"DESIGN AND ANALYSIS OF MULTILAYER HIGH PRESSURE VESSEL"

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Abstract

This technical paper presents design, and analysis of pres- sure vessel. High pressure rise is developed in the pressure vessel and pressure vessel has to withstand severe forces. In the design of pressure vessel safety is the primary consideration, due the potential impact of possible accident. There have a few main factors to design the safe pressure vessel. This writing is focusing on analyzing the safety parameter for allowable working pressure. Allowable working pressures are calculated by using Pressure Vessel Design Manual by Dennis Moss, third edition. The corruption of the vessel are probability occur at maximum pressure which is the element that only can sustain that pressure. Efforts are made in this paper to design the pressure vessel using ASME codes & standards to legalize the design.

Keywords: Pressure vessel, ASME code, Design, FEM, Stress.

Introduction

The pressure vessels are same as that of the containers or reservoirs which contains large amount of internal and external pressures. The storage of fluids under high pressures is done in Pressure vessel. The liquid being put away may experience a change of state inside the pressure vessels as if there should raise an occurrence of steam boilers or it may merge with different reagents as in chemical plants. Pressure vessels have wide applications in thermal and atomic power plants, chemical and process industries, in sea depths and space, and in water, steam, gas and air supply in industries. The material of a pressure vessel may be weak, for example, cast iron, or malleable, for example, mild steel. The pressure differential is dangerous, and fatal accidents have occurred in the history of pressure vessel development and operation.

Consequently, pressure vessel design, manufacture, and operation are regulated by engineering authorities backed by legislation. For these reasons, the definition of a pressure vessel varies from country to country, but involves parameters such as maximum safe operating pressure and temperature, and are engineered with a safety factor, corrosion allowance, minimum design temperature (for brittle fracture), and involve non destructive testing such as ultrasonic testing, radiography and pressure tests, usually involving water, also known as a hydro test but could be pneumatically tested involving air or another gas. The preferred test is hydrostatic testing because it's a much safer method of testing as it releases much less energy if fracture were to occur (water does not rapidly increase its volume while rapid depressurization occurs, unlike gases like air, i.e. gasses fail explosively). In the United States, as with many other countries, it is the law that vessels over a certain size and pressure (15 PSIg) be built to Code, in the United States that Code is the ASME Boiler and Pressure Vessel Code (BPVC), these vessels also require an Authorized Inspector to sign off on every new vessel constructed and each vessel has a nameplate with pertinent information about the vessel such as maximum allowable working pressure, maximum temperature, minimum design metal temperature, what company manufactured it, the date, its registration number (through the National Board), and ASME's official stamp for pressure vessels (U-stamp), making the vessel traceable and officially an ASME Code vessel.

MULTI-LAYER PRESSURE VESSEL

Multi-layer cylinders are assembled so as to have an interference fit between the respective layers. This will result in compressive residual stresses in the inner element and tensile residual stresses in the outer element. The interference fit between layers be accomplished by heating and "shrinking on" of outer elements having a bore diameter slightly smaller than that of the respective inner element or by having matched tapers on the inside and outside surface of the outer and inner elements respectively and forcing the elements into each other by means of a press. The resultant interface pressures, residual stresses, operating stresses and the yielding pressure and location of the onset of yielding will be a function of several variables. The most pertinent of these variables are the number of elements and their relative yield strengths and elastic modulus, and the diameter ratios of the elements. As an approach to presenting the design theory for multi-layer vessels, the simplest case of a two element construction having equal strengths and elastic modulus in the inner (liner) and outer (jacket) elements will be considered first. Following this, the two-element cylinder, wherein the yield strengths and elastic modulus differ between jacket and liner, will be discussed. Finally, the question of a cylinder consisting of more than two layers will be considered.

1. Two-element cylinders - same material

The simplest and most -generally used form of the multi-layer vessel involves two elements consisting of a jacket and liner. For the case where the yield strength and elastic modulus of the line and jacket are the same. The resulting residual stresses can be determined from the Lame equations. To determine the elastic stress state in the composite cylinder when subjected to an internal pressure, the stresses produced by the pressure are added to the residual stresses.

Multi-layer cylinders having more than two elements

The above analysis of a compound cylinder has considered only a two element cylinder. The analysis of a multi-element cylinder is basically the same. To determine the final yield pressure, the total stress state at the bore of each element is calculated and checked for yielding. The analysis of a compound cylinder having more than two elements has been investigated by Becker et al and by Pugh using the Tresca yield criteria. They are vessel with a fundamental base and a removable top head, and are generally outfitted with an inlet, heating and cooling system an agitator system. High Pressure vessels are used for a pressure capacity of 15 N/mm2 to a greatest of 300 N/mm2. These are essentially thick cylindrical vessels and hollow vessels, ranging in size from small tubes to a few meter diameters. Both the measure of the pressure and vessel included will manage the sort of construction utilized.

a. NEED OF MULTILAYER PRESSURE VESSEL

Disadvantages of single layer vessel

1. Mono block vessels as the operating pressure in the shell increases, the required shell thickness also increases.

2. Regardless of the theory employed to calculate the maximum stress in the wall of a thick walled vessel, a non-uniform stress distribution under pressure will be found to exist in a mono block vessel.

3. With increase in internal pressures in mono block vessels, the problems of economic use of material as well as those of fabrication become critical. So a better utilization of the material is possible by setting upon initial stresses in the shell, known as pre- stressing. One of the pre-stressing methods is Multi layer construction of Pressure Vessels, which is the best, suited for high pressure and high temperature operating conditions.

Multilayer pressure vessels

Multi layer pressure 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.

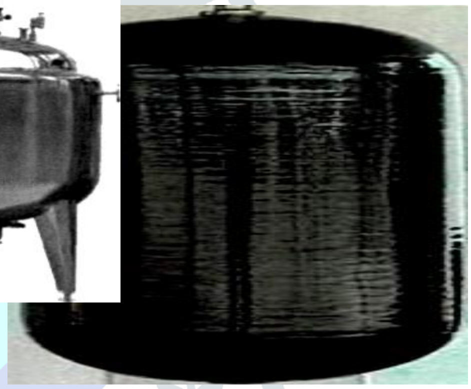


Figure 1 COMPOSITE PRESSURE VESSELE

Figure 2 MULTILAYER PRESSURE VESSELE

Figure 3 THIN PRESSURE VESSELE

APPLICATIONS OF MULTILAYER PRESSURE VESSEL

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* 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.

COMPONENETS OF PRESSURE VESSELS

Following are the main components of pressure Vessels in general

a) Shell

b) Head

c) Nozzle

d) Support

a). SHELL : It is the primary component that contains the pressure.

1. Pressure vessel shells in the form of different plates are welded together to form a structure that has a common rotational axis.

2. Horizontal drums have cylindrical shells and are constructed in a wide range of diameter and length

3. Shell of a spherical pressure vessel is spherical as well.

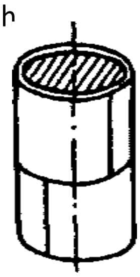


Fig. 4 shell

Fig.5 head

b) . HEAD:

1. All the pressure vessels must be closed at the ends by heads (or another shell section).

2. Heads are typically curved rather than flat.

3. The reason is that curved configurations are stronger and allow the heads to be thinner, lighter and less expensive than flat heads.

c). NOZZLE:

A nozzle is a cylindrical component that penetrates the shell or heads of a pressure vessel. The nozzle ends are usually flanged to allow for the necessary connections and to permit easy disassembly for maintenance or access. Nozzles are used for the following applications.

1. Attach piping for flow into or out of the vessel.
2. Attach instrument connections, (e.g., level gauges, thermo wells, or pressure gauges).
3. Provide access to the vessel interior at midways.

D) SUPPORT:

Support is used to bear all the load of pressure vessel, earthquake and wind loads. It is considered to be the non-pressurized part of the vessel. There are different types of supports which are used depending upon the size and orientation of the pressure vessel.

They are

1. Saddle support
2. Skirt support
3. Leg support
4. Lug support

MATERIAL SELECTION

The choice of materials for pressure vessels depends upon several factors including stress level, stress state, number of cycles, construction, stress discontinuities, failure criterion, environment, etc. Here again, as in the case of vessel design, it seems more pertinent in view of the wide spectrum of vessel design and application to consider the principles of material selection rather than specific materials for each possible application. To start, it may be helpful to consider what properties of a material are significant in pressure vessel applications. Different codes representing the strategies for the design, fabrication, inspection, testing and operation of vessels have been produced, somewhat as a safety measure. These methods outfit gauges by which any state can be guaranteed or the wellbeing of weight vessels introduced inside of its limits. The particulars in these codes were initially based upon the details produced for steam boilers. Section VIII of ASME Boiler and Pressure Vessel Code, 1956 is the code utilized for unfired pressure vessels.

Yield Strength

Yield strength is one of those properties whose significance is obvious and little need be said. One point worthy of mention, however, is that, in some materials from a practical standpoint, yield strength, or more appropriately fracture strength in the case of highly brittle materials, is anisotropic. For example, in some high carbon tool steels, carbide, etc., the strength in compression far exceeds the strength in tension. In the use of such materials then, one must consider the difference in the ability to withstand compressive versus tensile stresses. For example, tungsten carbide is a highly, desirable material for the segments of segmented vessels since the principal stress is compressive with no appreciable tensile tangential stresses due to the discontinuous sections.

Ductility and Toughness

All too often ductility and toughness have not been considered in the selection of a material. There has been a tendency to rationalize that if one can use a material of sufficient strength so that no plastic deformation will occur, ductility and toughness are of no importance. This often leads to the use of very high strength but often highly brittle materials. There are several pitfalls in the above rationalization. One may not be able to accurately predict the actual stress level. Thus, the use of fracture toughness data should be considered for use rather than the impact type data.

The Major Methods For Manufacture Of Thick-Walled Pressure Vessels Are As Follows:

1. Mono block Solid vessel wall.
2. Multilayer-Begins with a core about 1/2 in. thick and successive layers are applied. Each layer is vented (except the core) and welded individually with no overlapping welds.

3. Multiwall-Begins with a core about 1% in. to 2 in. thick. Outer layers about the same thickness are successively "shrunk fit" over the core. This creates compressive stress in the core, which is relaxed during pressurization. The

process of compressing layers is Called auto-frettage from the French word meaning “self-hooping.”

Construction of High-Pressure Vessels

1. A cylinder formed by bending a sheet of metal with longitudinal weld.

2. Shrink fit construction in which, the vessel is built up of two or more concentric shells, each shell progressively shrunk on from the inside outward. From economic and fabrication considerations, the number of shells should be limited to two.

3. A vessel built up by wire winding around a central cylinder. The wire is wound under tension around a cylinder of about 6 to 10 mm thick.

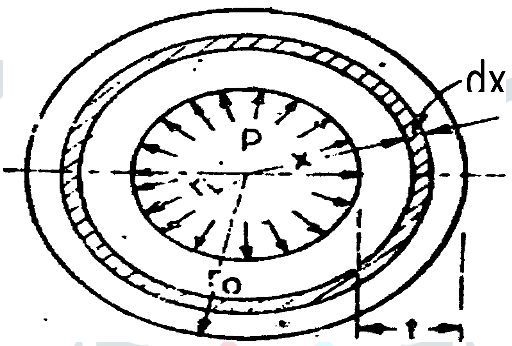


Fig. 6 Solid Wall Vessel

STRESS ANALYSIS USING FEM

The stress analysis of the exhaust is carried out for the determination of the stress concentration level at the failed region by the finite element method. The commercial finite element software ANSYS 14.0 is used for the analyses.

The Pre-processing consists of several steps like modeling, mesh generation, applying boundary condition.

- **Finite Element Modeling** The first step in Pre-processing is to prepare a proper CAD model of exhaust valve by using SOLIDWORKS software. After generating the CAD model it is saved in the file “abc.iges” and then it is imported in ANSYS Workbench.

- **Mesh Generation:** Finite element mesh is generated using automatic method. After that line sizing and edge sizing is given to the model so that the meshing can be done smoothly and we got better result after meshing.

Material Attributes

Material	SA516 Gr70
P	7750
E	192
o,	260
N	0.3

DESIGN DATA OF THE VESSEL:

Material = structural steel, UTS = 460 MPa, Yield Stress = 250 MPa, Inside diameter = 50 mm Outside diameter = 100 mm , Young's modulus E = 210 MPa Internal pressure P, = 35 MPa

For multilayer

Material same as above Inside diameter = 50

mm Outside diameter=100mm Young's modulus

E=210MPa Internal pressure P,=35MPa Internal

diameter = 75 mm

Compare results of Analytical & FEA for mono block & multilayer.

ANALYTICAL ESTIMATION OF HOOPSTRESSES

1-LAYER PRESSURE VESSEL:

Thickness (t) and outer diameter () of 1-layer pressure vessel is given by equation 1 &2,

$$Thickness = t = r_i \sqrt{\frac{\sigma_t + p_i}{\sigma_t - p_i}} - 1 \quad (1)$$

now, otzt er *diarnete(dy)* — *d* -I- *ft* x. 2) (2)

Hoop stress in 1-layer pressure vessel is given by equation (3),

$$\sigma_\theta = \frac{p_i({r_2}^2 + {r_1}^2)}{({r_2}^2 - {r_1}^2)} \quad (3)$$

3-LAYER PRESSURE VESSEL:

The Hoop stresses induced at outer and inner radius of layer 1 only due to contact pressure (ps12) at the Junction is given by equation,

RESULT AND DISCUSSION

A finite element (FE) model contains an arrangement of points, called "nodes", which frame the state of the design. Joined with these nodes are the finite elements themselves which frame the finite element mesh and contain the material and basic properties of the model, characterizing response of it in specific conditions. The density of the finite element mesh may differ al(through the material, contingent upon the foreseen change in stress levels of a specific part. Areas that experience high changes in stress for the most part require a higher mesh density than those that experience little or *no* stress variation.

STRESS ANALYSIS USING FEM

There are three steps in software based on Finite Element Analysis

1. Pre-processing
2. Solution
3. Post processing

1). Pre-processing

The Pre-processing consists of several steps like modelling; mesh generation, applying boundary condition.

Finite Element Modeling The first step in Pre-processing is to prepare a proper CAD model of exhaust valve by using SOLIDWORKS software. After generating the CAD model it is saved in the file "abc.iges" and then it is imported in ANSYS Workbench.

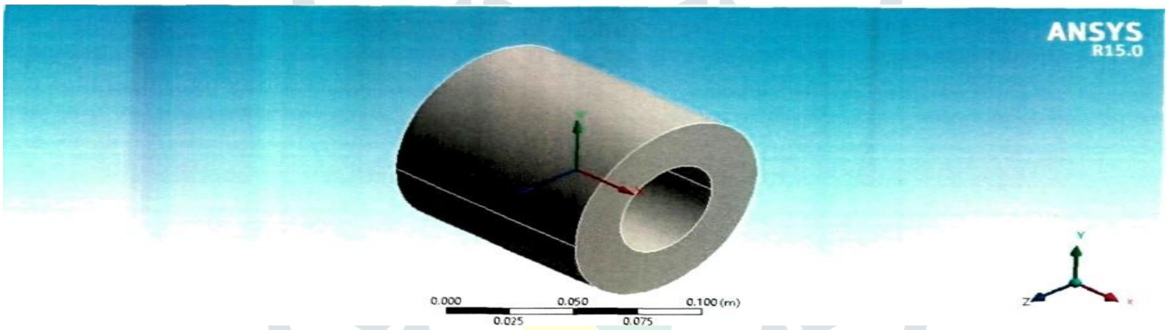


Figure 7 **Geometry Of Single Layer SA516Gr70**

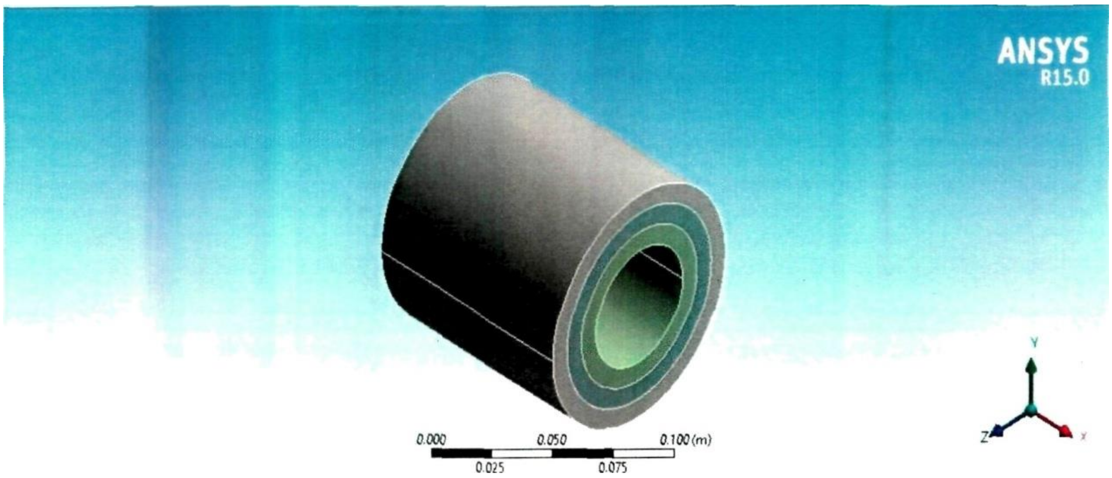


Fig. 8 Geometry of 3- Layer SA516Gr70

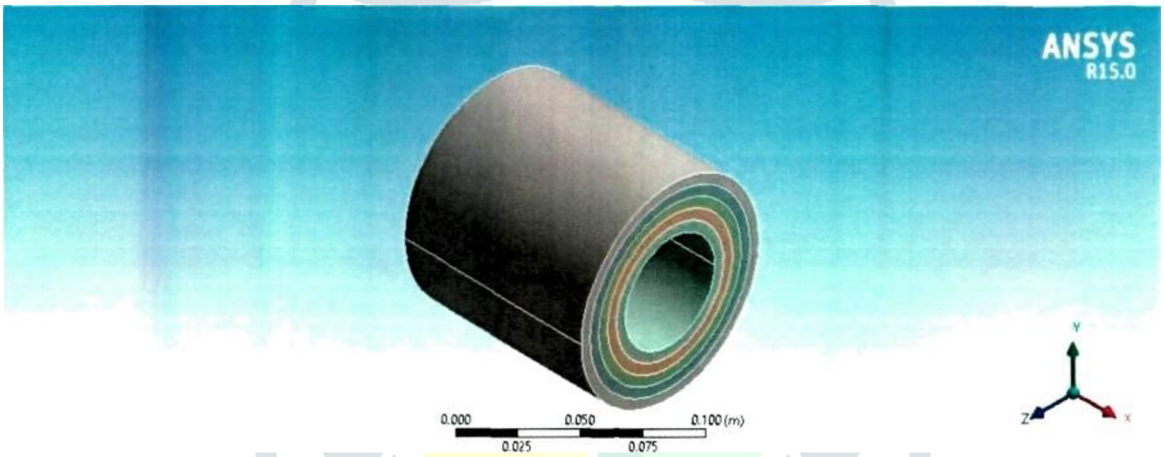


Fig. 9 Geometry Of 5- Layer SA516Gr70

- Mesh Generation: Finite element mesh is generated using automatic method. After that line sizing and edge sizing is given to the model so that the meshing can be done smoothly and we got better result after meshing

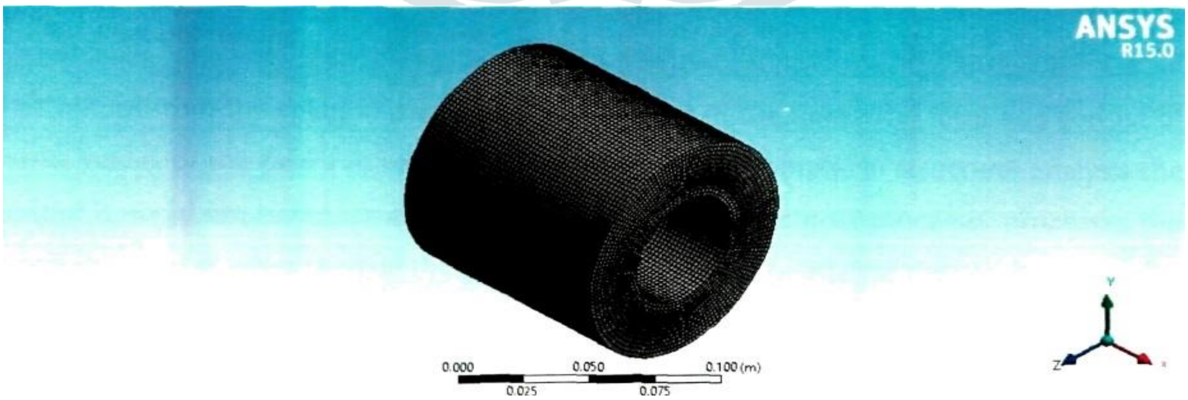


Fig. 10Meshing Of Single Layer SA516Gr70

Boundary Condition: The third and last step of pre-processing is applying boundary condition. The boundary condition is the collection of different forces, supports, constraints and any other condition required for complete analysis. All constraints and loads are assigned.

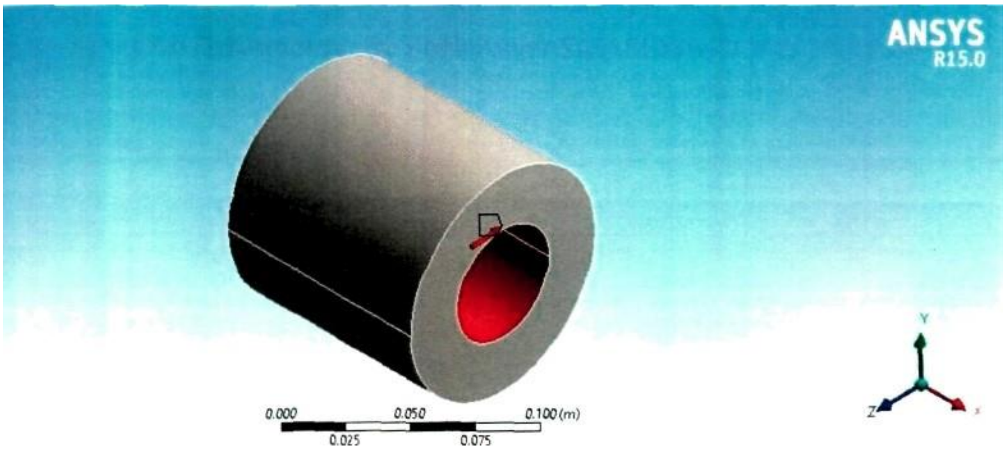


Fig. 11 loading Of Single Layer SA516Gr70

1) **Solution :**

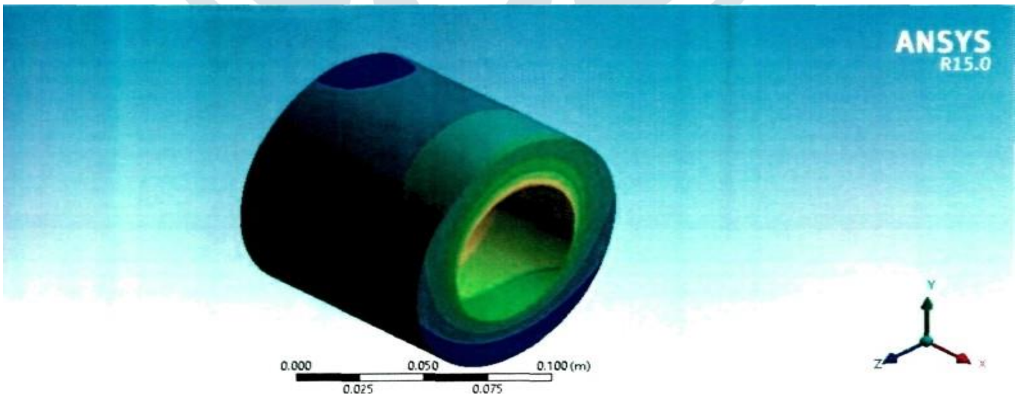
The solution phase deals with th€' Solution of the problem according to the problem definition. All the tedious work of formulating and assembling of matrices are done by the computer and finally deformation and stress value are given as output.

2) **Post processing**

The output from the solution phase (result data files) in the numerical form and consist of nodal values of the field variable and is derivatives. For example, in structural analysis the output is nodal displacement and stress in the elements. The post-processor processes the result data and displays them in the graphical form to check or analyse the result.

Deformation

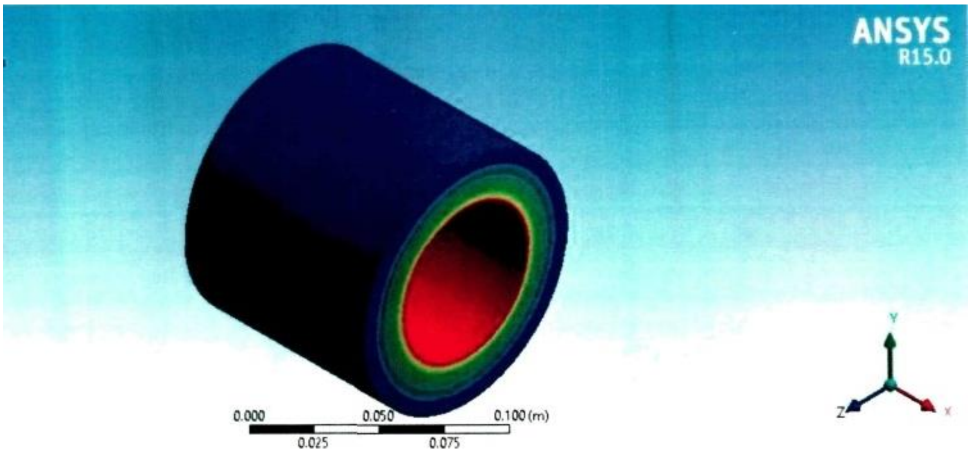
Fig.12 Deformation of Single Layer SA516Gr70



DISCUSSION

LAYERS	Deformation	Stress
Single	1.0703e-5	8.1732e 7
3-layer	9.6844e-6	8 .1773e7
5-layer	8.9677e-6	8.1773e7

Table 2 Comparison Of Stress And Deformation Values For Different Layers



The stresses developed in Solid wall pressure vessel and Multilayer pressure vessel is analyzed by using ANSYS, a versatile Finite Element Package .Also as numbers of layers are increasing the variation in rate of change of hoop stress is decreasing. It represents that the effectiveness of layers to reduce the hoop stresses is reducing with increasing the number of layers.

CONCLUSION

Solid wall pressure vessels are extensively used now-a-days. The huge difference of weight is observed by introducing the multi layered vessels. The usage of multilayer pressure vessel decreases the weight as well as the material cost required to manufacture. Decreasing the weight and also cost is the main aspect of the designer. Multi layered vessels are compared to solid vessels with respect to the stresses developed. The most important aspect of the designer is to minimize the stress concentration developed. The effective usage of material during the fabrication is also observed. By observing, the vessels are favoured to work under conditions of high temperature and high pressures. The usage of multilayer pressure vessels is having more advantages than single wall pressure vessels.

SCOPE

Research is going on pressure vessel design for carrying fluid at high pressure as well as for safety purposes. It emerges many fields ofresearch.

1. Single layer vessels are replaced by multilayer vessels. Initially layers was of same material but research is going for composite material layers for maximum rigidity with minimum weight.
2. Decreasing thickness as well as variable thickness
3. Local pressure testing not full pressure testing
4. Optimization of material (not using very high factor of safety)

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