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Design and Analysis of Horizontal Pressure Vessel

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Abstract
A pressure vessel is a container in which fluid at a pressure higher than the atmospheric pressure is stored. A pressure vessel was maybe fixed or movable. A pressure vessel consists of a vessel or shell where the fluid is stored, a manhole or opening, and lifting support for the manhole, support, and nozzles. Pressure vessel finds its use in many industries such as thermal and nuclear power plant, Oil and gas industries, food industries, etc. The design of pressure vessels is very important as the failure of it may have many devastating consequences. The design parameters of a pressure vessel include the temperature of the fluid inside, the ambient temperature of vessel surroundings, the average load acting on the vessel, corrosion allowance, material selection, etc. A pressure vessel may be stationary or movable, horizontal or vertical. So, the design parameters vary according to the type and application of the pressure vessel. The pressure vessel must be designed according to the ASME (American Society of Mechanical Engineers). The pressure vessel is designed using CATIA V5R21 and analysis is carried out using ANSYS 18.1. Generally, carbon steel is used for the construction of vessels. Titanium is used when the corrosion is highest.
Keywords: Pressure Vessels, Catia Design model, Ansys Simulation, Structural Steel, Aluminium Alloy, Titanium Alloy

1. Introduction

A pressure vessel is a closed container that contains a significantly different pressure from the ambient pressure on gases or liquids. The pressure differential is dangerous and in the history of vessel construction and service, fatal accidents occurred. The pressure vessel, therefore, Engineering authority supported by legislation control design, manufacture, and service. For these purposes, a vessel's concept is country-by-country but includes the highest safe operating pressure and temperature in parameters. The design of pressure vessels is very important as the failure of it may have many devastating consequences.

The design parameters of a pressure vessel include the temperature of the fluid inside, the ambient temperature of vessel surroundings, the average load acting on the vessel, corrosion allowance, material selection, etc.

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A pressure vessel may be stationary or movable, horizontal or vertical. So, the design parameters vary according to the type and application of the pressure vessel. The pressure vessel must be designed according to the ASME (American Society of Mechanical Engineers). The pressure vessel is designed using CATIA V5R21 and analysis is carried out using ANSYS. The material used for making pressure vessels may be brittle such as cast iron or ductile such as mild steel. Titanium is used when the corrosion is high. Due to a lot of requirements, these pressure vessels are often equipped with various sizes, shapes, and positions. Failure in pressure vessels occurs due to improper selection of material, design method, incorrect design data, and improper or insufficient fabrication process including welding. Corrosion allowance is the major consideration in the vessel design i.e., corrosion occurring over the life of the vessel. Cylindrical and spherical pressure vessels are used in industrial applications to carry fluids i.e., both liquids and gases under pressure. The pressure vessels are designed with great care because of the rupture which leads to a threat to human life. The design of a pressure vessel depends on factors such as temperature, pressure, selection of materials, corrosion, loadings, and many other parameters depending on various applications.

In pressurized boilers and boiler's performance steels, the oil industry (including inshore and offshore) and the petrochemical industry, and the gas industry are also involved. The highest performing, testing and supply conditions and the expertise needed of the business in these industries are met by Masteel UK Limited to satisfy these requirements.

Furthermore, MASTERHIC is provided ex-stock to show HIC resistant properties because of the increased demand for pressure vessel steel sheets. MASTERHIC is particularly suitable for pressure systems that can present wet H2S corrosion problems.

Pressure vessels are the majority of containers for commercial use. Tanks and diving cylinders are used by the private sector to store heat water. The industrial uses of pressure vessels include distillation towers, hydraulic reservoirs, and liquefied gas containment. Pressurized containers may be used for industrial high pressure or low-pressure containment, based on consumer specifications and products used. We may also use them for refrigeration and heating processes and the safety of secondary containment in manufactured goods.

Pressure vessels can be used in tandem with gas or liquids with electronic immersion heaters. These heaters are generated by direct contact with various substances for industrial purposes (water, oils, gasses, and solvents). The immersion heater may be placed on a pressure vessel using flanged, welded, or threaded connections.

The air receivers and hot water storage tanks are used in these industries. Other examples of pressure vessels are diving, repair chambers, distillate towers, pressure reactors and many other mining vessels, oil and petrochemical refineries, reactor vessels, submarines, and petrochemical plants, and theoretical pressure vessels may be almost any type, but shapes are common of spatial vessels, pneumatic reservoir, rail vehicle air-brake reservoirs, and storage vessels for liquefied gases such as ammonia, chlorine, propane, butane, and LPG. A cylinder with end caps called heads to have a common design.

2. Literature Reviews

According to the thin cylindric process, the pressure vessel is built with a diameter >20. The small cylinder supports fluid and thermal friction indoors. The Von Misses pressurized in the pressure test chamber is 220 MPa lower than the pressure material in FINITE ELEMENT METHOD (400Mpa). The design is also safe for pressure loads. This construction factor cuts the time to build a new pressure vessel significantly. The stack is a heat exchanger built with 2 or 3 horizontal heat exchangers. A saddle heat exchanger and a horizontal shell are investigated in this article. Finite elements are studied with ANSYS for various saddle-support configurations. The stress intensities in certain cases are evaluated and the optimal stresses of the load-bearing in the saddle are taken into account as the most suitable heat exchanger arrangement in a stack. One case reveals that stress levels are lowered in the ANSYS Workbench, 4441 cycles (Fully Reversed) type fatigue analysis is conducted on the full-pressure vessel assembly to achieve the number of cycles that the vessel can endure without observable failure. Technology such as PV Elite offers reliable reports to meet the expectations to save preparation time and expenses. For a variety of applications with better mechanical properties than single composites, the hybrid reinforced aluminium metal matrix may be used. Smart memory alloys are designed for special applications including biomedicine, aerospace, and robotics. The three standards are used for the simulation of PVElite and stress analysis. For later buildings of the PLG storage tank, PVElite is used. The practical code is different from (1) pressure and (2) temperature, in compliance with the internal specification specifications. Tank size, form, shape, exterior configuration, and head type shall be limited to the simulation. The exterior temperature is set at 250◦C and the internal temperature ranges between 0◦C and 600◦C with an improvement of 200◦C. The manual estimation of the thickness is about 7% higher, while the working pressure estimate is about 10% lower than the PV-ELITE program. However, the FEM helped to affirm the outcome of the PV Elite. The stress distribution was then calculated using the FEM solver. FEM analysis reviewed the effects of the PV-Elite program. The error rate is 4,99% and is within the permissible 95% accuracy limit. The accuracy of the FE model is largely dependent on the mesh used, particularly when high-order elements (cube, quadratic...) are not in use. A finer mesh provides typically more informative outcomes than a wide mesh. Somewhere we approach a diminishing point of return, where the increased mesh density doesn't dramatically change the performance. The mesh at this stage is known as "converged". The most exact way to measure the model's precision is also meshing convergence. Compared with theoretical values for maximal ANSYS stress equivalent pressures, cylinder pressure vessel analysis with hemispheric head type is performed. It is concluded that smaller concentrations of the same stress exist in pressure vessels with hemispherical heads, and therefore a preferable distribution of the equivalent pressure in that case of head geometry. If it is so built-in a saddle horn that it is durable, the saddle radius cannot be surpassed by adding a wear plate between the saddles and the vessels. The saddle is not more flexible than the external radius. Since its benefits are better in high pressures and high-temperature conditions compared to traditional Monoblock pressures in multilayers. In comparison, the SAIS Software minimizes the time required to measure the pressure vessel. Design analysis of the high-pressure vessel shall be performed. The overall load on a saddle is conservative or liberal, depending on the importance of the A/L ratio used. The conclusion is that the DBA-L process is explicit and convenient for engineers to use. The DBA-L solution can be used rather than categorizing stress, where categorizing stress is not difficult to overcome. For the observance of findings from the SA516GR65, the analysis portion uses 3 components, consistent with ASME regulations.

The literary study shows that ASME and other codes can provide a solution for a more general case and a higher safety factor and also that load and stress concentration formulae for non-standard shape and intersections and geometric discontinuity are not available. Most researchers have also worked in thin-pressure vessels and there is scope in studying the opening in thick pressure vessel, from the above discussion it is cleared that study the effect of change in size, position, location of the opening in a pressure vessel to study the stress concentration is essential, the position and location of the opening on a cylinder are not studied in past by researcher and there is no code provision for such design.

The literary analysis illustrates that ASME and other codes provide a more general and higher protection factor approach and also that no-load and stress concentration formulas are required for unstandardized shape and intersections and geometric discontinuity. The majority of researchers have already been working in thin-pressure vessels, and space is available for studying thick-pressure vessel opening. From the above topic, it is cleared up that the study of the impacts of size change, location, and position of the opening in pressure vessels is important to study the stress concentration. The stress concentration in the pressure vessel opening is a critical element in the study. The direction and size of the opening must also be checked for a literature analysis concerning the stress concentration in the opening of the pressurized vessel. This paper covers all dynamic stress analysis for the potential scopes of horizontal pressure vessels.

3. Design of pressure vessel using CATIA

We have designed a stationary horizontal pressure vessel. The design consists of three parts, namely, vessel, lifting support, and manhole cover. The thickness of the vessel also plays an important role in the design. The pressure vessel is designed for a particular internal pressure and temperature. The surrounding conditions of the pressure vessel are also taken into consideration while designing it. We have designed a simple pressure vessel with a vessel wall thickness of 2 mm. The material used is structural steel and the total mass of the designed vessel (including the standing support for the vessel) is 725.67 kg. The capacity of the vessel is 92.4 litres. The part designs of the vessel, lifting support, and manhole cover have been designed separately and then was assembled. The pressure vessel is designed for an internal pressure of 0.4 MPa.

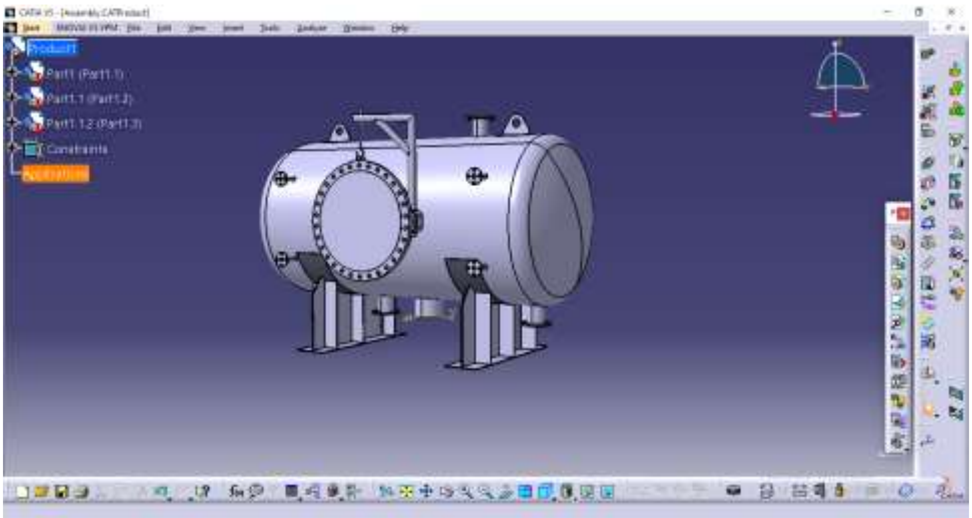


Fig 1: The completed assembly of pressure vessel in CATIA V5

With the help of CATIA V5, we can also draft the final design. We have drafted our final design in CATIA V5. Three simple views are shown in the drafting (Front view, Top and side view).

There are few constraints associated with CATIA V5. There are times when simple sketches are adequate for the design process, but working on more complex sketches requires a rich set of geometrical or dimensional constraints. The Sketcher Workbench provides constraint commands which will allow to fully sketch the profiles.

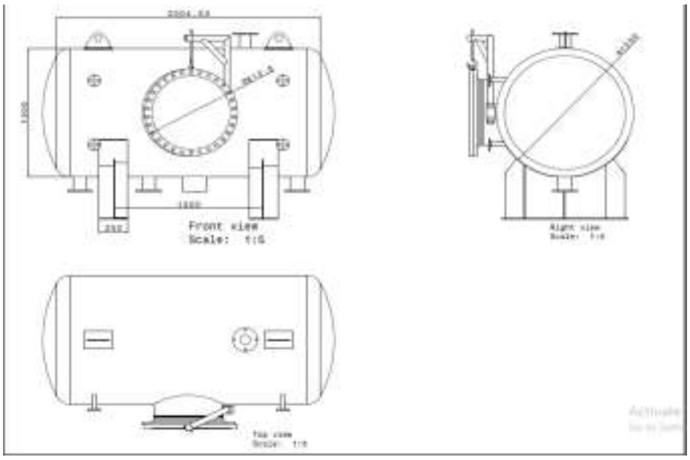


Fig 2: Final draft of the pressure vessel design

Dimensions of the Pressure Vessel:

1. Wall thickness of the pressure vessel: 2mm
2. The total length of the cylinder: 2304.3mm
3. Side diameter: 1200mm
4. Front diameter: 812.8mm
5. Scale considered: 1:5

4. Analysis of the pressure vessel using ANSYS

The possible types of analysis that can be performed on a horizontal stationary pressure vessel are static structural and thermal analysis. Static structural analysis is done by finite element analysis. In the finite element analysis method, the entire design is divided into small elements and the individual effect of each element is summed up.

We have designed a simple pressure vessel with a vessel wall thickness of 2 mm. The materials used for analysis are structural steel, aluminium alloy, and titanium alloy. The total deformation and equivalent (von-misses) stresses have been solved for using the above materials. The first step to structural analysis is generating a mesh. There is an option of choosing coarse, medium, or fine mesh. I have used fine mesh for more accuracy. The total number of nodes is 181795 and the number of elements is 82764. Next is selecting the constraints. The bottom stand of the vessel is kept fixed for analysis. I have considered a uniform pressure force of 1.5 Mpa throughout the vessel surface.

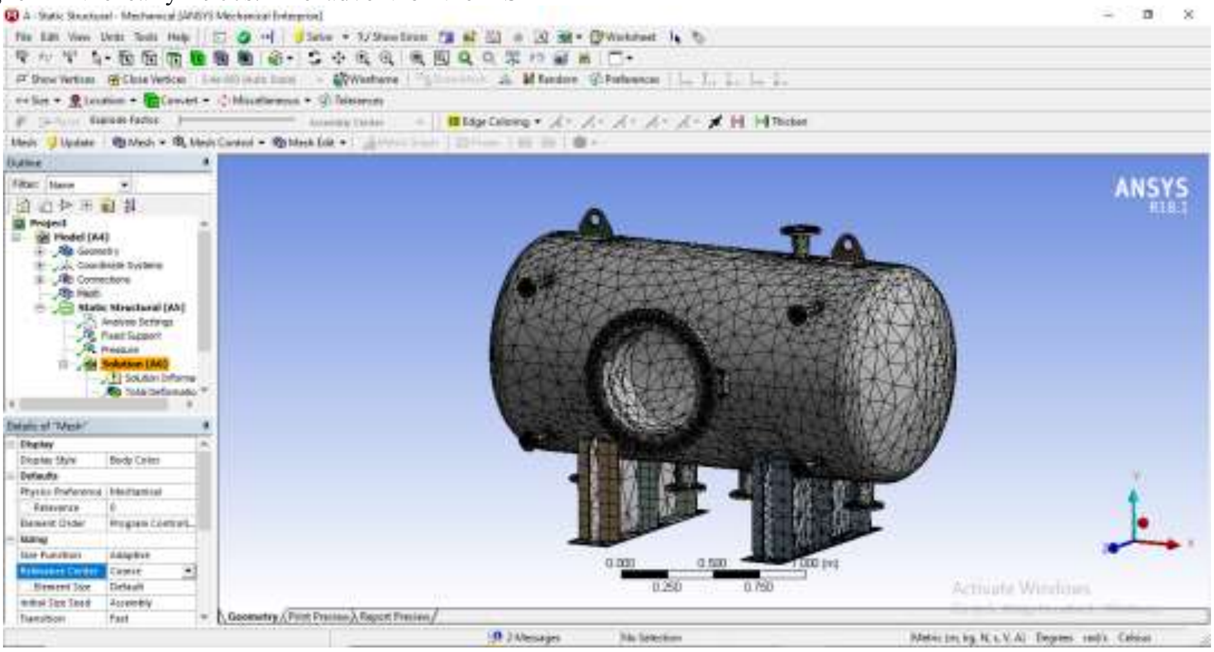
Fig 2: Fine Mesh generated in ANSYS

We have performed the analysis of the pressure vessel using ANSYS 18.1. We have first converted the CATIA assembly file to a .igs file and then opened it using Ansys. We have performed static structural analysis using the finite element method. In Finite element analysis, we divide the entire body into small segments or nodes. This process is called meshing. We have used two different kinds of mesh (coarse and fine) that are generated automatically by the ANSYS program. Fine mesh gives the results more accurately as the mesh size decreases.

In course meshing, the number of nodes is 52579 and the number of elements is 23677. In fine meshing, the number of nodes is 88528, and the number of elements are 37328. The sizing of the nodes was set in adaptive for both the mesh types.

Type of Mesh	**No of Nodes**	**No of Elements**	**Sizing mode**
Course mesh	52579	23677	adaptive
Fine mesh	88528	37328	adaptive

The use of finite element methods to design and analyse pressure vessels is a relatively recent development in the overall historical perspective of the ASME Code. The finite element method first became a useful tool for the designer in the early 1960s. The advent of the ASME Nuclear Code, Section III, which first appeared in about 1964, provided for a "design by analysis" procedure. Up until this time, the pressure vessel design codes all used the "design by formula" approach, which is essential that is now used in Section VIII, Division 1 of the ASME Code.



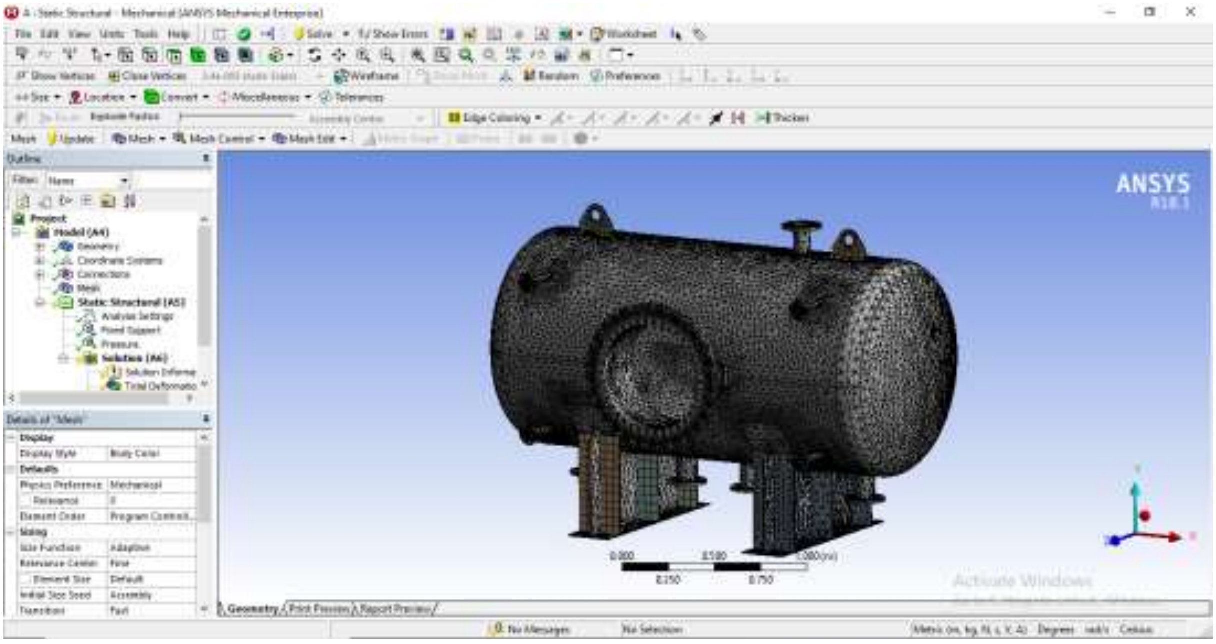


Fig 3: The different types of mesh used. (a) Coarse Mesh (b) Fine Mesh

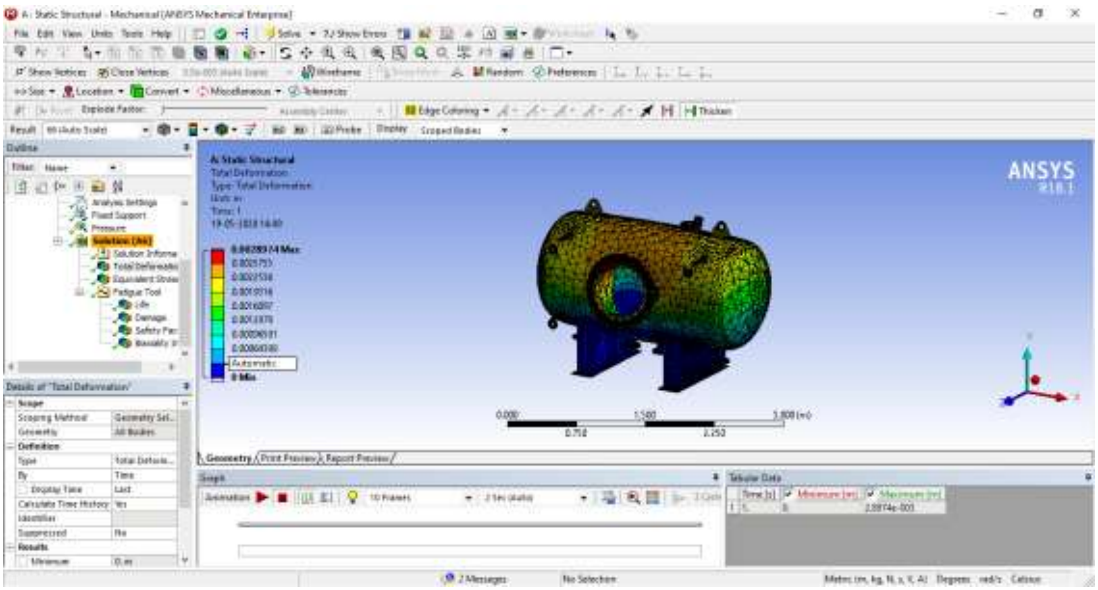
For the analysis, we have considered a uniform internal pressure of 0.4 MPa. Both the legs of the vessel were fixed for analysis of the pressure vessel. The material used is structural steel.

Boundary Conditions:

1. Internal Pressure: 0.4 MPa

2. Weight of the Vessel: 725.67 kg

a. Analysis using Coarse Mesh



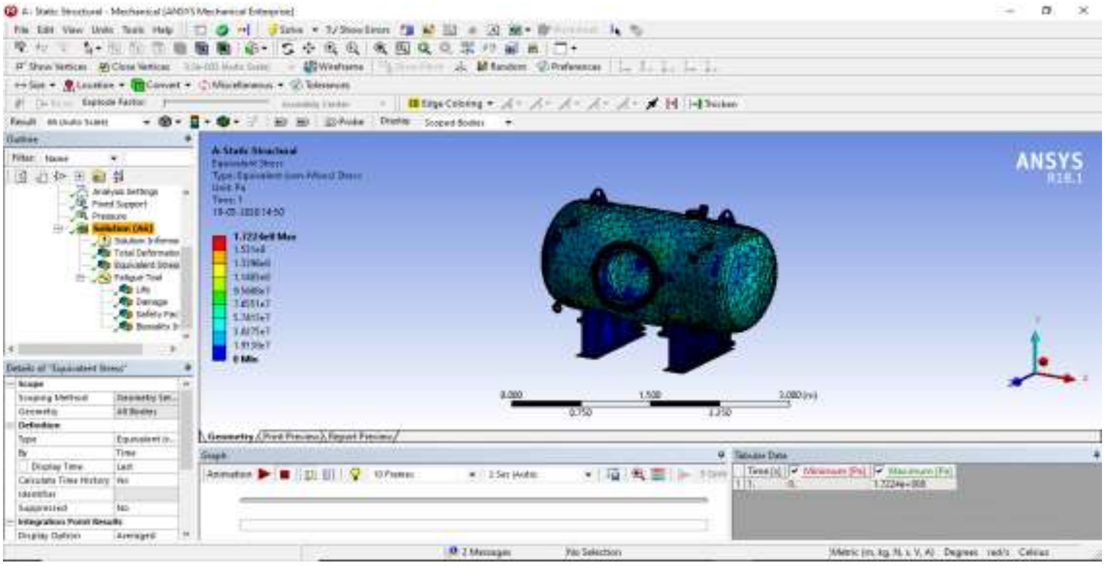
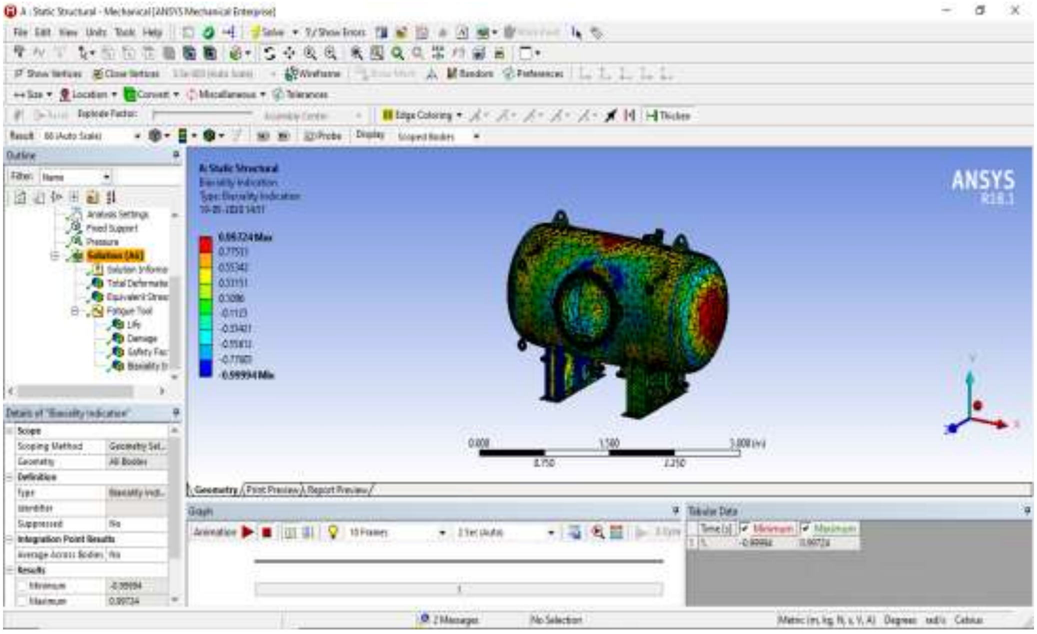


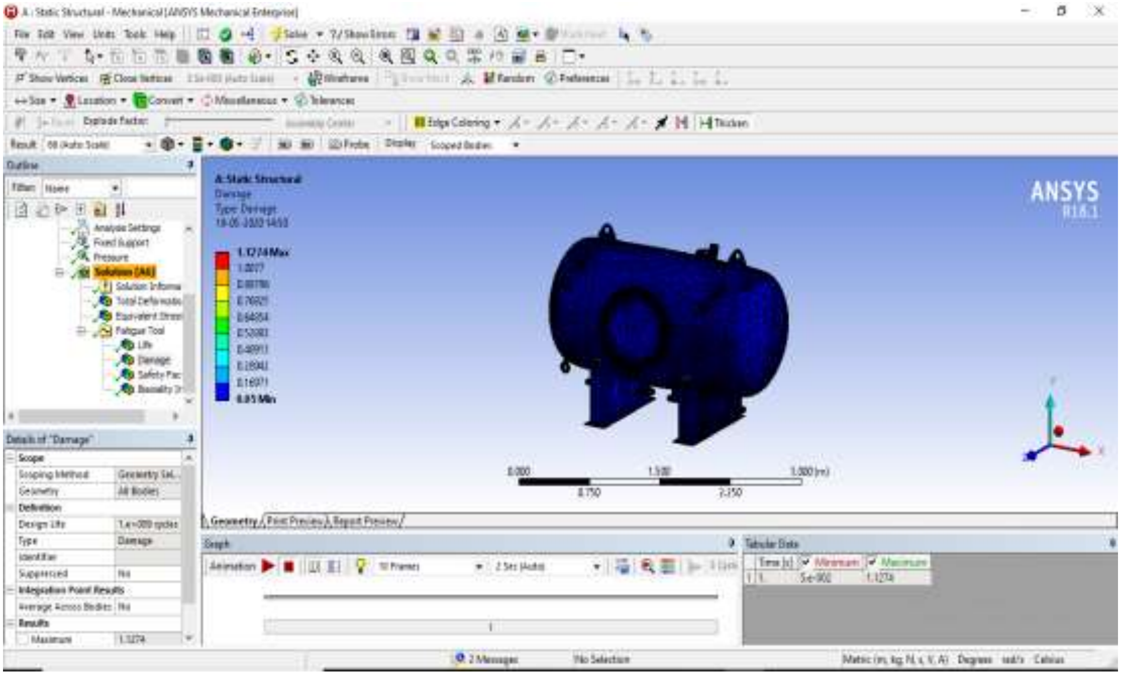
Fig 4: Total Deformation and Equivalent (Von- misses) stress

The maximum deformation was found to be 0.0028 m. The maximum stress is found to be 172.24 MPa. The results show a minimum safety factor of 0.96 and a maximum of 15.

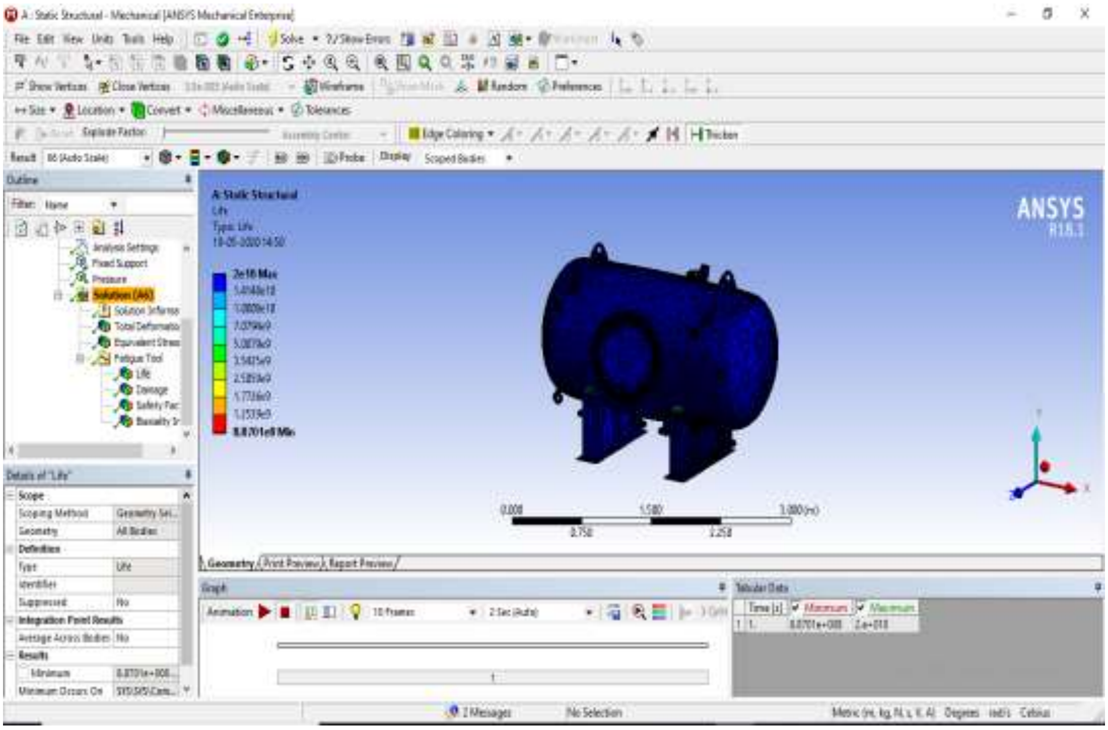
a)



b)


A : Static Structural - Mechanical [ANSYS Mechanical Enterprise]
A: Static Structural
Damage
Type: Damage
1.1274 Max
0.05 Min
ANSYS
R18.1

c)


A : Static Structural - Mechanical [ANSYS Mechanical Enterprise]
A: Static Structural
Life
Type: Life
2e10 Max
8.8701e8 Min
ANSYS
R18.1

d)

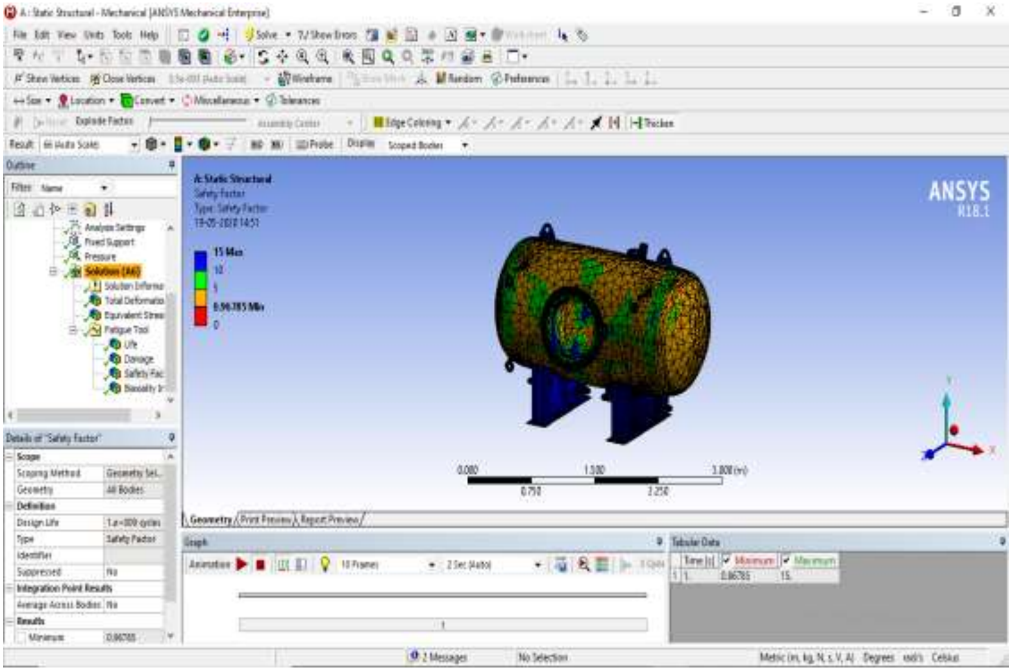
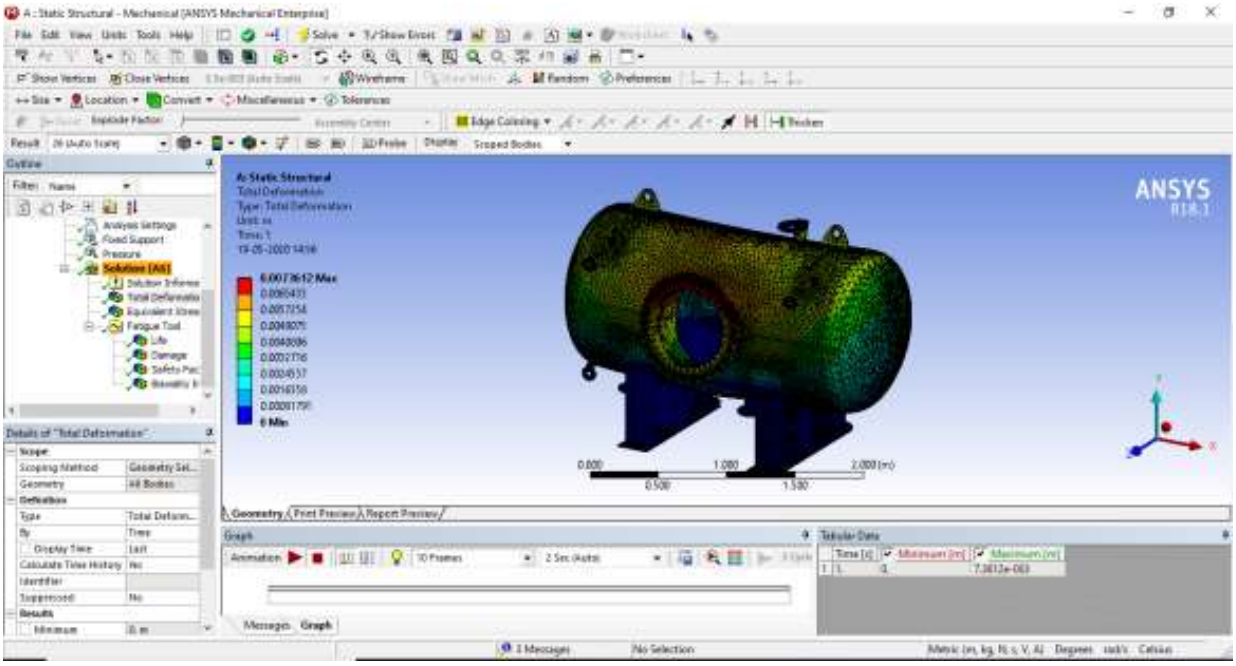
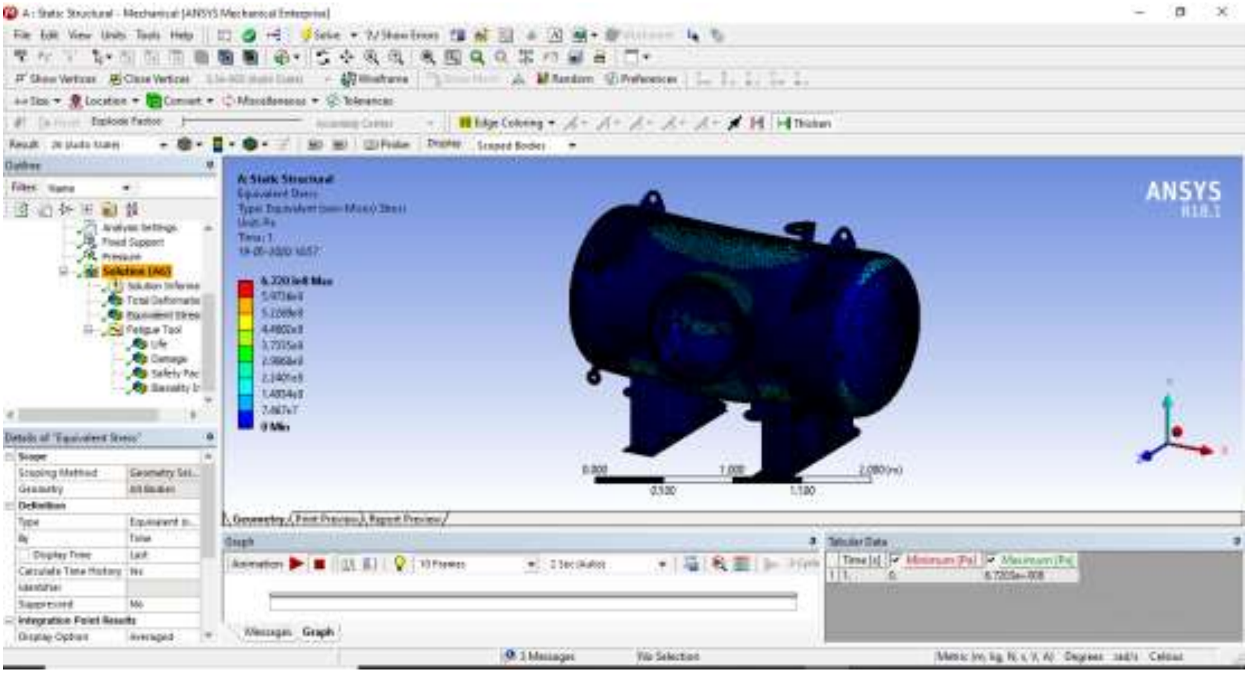


Fig 5: (a) Biaxiality Indication (b) Damage (c) Life (d) Safety Factor

b. Ansys using Fine Mesh





Structural Steel

5. RESULTS

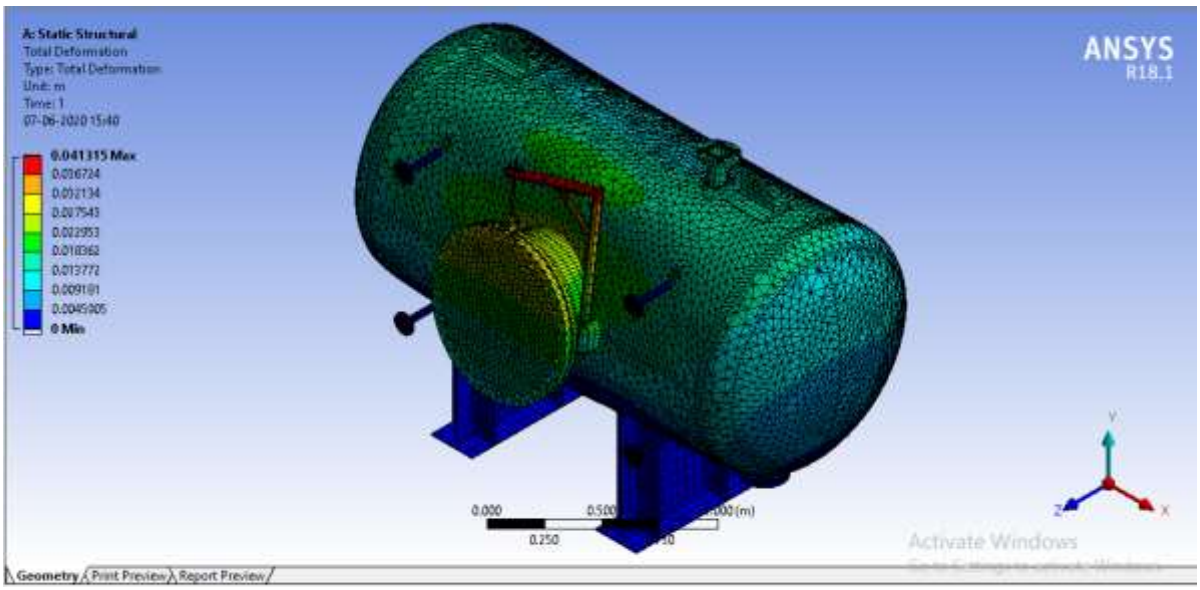


Fig 3: Total Deformation

It is a static structure with a total deformation value of 0.04131m

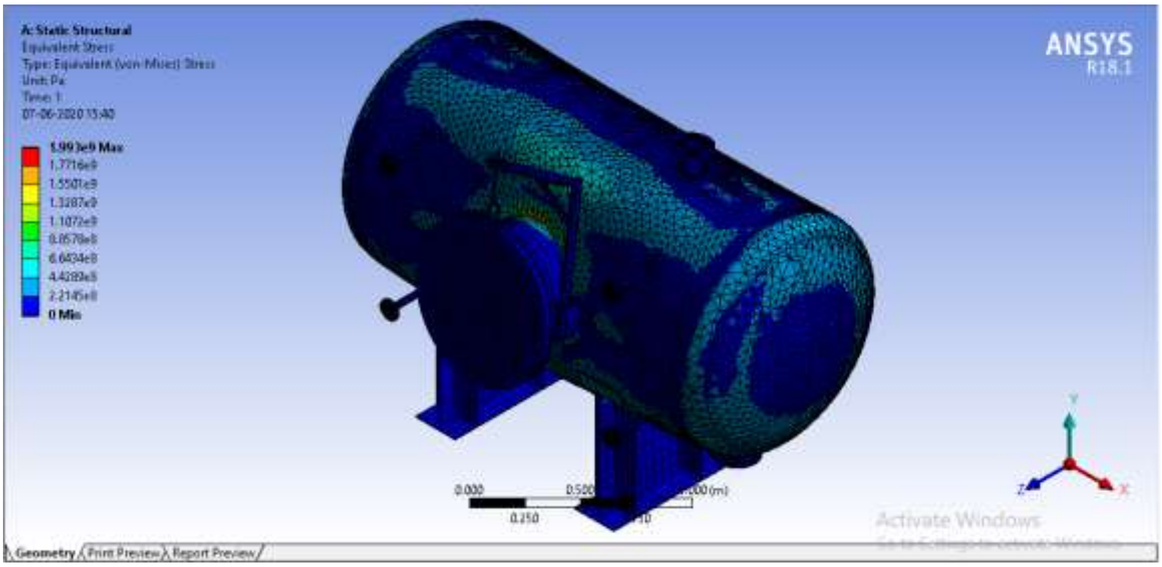


Fig 4: Equivalent (von-misses) stress

It is a static structure with an Equivalent (von-misses) stress value of 1.993e9 Pa

Stainless Steel**:** Pressure containers require robust construction, and this requirement is fulfilled by using different types of stainless steel. The following properties of this material are the reasons for using it for these containers:

1)Extremely resistant to chemicals

2)Has a high resistance to corrosion

3)304L stainless steel has a great weldability

4)Capability of withstanding humid conditions, sunlight, or high temperatures

Aluminium Alloy

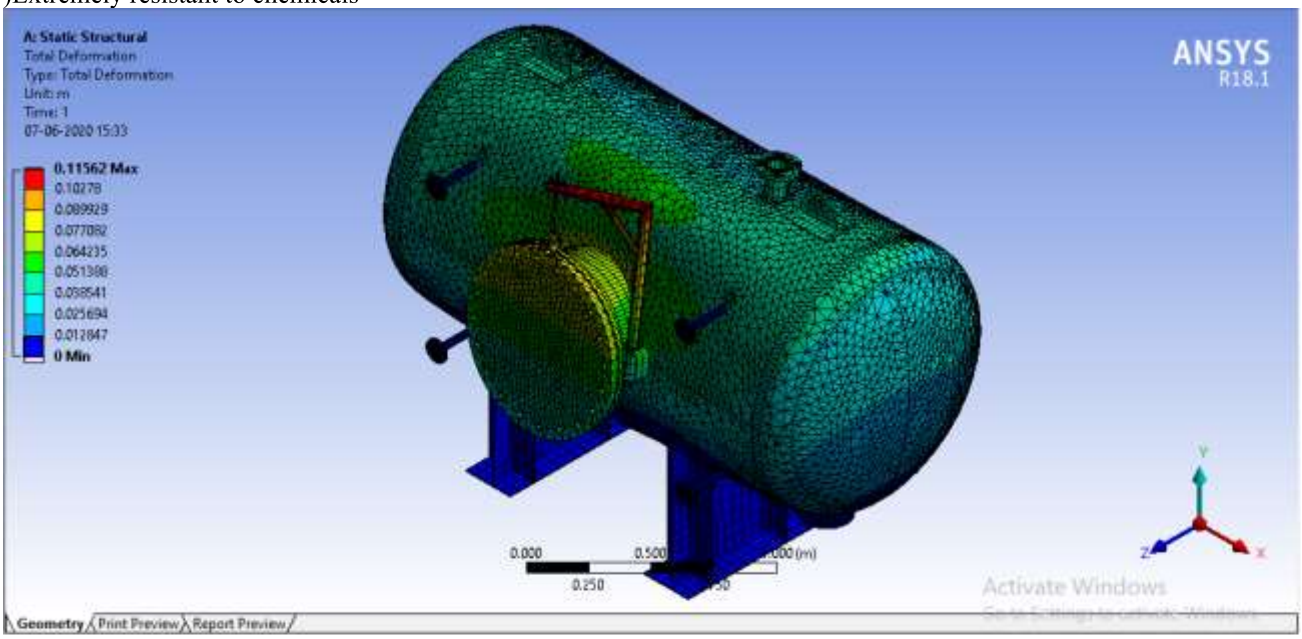


Fig 5: Total Deformation

It is a static structure with a total deformation of 0.11562m

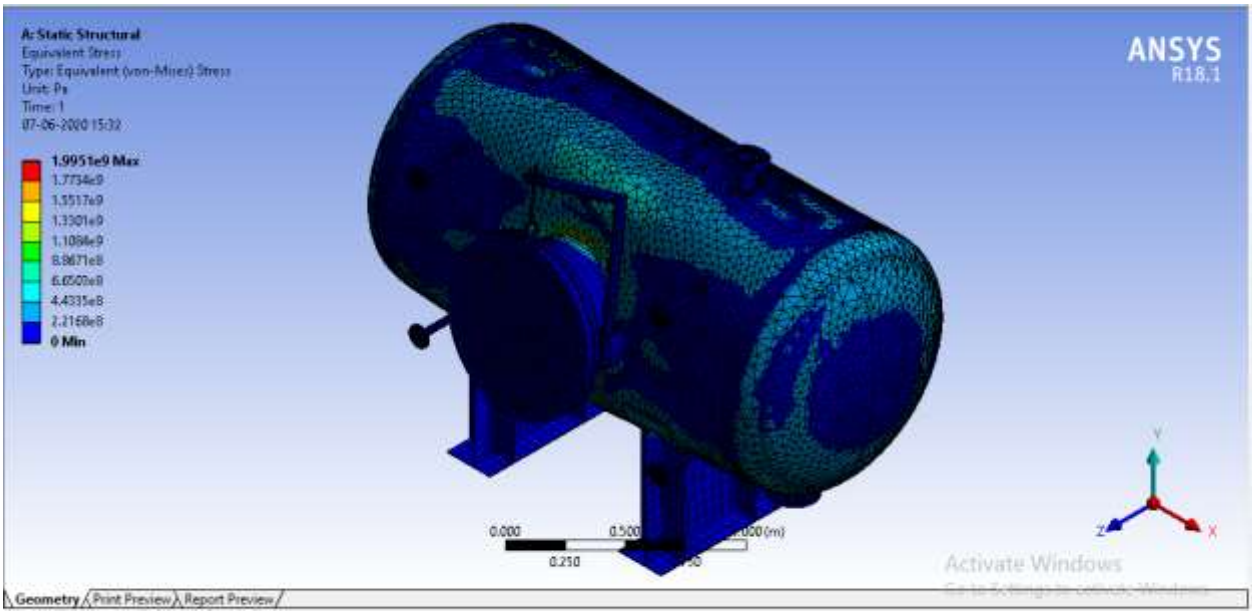


Fig 6: Equivalent (von-misses) stress

It is a static structure with maximum equivalent stress as 1.9951e9 Pa

Aluminium: This is yet another material, which is most commonly used in these vessels, for the following set of its properties:

1)Capable of maintaining high tensile strength between 70 and 700 MPa

2)Easier and more cost-effective to machine compared to stainless steel

3)Has a larger coefficient of expansion compared to other metals

Titanium Alloy

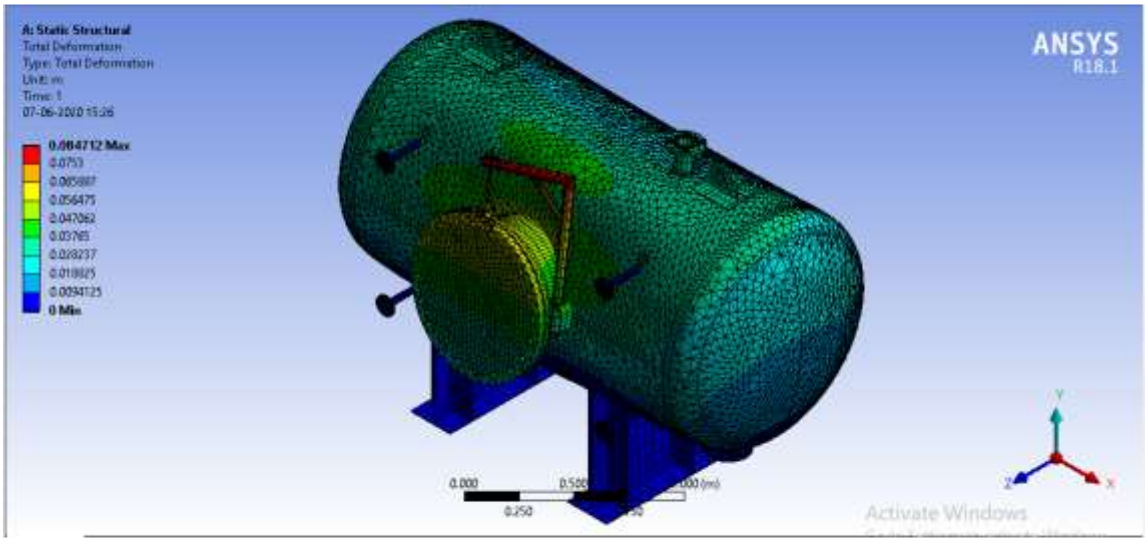


Fig 7: Total Deformation

The total deformation for the titanium-based static structural is 0.084712m

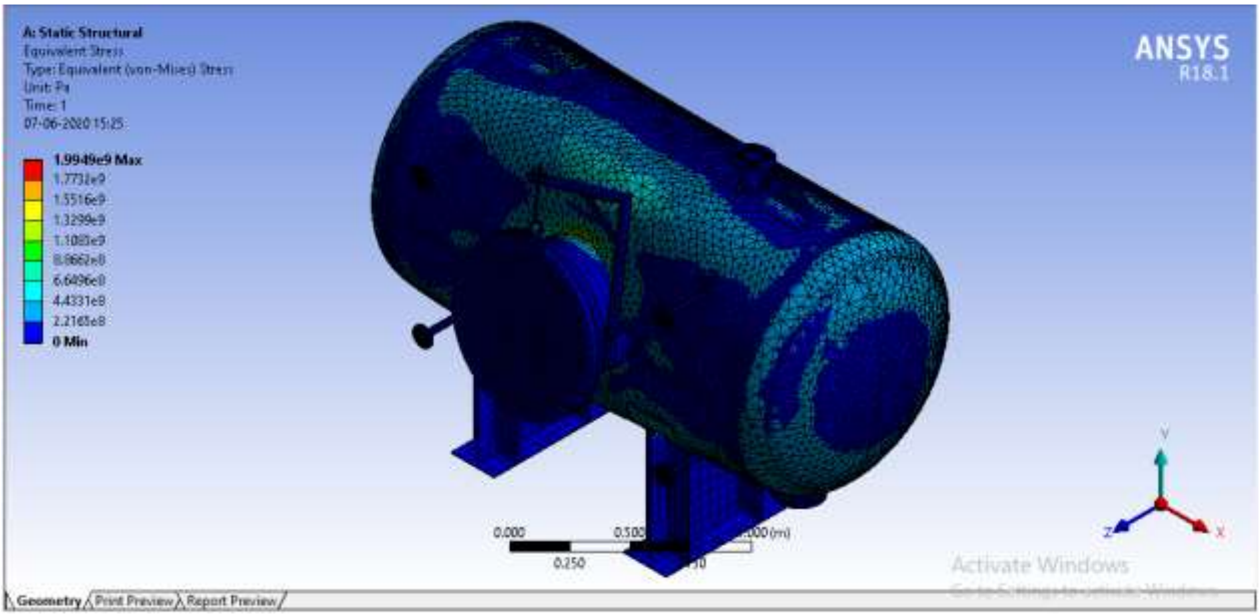


Fig 8: Equivalent (von-misses) stress

The total Equivalent (von-misses) stress is 1.9949e9 Pa

Titanium: There are several properties of this material, which make it ideal for pressure vessel application. These properties are as follows:

1)Capability of retaining its structural properties
2)Extremely resistant to corrosion
3)Requires very little maintenance
4)Excellent tensile strength ranging from 30,000 psi to 200,000 psi (210-1380 MPa)
5)Higher melting point compared to steel and aluminium materials
6)Great biocompatibility
7)Non-toxic

Type of the material	Total Deformation	Equivalent (Von-misses) stress
Structural Steel	Min:0 m Max:0.04 m	Min:0 N/mm^2 Max: 1993 N/mm^2
Aluminium Alloy	Min:0 m Max:0.11 m	Min:0 N/mm^2 Max:1995 N/mm^2
Titanium Alloy	Min:0 m Max:0.08 m	Min:0 N/mm^2 Max:1995 N/mm^2

6. CONCLUSION

The values of maximum and minimum values of von-misses stresses are almost the same in the case of steel, aluminium alloy, and titanium alloy. The maximum value of total deformation is less in the case of steel and maximum in case of aluminium alloy. Hence the best material for the design can be concluded as structural steel. Pressure vessels are also fabricated using a partially load-bearing liner, made from metal, ceramic, or a polymer. This liner not only helps to bear the load of the interior pressure, but also protects the vessel from the contained substance and protects against leaking. Pressure vessels must follow strict manufacturing standards for fabrication. Some mechanical properties of steel, achieved by rolling or forging, could be adversely affected by welding, unless special precautions are taken. Even when a fabrication service has access to the finest manufacturing facilities, it's not possible to manufacture a high-performance pressure vessel if it's not equipped with an alloy-strengthened material backbone. Stretching that metaphor just a little further, the materials require flexibility, again, just like a backbone. To put it another way, the fluid containment alloy must be ductile so that the vessel walls can expand and contract.

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