DESIGN AND ANALYSIS OF PRESSURE VESSEL AT WELDED JOINTS FOR DIFFERENT WELD EFFICIENCES

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ABSTRACT: Pressure vessel cylinders find wide applications in thermal and nuclear power plants, process and chemical industries, in space and ocean depths, and fluid supply systems in industries. Good design practice is allowable pressure for weld strength expressed as weld efficiency. Efficiency is defined as the ratio of longitudinal (axial) strength of a welded joint to the longitudinal strength of pipe or tank shell.

In this thesis, the pressure vessel is designed according to the weld efficiency and analyzed for its strength using Finite Element analysis software ANSYS. Mathematical correlations will be considered for the design of pressure vessel whose design parameters are specified by a company according to the required weld efficiency. Modeling will be done in Pro/Engineer.

Structural and fatigue analysis will be done in ANSYS on the welded joint of pressure vessel for different weld efficiencies.

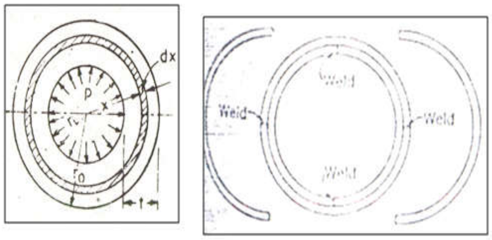
I.INTRODUCTION TO PRESSURE VESSELS

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.

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.

The following are few methods of construction of high-pressure vessels.

1. A solid wall vessel produced by forging or boring a solid rod of metal.
2. A cylinder formed by bending a sheet of metal with longitudinal weld.
3. 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.
4. 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.
5. A vessel built up by wrapping a series of sheets of relatively thin metal tightly round one another over a core tube, and holding each sheet with a longitudinal weld. Rings are inserted in the ends to hold the inner shell round while subsequent layers are added. The liner cylinder generally up to12 mm thick, while the subsequent layers are up to 6 mm thick.



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

Fig.1 Types of High Pressure Vessels

FACTORS CONSIDERED IN DESIGNING HIGH PRESSURE VESSELS:

The application of high pressure to the chemical process industries opened a new field to the design engineer. This relatively new technique originated in the industrial synthesis of ammonia from its elements and with the process for the cracking of oil. Now the high pressure vessels are extended up to 350 MPa.

In designing high pressure vessels, the main factors to be considered are:

- Dimensions – Diameter, length, and their limitations.
- Operating conditions – Pressure and temperature.
- Available materials and their physical properties and cost.
- Corrosive nature of reactants and products.
- Theories of failure.
- Types of construction i.e. forged, welded or casted.
- Method of fabrication
- Fatigue, Brittle failure and Creep.
- Economic considerations.

SOLID WALL PRESSURE VESSEL:

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.

WHEN TO USE A MULTILAYER VESSEL:

It is hard to give firm and fast rules as when a multilayer vessel is more suitable than a solid wall vessel. Generally, though, the thicker the vessel wall and the longer the vessel, the more attractive a Multilayer vessel will be, since the economy is gained solely in the shell of the vessel.

It often is more economical to make a Multi layer vessel as long as possible considering a constant volume. This is due to the fact that the shell of a multilayer vessel is the least expensive portion of the vessel on a Rs/kg/N/mm^2. Therefore, the more weight in the shell, in proportion to the weight of the heads, the less the total cost of the vessel.

Usually, the selection of a Multilayer vessel is predicated on economics. However, in some cases where solid wall limits are exceeded for e.g. Nuclear reactors, which use water as a coolant and hence evolve hydrogen by radiolysis. Storage vessels for missiles, which must operate at extremely high stresses to minimize the weight, carried a lot, are failing due to hydrogen in suspension.

DESIGN PAREMETERS:

The design of solid pressure vessel includes,

(a) Design of Vessel thickness
(b) Design of Dished ends thickness.
(c) Calculation of Hydrostatic Test Pressure
(d) Calculation of Bursting Pressure

DESIGN OF VESSEL THICKNESS (t):

The Vessel holds the fluid under pressure and the tangential stress is taken as design stress. A joint in the longitudinal direction, which is considered in terms of joint efficiency, forms the Vessel.

II. LITERATURE SURVEY

The importance of a well engineered vessel, manufactured with careful inspection and quality control methods, remain as the crucial factor for obtaining a safe, economical, and serviceable unit.

As early as 1890 Mr. Carl Schaeffer of Oberhauson, Germany, obtained a U.S. patent covering the multiple layer construction for “riveted” boilers and the like vessels. The patent is required for the ever-increasing tension of steam required for steam boilers, the damage imparted to thick sheet iron during forming and the un proportional cost of the thick plates. But from the early investigations, the patent was prompted by the current limitations of the solid wall constructions and was never widely accepted.

However, with advent of welding and the increase need for high-pressure vessels, designers in the 1930’s started to develop vessel concepts, which employed multiple layers of material for the vessel wall. Since that time thousands of multiple wall vessels have been put into service, both here and abroad, with an excellent record of performance. There are a number of multilayer vessel concepts available to the user today. The wicker type vessel, developed in Germany, uses a corrugated metal tape or ribbon spiral wound around an inner core cylinder. Spiral grooves to match the corrugations of the tape are first machined into the outer surface of the inner cylinder. Then, layer at a time, until the full wall thickness is reached.

III. Problem description &methodology

Pressure vessel cylinders find wide applications in thermal and nuclear power plants, process and chemical industries, in space and ocean depths, and fluid supply systems in industries. Good design practice is allowable pressure for weld strength expressed as weld efficiency. Efficiency is defined as the ratio of longitudinal (axial) strength of a welded joint to the longitudinal strength of pipe or tank shell.

Materials	Models	Software's	Problems
Steel, S2glass fiber & e-glass fiber	Weld efficiency 0.85 and weld efficiency 1.0	CREO for modeling ANSYS for analysis	Static analysis , fatigue analysis and linear layer analysis

IV. INTRODUCTION TO CAD

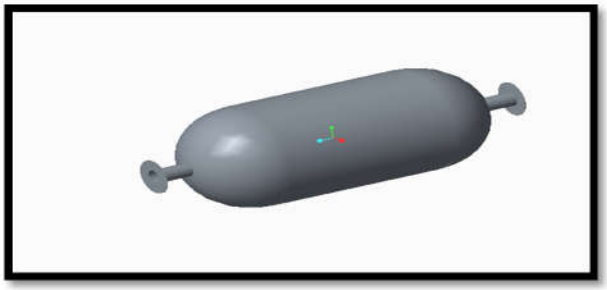
Throughout the history of our industrial society, many inventions have been patented and whole new technologies have evolved. Perhaps the single development that has impacted manufacturing more quickly and significantly than any previous technology is the digital computer. Computers are being used increasingly for both design and detailing of engineering components in the drawing office. Computer-aided design (CAD) is defined as the application of computers and graphics software to aid or enhance the product design from conceptualization to documentation.

INTRODUCTION TO PRO/ENGINEER

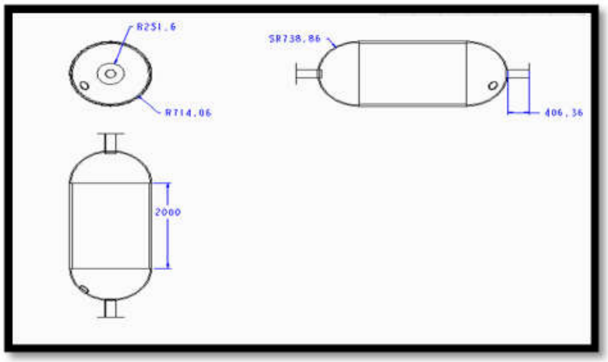
Pro/ENGINEER, PTC's parametric, integrated **3D CAD/CAM/CAE solution**, is used by discrete manufacturers for mechanical engineering, design and manufacturing.

Created by Dr. Samuel P. Geisberg in the mid-1980s, Pro/ENGINEER was the industry's first successful parametric, 3D CAD modeling system. The parametric modeling approach uses parameters, dimensions, features, and relationships to capture intended product behavior and create a recipe which enables design automation and the optimization of design and product development processes.

3D MODEL OF PRESSURE VESSEL



2D MODEL OF PRESSURE VESSEL



INTRODUCTION TO FINITE ELEMENT METHOD

Finite Element Method (FEM) is also called as Finite Element Analysis (FEA). Finite Element Method is a basic analysis technique for resolving and substituting complicated problems by simpler ones, obtaining approximate solutions Finite element method being a flexible tool is used in various industries to solve several practical engineering problems. In finite element method it is feasible to generate the relative results.

ANSYS Software:

ANSYS is an Engineering Simulation Software (computer aided Engineering). Its tools cover Thermal, Static, Dynamic, and Fatigue finite element analysis along with other tools all designed to help with the development of the product. The company was founded in 1970 by Dr. John A. Swanson as Swanson Analysis Systems, Inc. SASI. Its primary purpose was to develop and market finite element analysis software for structural physics that could simulate static (stationary), dynamic (moving) and heat transfer (thermal) problems. SASI developed its business in parallel with the growth in computer technology and engineering needs. The company grew by 10 percent to 20 percent each year, and in 1994 it was sold. The new owners took SASI's leading software, called ANSYS®, as their flagship product and designated ANSYS, Inc. as the new company name.

STATIC ANALYSIS OF PRESSURE VESSEL

CASES

Case 1: welding efficiency -1.0

Case 2: welding efficiency -0.85

USED MATERIALS

- Steel
- S2 glass fiber
- E –glass fiber

Material properties of steel

Young's modulus=205000Mpa

Poisson's ratio=0.3

Density=0.0000078kg/mm^3

Material properties of S2 glass fiber

Young's modulus=89000Mpa

Poisson's ratio=0.23

Density=0.00000249kg/mm^3

Material properties of e-glass fiber

Young's modulus=80000Mpa

Poisson's ratio=0.21

Density=0.00000255kg/mm^3

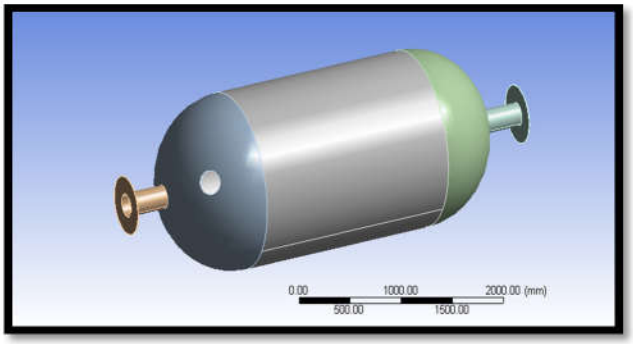
CASE 1: WELDING EFFICIENCY -1.0

MATERIAL -STEEL

Used software for this project work bench

Open work bench in Ansys 14.5

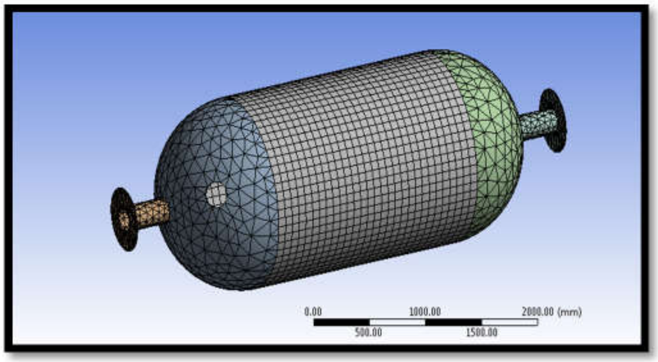
Select static structural>select geometry>import IGES model>OK



Click on model>select EDIT

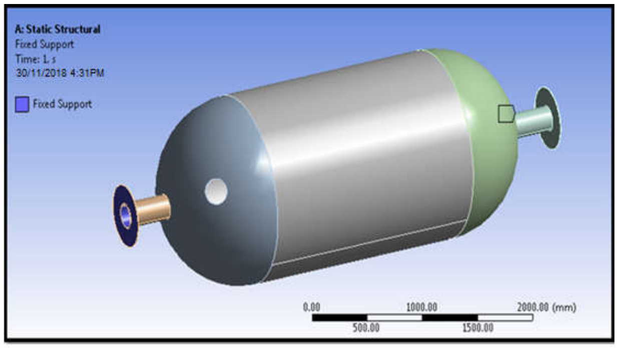
Select model >apply materials to all the objects (different materials also)

Mesh> generate mesh>ok

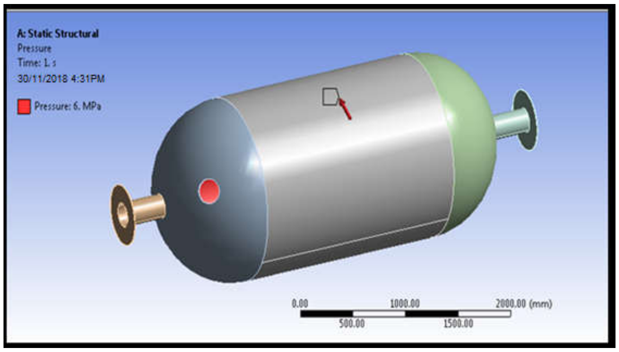


Finite element analysis or FEA representing a real project as a "mesh" a series of small, regularly shaped tetrahedron connected elements, as shown in the above fig. And then setting up and solving huge arrays of simultaneous equations. The finer the mesh, the more accurate the results but more computing power is required.

Static structural A5>insert>select .displacement>select fixed areas>ok


A: Static Structural
Fixed Support
Time: 1. s
30/11/2018 4:31PM

>Select pressure>select pressure areas> enter pressure value

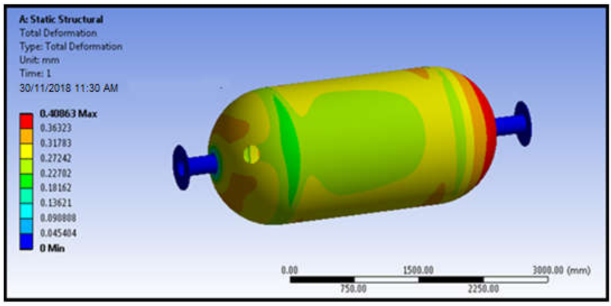


Solution A6>insert>total deformation>right click on total deformation>select evaluate all result
Insert>stress>equivalent (von misses)>right click on equivalent >select evaluate all results

Insert>strain>equivalent (von misses)>right click on equivalent >select evaluate all results

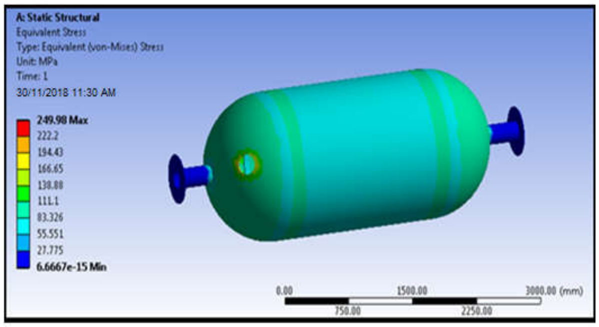
MATERIAL –E GLASS FIBER

Deformation



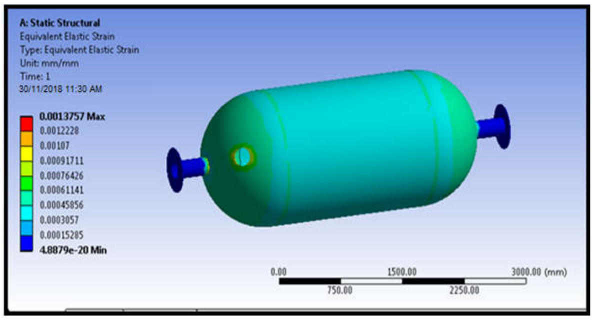
According To the Counter Plot, the maximum deformation at head of the pressure vessel and minimum deformation at nozzle of the pressure vessel. The maximum deformation is 1.1776 mm and minimum deformation is 0.13085 mm.

Stress



According To the Counter Plot, the maximum stress is inside of the pressure vessel and minimum stress at nozzles of the pressure vessel. The maximum stress is 262.73 N/mm^2 and minimum is 7.2127e-15.

Strain

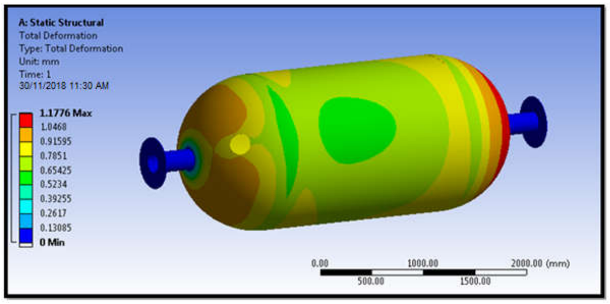


According To the Counter Plot, the maximum strain is inside of the pressure vessel and minimum strain at nozzles of the pressure vessel. The maximum strain is 0.0036276 and minimum is 1.0766e-19.

CASE 2: WELDING EFFICIENCY -0.85

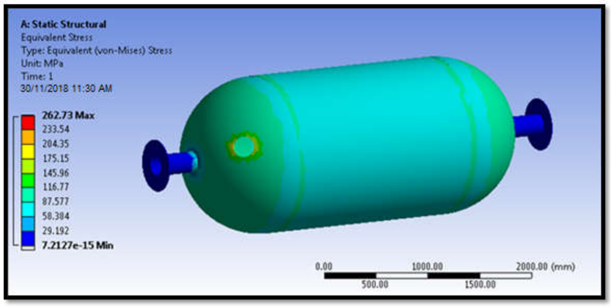
MATERIAL –E GLASS FIBER

Deformation



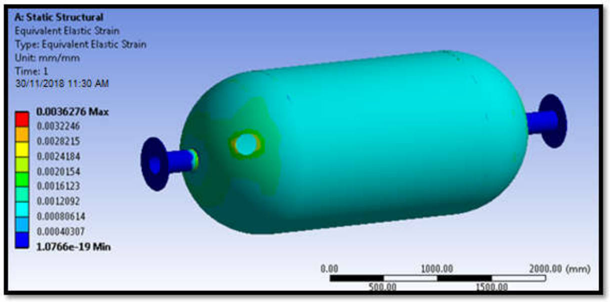
According To the Counter Plot, the maximum deformation at head of the pressure vessel and minimum deformation at nozzle of the pressure vessel. The maximum deformation is 0.73561mm and minimum deformation is 0.081735 mm

Stress



According To the Counter Plot, the maximum stress is inside of the pressure vessel and minimum stress at nozzles of the pressure vessel. The maximum stress is 85.691 N/mm^2 and minimum is 4.0675e-15.

Strain



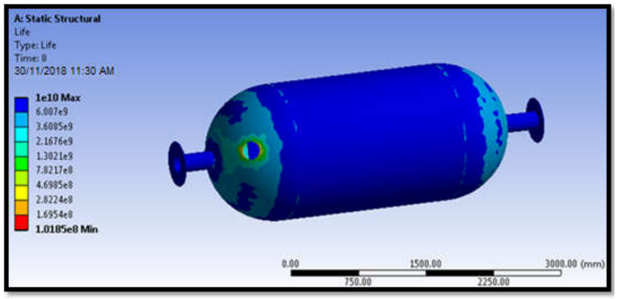
According To the Counter Plot, the maximum strain is inside of the pressure vessel and minimum strain at nozzles of the pressure vessel. The maximum strain is 0.0010711 and minimum is 5.245e-20.

FATIGUE ANALYSIS OF PRESSURE VESSEL

CASE 1: WELDING EFFICIENCY -1.0

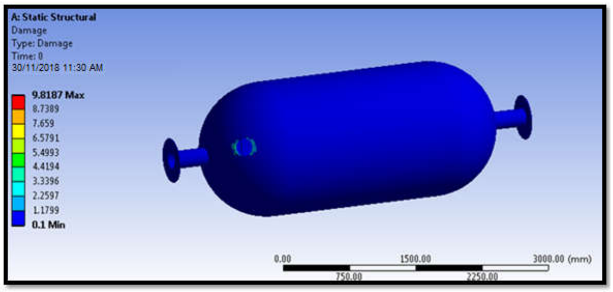
MATERIAL –E GLASS FIBER

Life



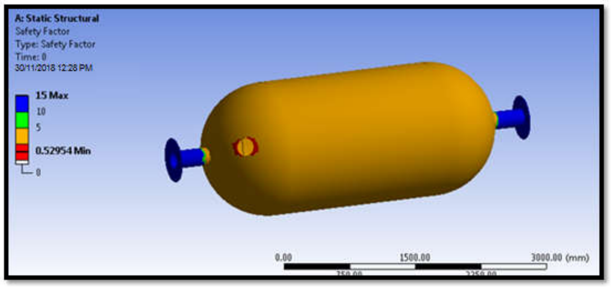
According To the Counter Plot, the maximum life at head of the pressure vessel and minimum life at nozzle of the pressure vessel. The maximum life is 1e10 and minimum life is 9.9144e

Damage



According To the Counter Plot, the maximum damage at head of the pressure vessel and minimum damage at nozzle of the pressure vessel. The maximum damage is 10.086 and minimum life is 0.1.

Safety factor

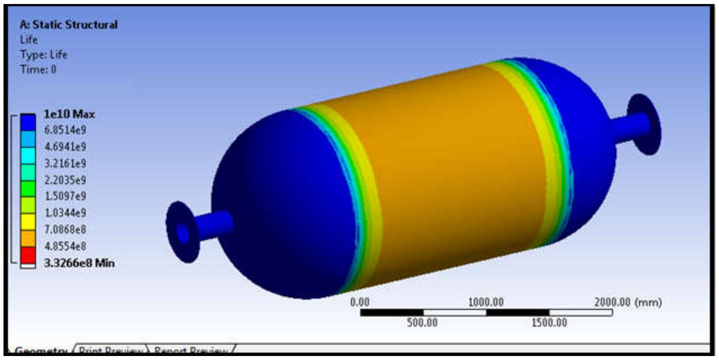


According To the Counter Plot, the maximum safety factor at head of the pressure vessel and minimum life at nozzle of the pressure vessel. The maximum safety factor is 15 and minimum life is 0.52525

CASE 2: WELDING EFFICIENCY -0.85

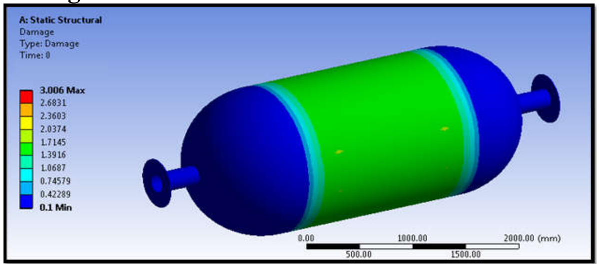
MATERIAL –E GLASS FIBER

Life



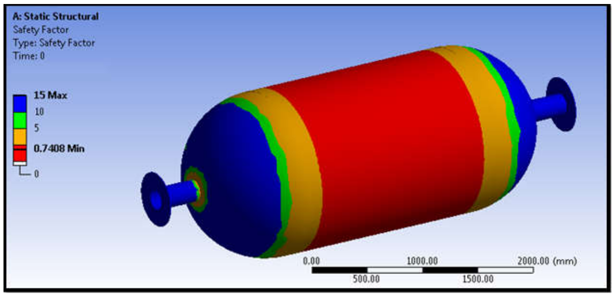
According To the Counter Plot, the maximum life at head of the pressure vessel and minimum life at nozzle of the pressure vessel. The maximum life is 1e10 and minimum life is 3.3266e8

Damage



According To the Counter Plot, the maximum damage at head of the pressure vessel and minimum damage at nozzle of the pressure vessel. The maximum damage is 3.006 and minimum life is 0.1.

Safety factor



According To the Counter Plot, the maximum safety factor at head of the pressure vessel and minimum life at nozzle of the pressure vessel. The maximum safety factor is 15 and minimum life is 0.7408.

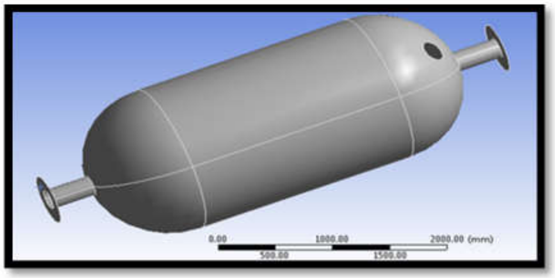
LINEAR LAYER STATIC ANALYSIS OF PRESSURE VESSEL

CASE 1: WELDING EFFICIENCY -1.0

Used software for this project work bench

Open work bench in Ansys 14.5

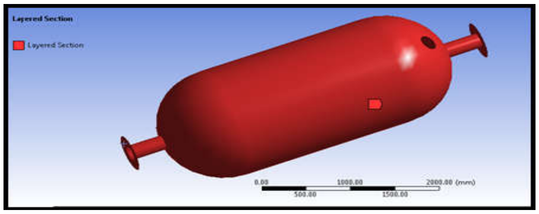
Select static structural>select geometry>import IGES model>OK

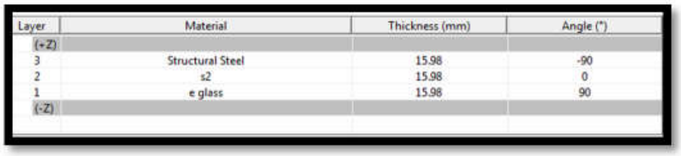


Click on model>select EDIT

Select geometry> right lick >layered selection>select object>work sheet >entered no.of layers

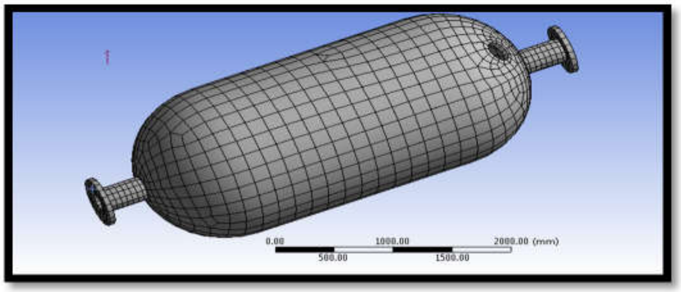
Select model >apply materials to all the objects (different materials also)



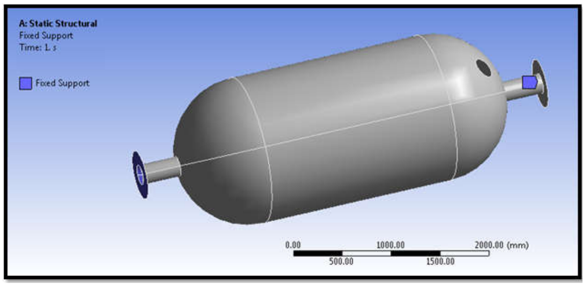


Layer	Material	Thickness (mm)	Angle (°)
(+Z)			
3	Structural Steel	15.98	-90
2	s2	15.98	0
1	e glass	15.98	90
(-Z)			

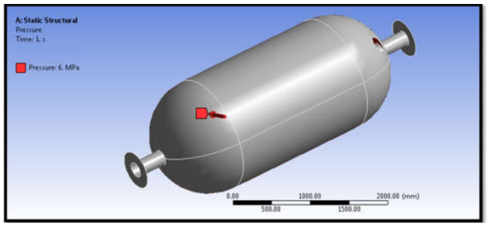
Mesh> generate mesh>ok



Finite element analysis or FEA representing a real project as a “mesh” a series of small, regularly shaped tetrahedron connected elements, as shown in the above fig. And then setting up and solving huge arrays of simultaneous equations. The finer the mesh, the more accurate the results but more computing power is required.



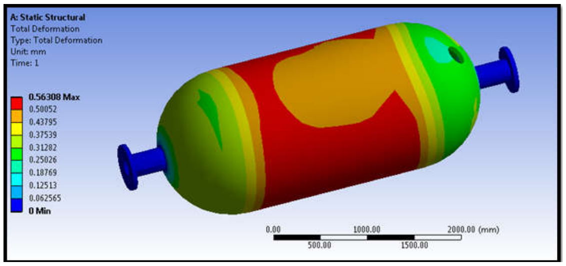
>Select pressure>select pressure areas> enter pressure value



Solution A6>insert>total deformation>right click on total deformation>select evaluate all result
Insert>stress>equivalent (von misses)>right click on equivalent >select evaluate all results

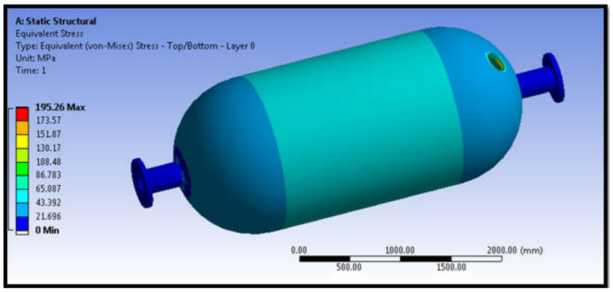
Insert>strain>equivalent (von misses)>right click on equivalent >select evaluate all results

Deformation



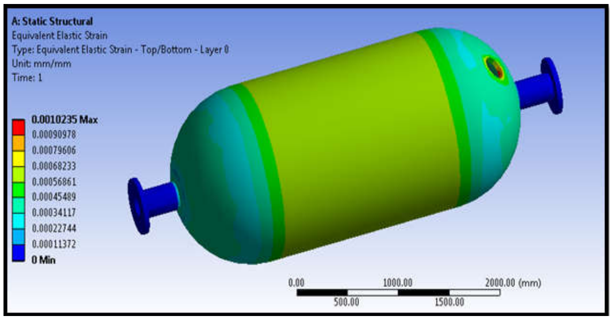
According To the Counter Plot, the maximum deformation at head of the pressure vessel and minimum deformation at nozzle of the pressure vessel. The maximum deformation is 0.56308 mm and minimum deformation is 0.062565 mm.

Stress



According To the Counter Plot, the maximum stress is inside of the pressure vessel and minimum stress at nozzles of the pressure vessel. The maximum stress is 195.26 N/mm^2 and minimum is 21.696.

Strain



According To the Counter Plot, the maximum strain is inside of the pressure vessel and minimum strain at nozzles of the pressure vessel. The maximum strain is 0.0010235 and minimum is 0.00011372.

STATIC ANALYSIS RESULT TABLES

Cases	Material	Deformation (mm)	Stress (N/mm^2)	Strain
Welding efficiency -1.0	**Steel**	0.40863	249.98	0.0013757
	S2 glass fiber	1.0275	260.6	0.0032303
	E glass fiber	1.177	262.73	0.0036296
Welding efficiency -0.85	**Steel**	0.29397	84.938	0.00041433
	S2 glass fiber	0.66446	85.529	0.000961
	E glass fiber	0.73561	85.691	0.0010711

FATIGUE ANALYSIS RESULT TABLES

Cases	Material	Life	Damage	Safety factor	
				Min	Max
Welding efficiency -1.0	**Steel**	1 e10	8.5139	0.55205	15
	S2 glass fiber	1 e10	9.81887	0.52954	15
	E glass fiber	1 e10	10.086	0.52525	15
Welding efficiency -0.85	**Steel**	1 e10	2.9103	0.74737	15
	S2 glass fiber	1 e10	2.9852	0.74221	15
	E glass fiber	1 e10	3.006	0.7408	15

LINEAR LAYER STATIC ANALYSIS RESULT TABLES

Cases	Layer stacking	Deformation (mm)	Stress (N/mm^2)	Strain
Welding efficiency -1.0	**3**	0.56308	195.26	0.0010235
	6	0.5684	197.69	0.0010356
	9	0.56212	195.64	0.0010245
	12	0.5612	195.36	0.0010229
Welding efficiency -0.85	**3**	1.9772	437.5	0.0033964
	6	1.9882	444.48	0.0030543
	9	1.9953	447.53	0.0029582
	12	1.9942	448.07	0.0029053

CONCLUSION

In this thesis, the pressure vessel is designed according to the weld efficiency and analyzed for its strength using Finite Element analysis software ANSYS. Mathematical correlations will be considered for the design of pressure vessel whose design parameters are specified by a company according to the required weld efficiency. Modeling will be done in CREO Parametric software..

Structural and fatigue analysis will be done in ANSYS on the welded joint of pressure vessel for different weld efficiencies.

By observing the static analysis the stress values are increases by increasing the weld efficiency. The stress values are less for steel material compare with S2 glass fiber and e-glass fiber. But s-2 glass has more yield strength compare with steel.

By observing the fatigue analysis the safety factor values increases by decreasing the weld efficiency 0.85.

So it can be concluded the s2 glass fiber material is better material for pressure vessel at welding efficiency 0.85.

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