Single	$8.1732e^7$	$2.331e^7$	$4.6e^8$
2	3-layer	$8.1773e^7$	$2.330e^7$	$4.6e^8$
3	5-layer	$8.1773e^7$	$2.329e^7$	$4.6e^8$

VII. Conclusion

The various parameters of design were studied and a best material for design was selected on basis of these parameters. The significant design parameters of pressure vessel are Design Pressure, Allowable stress, Corrosion Allowance. The stresses developed in Solid wall pressure vessel and Multilayer pressure vessel is analyzed by using ANSYS, a versatile Finite Element Package as well as theoretically. As numbers of layers are increasing the variation in rate of change of hoop stress is decreasing. It represents that the effect of layers to reduce the hoop stresses is reducing with increasing the number of layers. Hence the design is safe.

Appendix

ρ= Density of material, kg/m^3
E= Modulus of elasticity, GPa.
σ_Y = Yield strength of the material, MPa.
ν = Poisson Ratio
Di=Inside diameter
Do=Outside diameter

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