DESIGN AND ANALYSIS OF MULTILAYER HIGH PRESSURE VESSELS

Siva Krishna Raparla[1] ,T.Seshaiah[2]
[1] PG Student, [2] Associate Professor
Department of Mechanical Engineering
QIS College of Engineering &Technology
Ongole, Andhra Pradesh

ABSTRACT :

The main objective of this paper is to design and analysis of multilayer high pressure vessels features of multilayered high pressure vessels, their advantages over mono block vessel are discussed. Various parameters of Solid Pressure Vessel are designed and checked according to the principles specified in American Society of Mechanical Engineers (A.S.M.E) Sec VIII Division 1. Various parameters of Multilayer Pressure vessels are designed and checked according to the principles specified in American Society of Mechanical Engineers (A.S.M.E) Sec VIII Division 1.

The stresses developed in Solid wall pressure vessel and Multilayer pressure vessel is analyzed by using ANSYS, a versatile Finite Element Package.

The theoretical values and ANSYS values are compared for both solid wall and multilayer pressure vessels.

Keywords : Design, Analysis, Solid & Multilayer Pressure vessel, ANSYS.

1.0 INTRODUCTION

In Process Industries, like chemical and petroleum industries designers have recognized the limitations involved for confining large volumes of high internal pressures in single wall cylindrical metallic vessels.

In process engineering as the pressure of the operating fluid increases, increment in the thickness of the vessel intended to hold that fluid is an automatic choice. The increment in the thickness beyond a certain value not only possesses fabrication difficulties but also demands stronger material for the vessel construction.

The media which a pressure vessel contains produce critical changes to the physical properties of the vessel material during service. One of these that is often encountered is hydrogen, which under the action of high pressure and / or high temperature produces tow effects: (1) A diffusion into the metal as atomic hydrogen and a process of recombining to its molecular form within the metal, thereby creating extremely high pressures with resulting surface bulging or blistering, and (2) a mechanical decarburizing, and reducing effect on sulfides or oxides present in the steel creating a brittleness and resultant cracking under high stress.

These points out the fundamental importance of both minimizing stress concentrations in vessels designed to low factors of safety and considering the various media to which these vessels are to be subjected throughout their life.

With increasing demands from industrial processes for higher operating pressures and higher temperature, new technologies have been developed to handle the present day specialized requirements. Multilayer Pressure Vessels have extended the art of pressure vessel construction and presented the process designer with a reliable piece of equipment useful in a wide range of operating conditions for the problems generated by the storage of hydrogen and hydrogenation processes

The term pressure vessel referred to those reservoirs or containers, which are subjected to internal or external pressures.

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. Pressure vessels find wide applications in thermal and nuclear power plants, process and chemical industries, in space and ocean depths, and in water, steam, gas and air supply system in industries.

The material of a pressure vessel may be brittle such as cast iron, or ductile such as mild steel.

(a) Solid Wall Vessel *(b)Multi Layered Cylindrical Vessel*

Fig.1 Types of High Pressure Vessels

High Pressure vessels are used as reactors, separators and heat exchangers. They are vessel with an integral bottom and a removable top head, and are generally provided with an inlet, heating and cooling system and also an agitator system. High Pressure vessels are used for a pressure range of 15 N/mm^2 to a maximum of 300 N/mm^2. These are essentially thick walled cylindrical vessels, ranging in size from small tubes to several meters diameter. Both the size of the vessel and the pressure involved will dictate the type of construction used.

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. In general, the physical criteria are governed by the ratio of diameter to wall thickness and the shell is designed as thick cylinder, if its wall thickness exceeds one-tenth of the inside diameter. A solid wall vessel is also termed as Mono Block pressure vessel.

2.0 DESIGN OF MULTILAYER HIGH PRESSURE VESSEL

Multi layer vessels are built up by wrapping a series of sheets over a core tube. The construction involves the use of several layers of material, usually for the purpose of quality control and optimum properties. Multi layer construction is used for higher pressures. It provides inbuilt safety, utilizes material economically, no stress relief is required. For corrosive applications the inner liner is made of special material and is not considered for strength criteria. The outer load bearing shells can be made of high tensile low carbon alloys.

2.1 DESCRIPTION OF THE PROBLEM

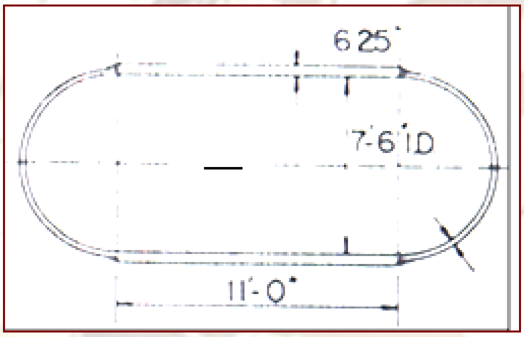


Fig. 2 A typical Multilayer Pressure Vessel to be designed

2.2 Design Objectives

1. To show that multilayer pressure vessels are suitable for high operating pressures than solid wall pressure vessels.
2. To show a significant saving in weight of material may be made by use of a multilayer vessel in place of a solid wall vessel.
3. To show there may be a uniform stress distribution over the entire shell, which is the indication for most effective use of the material in the shell.
4. To check the suitability of using different materials for Liner shell and remaining layers for reducing the cost of the construction of the vessel.
5. To verify the theoretical stress distribution caused by internal pressure at outside surface of the shell and to ascertain that the stresses do not reach yield point value during testing.
6. Finally check the design parameters with FEM analysis by using ANSYS package to ascertain that FEM analysis is suitable for multilayer pressure vessel's analysis.

2.3 Design Considerations

1. A multilayer Vessel is designed to ASME Code Section VIII division I.
2. A Safety Factor of **"3"** on Ultimate Tensile Strength is considered in the design of the multi layer shell only. For other parts the Factor of Safety is taken as "4" at room temperature.
3. A joint efficiency of 100% for longitudinal seam on liner shell is taken.
4. 100% radiography for longitudinal seam of liner shell.
5. Fully ultrasonic test for dished end plates is considered.
6. Dished ends to be stress relieved after attachment of boss, nozzle etc.,
7. The longitudinal welds in a multilayered shell were staggered.
8. The number segments (longitudinal welds) in a layer are taken as "3".
9. The coefficient of weld shrinkage is taken as 10%.(From Davis R.L, "Circumferential welds in Multilayer Pressure Vessel" Paper .70-WA/PVP-6.)

10. The thickness of the liner shell is taken as 12 mm.
11. The thickness of subsequent layers is 6 mm.

3.0 DESIGN DATA OF THE VESSEL:

Design Pressure P - 21 N/mm^2, Hydrogen.
Design Temperature, T - 20^0C
Hydrostatic Pressure P_H - 27.3 N/mm^2

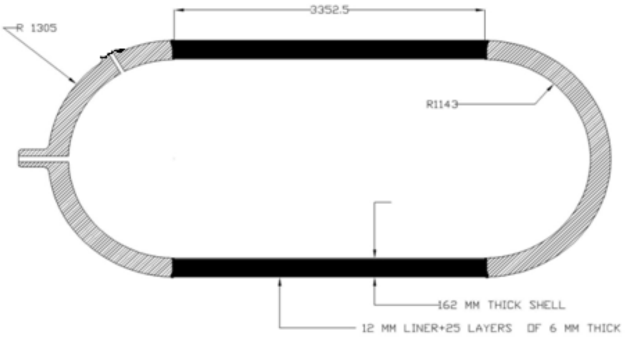


Fig 3 Drawing of Multilayer Pressure Vessel

CASE 1: MATERIALS OF CONSTRUCTION

Description	Material	Type of Steel	UTS (Min) N/mm^2	YP (Min) N/mm^2
Shell Liner	SA 515 GR 70	Austenitic	492.9	267.6
Shell Layers	SA 515 GR 70	Austenitic	492.9	267.6
Dished Ends	SA 515 GR 70	Austenitic	492.9	267.6

CASE 2: MATERIALS OF CONSTRUCTION

Description	Material	Type of Steel	UTS (Min) N/mm^2	YP (Min) N/mm^2
Shell Liner	SA 515 GR 70	Austenitic	492.9	267.6
Shell Layers	SA 212 GR B	Carbon Steel	490.0	-
Dished Ends	SA 515 GR 70	Austenitic	492.9	267.6

CASE 3: MATERIALS OF CONSTRUCTION

Description	Material	Type of Steel	UTS (Min) N/mm^2	YP (Min) N/mm^2
Shell Liner	SA 515 GR 70	Austenitic	492.9	267.6
Shell Layers	SA 204 GR C	Low Carbon Alloy	525.0	-
Dished Ends	SA 515 GR 70	Austenitic	492.9	267.6

For all the three cases, Allowable Stress values:

Shell Liner & Layers ; 164 N/mm^2

Dished Ends : 123 N/mm^2

4.0 STRUCTURAL ANALYSIS RESULTS

4.1 Solid Wall Pressure Vessel

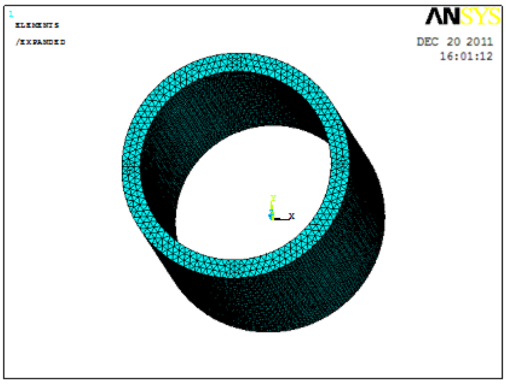


Fig: 4 Finite Element Model of Solid Wall Pressure Vessel in ANSYS 11.0

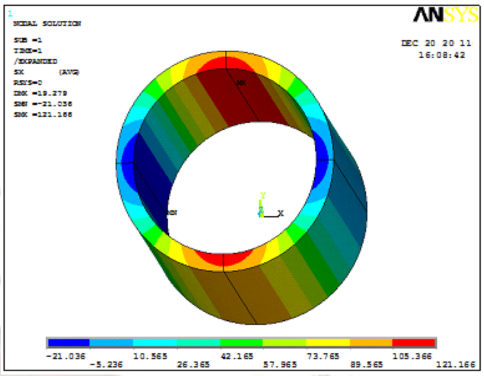


Fig:5 Stresses in X-Direction.

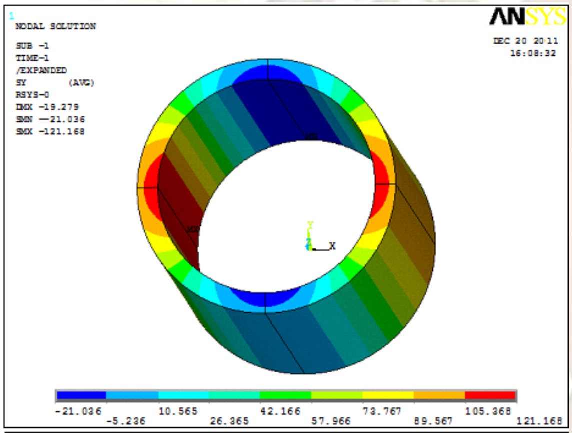


Fig:7 Stresses in Z-Direction.

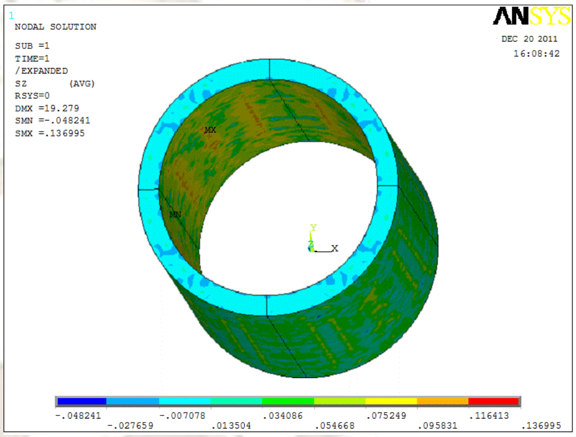


Fig:6 Stresses in Y-Direction

4.2 Multi Layer Pressure Vessel

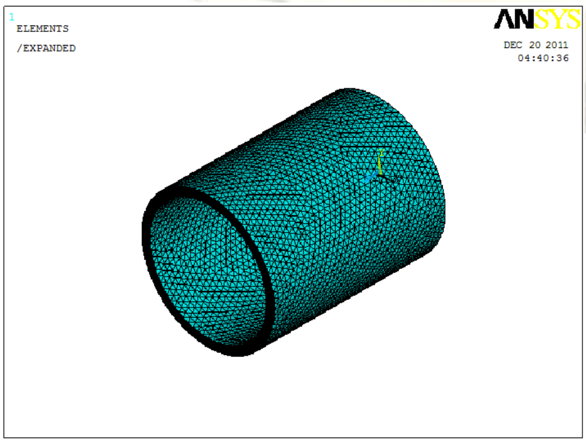


Fig: 8 Finite Element Model of Multi Layer Pressure Vessel in ANSYS 11.0

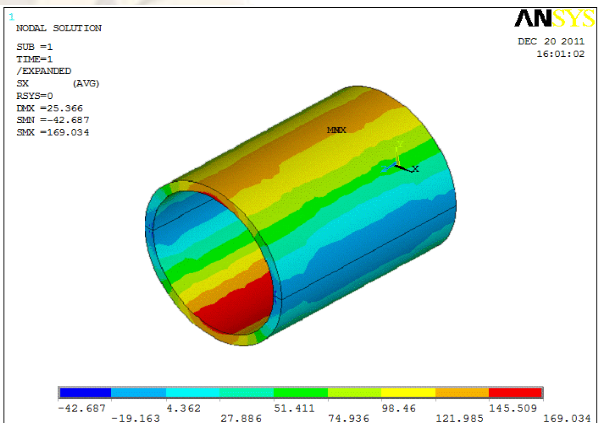


Fig:9 Stresses in X- Direction

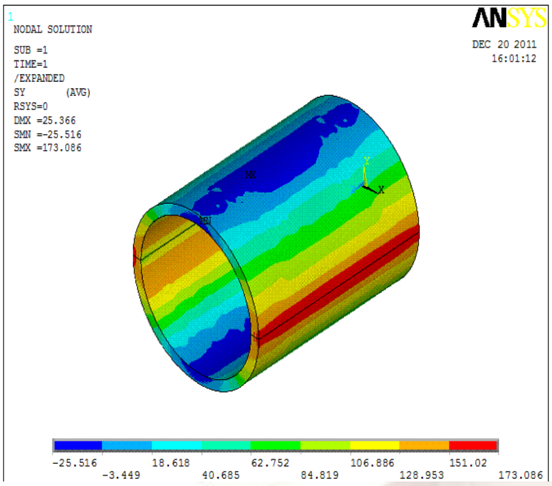


Fig:11 Stresses in Z-Direction

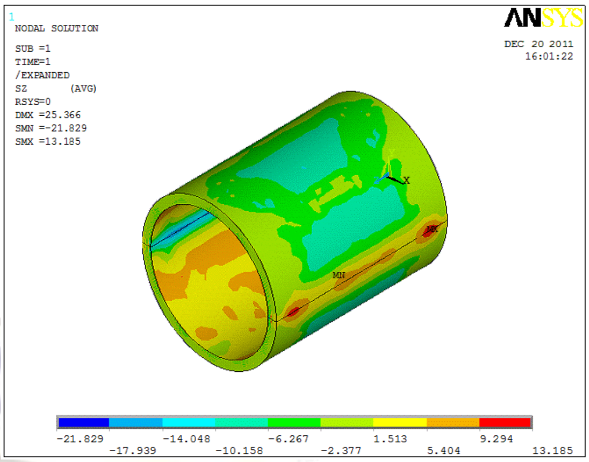


Fig: 10 Stresses in Y-Direction

4.4 Von-Mises Stesses

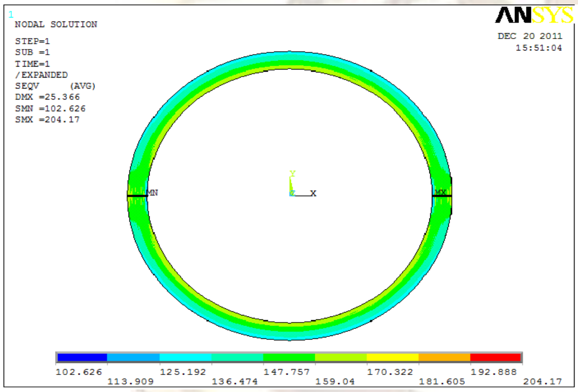


Fig: 12Von-Mises Stesses

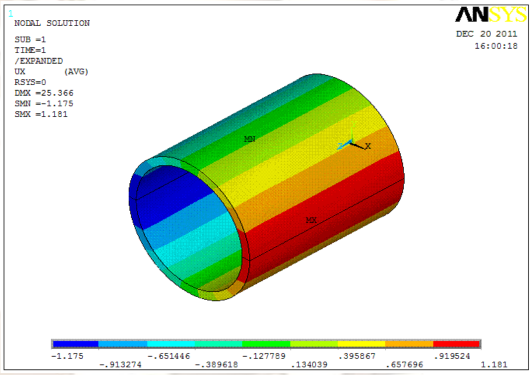


Fig :13 Displacement in X-Direction

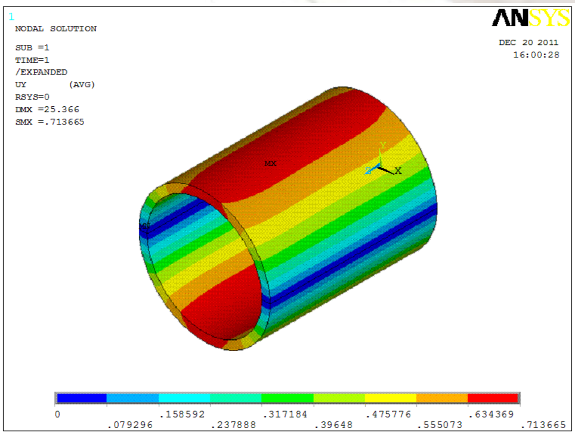


Fig: 14 Displacement in Y-Direction

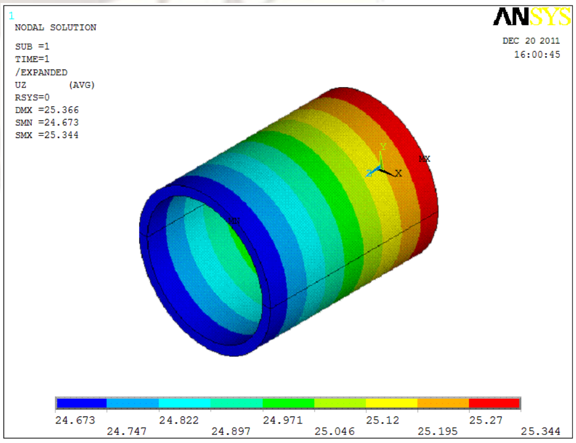
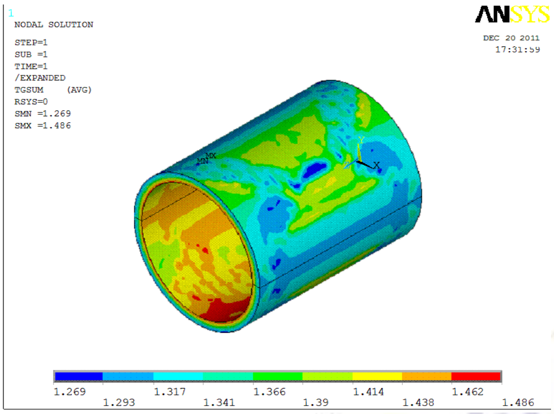


Fig: 15 Displacement in Z – Direction



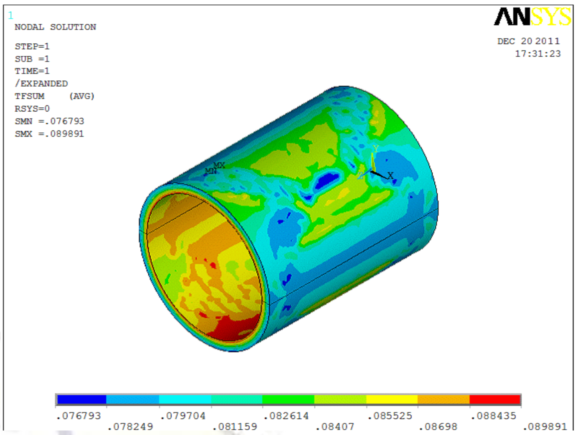


Fig :16 Temperature Gradient Sum

Fig :17 Temperature Flux Sum

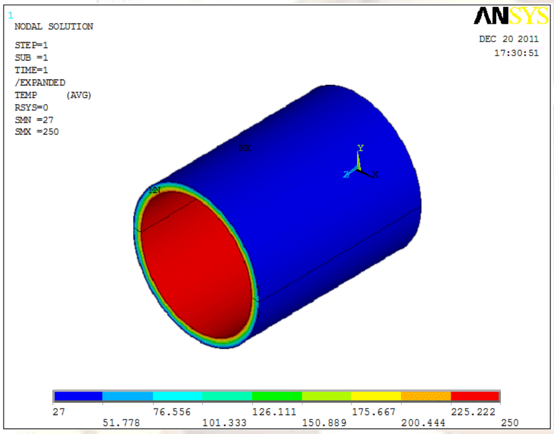


Fig :18 Temperature Distribution

5.0 C O N C L U S I O N S

The following conclusions are drawn from the above work

1. 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. This is one of the main aspects of designer to keep the weight and cost as low as possible.
2. The Stress variation from inner side to outer side of the multilayered pressure vessel is around **12.5%,** where as to that of solid wall vessel is **17.35%.** This means that the stress distribution is uniform when compared to that of solid wall vessel. Minimization of stress concentration is another most important aspect of the designer. It also shows that the material is utilized most effectively in the fabrication of shell.
3. Theoretical calculated values by using different formulas are very close to that of the values obtained from ANSYS analysis. This indicates that ANSYS analysis is suitable for multilayer pressure vessels.
4. 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.

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