DESIGN AND ANALYSIS OF PEEK BASED PRESSURE VESSEL THROUGH ANSYS SOFTWARE

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Abstract: The traditional material bases pressure vessels are having more strength due to their high weight to strength ratio but they extremely heavy and are not chemically inert. For better corrosion resistance the material is coated with external agents which is an additional expense. In recent years most of the sectors have replaced traditional materials with lighter material such as Aluminium Matrix Composites which shows that industries are working to make the vessel lighter and more mobile; which makes the material PEEK a perfect choice for manufacturing pressure vessel. It is light and nearly resistant to chemical corrosion without any external coating. A lighter pressure vessel can be used in the Aerospace and Automobile industry to decrease weight and increase efficiency. For the same geometrical parameters of steel pressure vessel, FE analysis of PEEK based pressure vessel is carried out and stresses and corrosion resistance for different internal pressures are determined. And the design and analysis are carried out in the software ANSYS Workbench.

Index Terms - *polyether ether ketone; pressure vessels; Finite Element Analysis.*

1.INTRODUCTION

In this paper we have performed design and analysis of horizontal pressure vessel based on the material PEEK (Polyether ether ketone) with the virtue to create and lighter and more durable pressure vessel when compared to conventional products.

1.1 Pressure vessel

The term pressure vessel refers to those reservoirs or containers which are used to withstand both external and internal pressure. They are used to store fluid in ambient temperature and pressure. Pressure vessels have wide- range of applications in industrial, thermal, aerospace, nuclear power plants, process and chemical industries, marine industries and air, water, steam and gas supply systems. They require an authorized quality inspector to sign on each new vessel produced and each pressure vessel has a unique nameplate with information on vessel such as maximum permissible working pressure, maximum temperature, minimum temperature, date of manufacturing, registration number (through the National Board) and official pressure vessel stamping (U- Stamp) from ASME. The nameplate makes the vessel traceable. They are significant as they are used to store fluids under high pressure.

1.2 Types of pressure vessel

In general, there are three main types of pressure vessel. They are

- Spherical pressure vessel.
- Horizontal pressure vessel.
- Vertical pressure vessel.

1.3 Existing materials for pressure vessel

Pressure vessels are made of different materials ranging from carbon steel, stainless steel and nickel alloy up to sophisticated anti-corrosive metals such as titanium, zirconium and tantalum. Here are a few existing materials in use and its properties

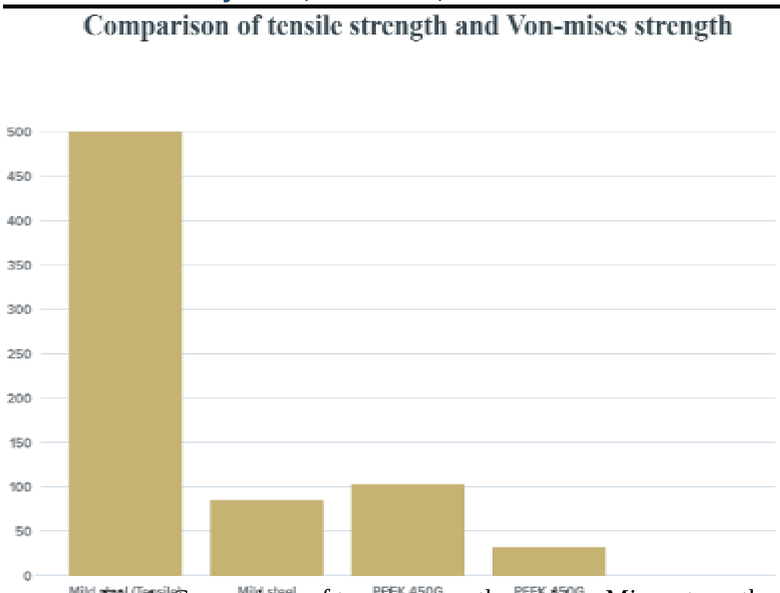

Fig.1. Comparison of tensile strength and Von-Mises strength

Carbon Steel – Carbon steel provides a number of advantages as a pressure vessel material. In addition to being highly resistant to corrosion, shock, and vibration, it possesses a high tensile strength — making it ideal for demanding tank applications in a wide range of industrial processes. It also retains strength at minimal thicknesses, which reduces the amount of material needed for tank fabrication, thereby lowering fabrication costs. Carbon steel is also highly recyclable and accounts for more recycled weight annually than aluminum, plastic, paper, and glass combined. In fact, approximately 50% of its production comes from reclaimed materials.

Stainless Steel – Like carbon steel, stainless steel offers high strength at low thickness. Also, like carbon steel, it is highly recyclable. There are a number of different types of stainless steel. Type 304, for instance, is widely known for its superior chemical and corrosion resistance. Type 304L, on the other hand, has low carbon content and exhibits excellent weldability. Choosing the correct type of stainless steel will ultimately depend on the unique requirements of the application that the pressure vessel is being used in. In general, however, it is ideal for tanks and vessels that are exposed to the natural environment (humidity, sunlight, etc.) or high temperatures.

Hastelloy – Hastelloy pressure vessels are widely used for chemical, petrochemical, and oil and gas applications. With proper maintenance, they can last for decades, creating great cost-efficiency over their entire lifecycle. Their inherent reliability also reduces maintenance-related downtime. Hastelloy is extremely resistant to corrosive liquids and provides protection against both localized and uniform attack. It is also very durable and resistant to cracking. Moreover, it is extremely workable (easy to weld or fabricate) and is available in a wide range of types (B2, S, C, C276, etc.), which makes it suitable for a broad range of tank applications and industries.

Nickel Alloy – Nickel alloy comes in a variety of grades. For instance, chromium can be added to nickel alloy to provide more heat resistance. Copper can also be added for use in salt-water environments. Perhaps the most notable use of nickel alloy tanks is in Liquefied Natural Gas (LNG) applications.

It's important to note that the manufacturing process for this alloy can be more complex than with other amalgams. During tank fabrication, only the purest materials should be used in order to ensure its integrity. Despite this complexity and associated cost, nickel alloy has plenty to offer as a pressure vessel material – providing excellent corrosion resistance, as well as protection against thermal expansion.

Aluminum – Aluminum is often considered as an alternative to stainless steel for many pressure vessel applications. It is roughly three times less dense than stainless steel and can maintain high tensile strength with certain heat treatments and alloy compositions. One of the most significant advantages of aluminum is that it is cheaper and much easier to machine than stainless steel. In many instances, however, labor costs may be higher, as some aluminum tank fabrication requires the use of special welding techniques. Because of its lower density, aluminum is typically not suitable for pressure vessels that are exposed to extremely high pressures.

Titanium – Like copper nickel alloys, titanium provides a number of advantages in salt-water environments and its inherent resistance to corrosion reduces cleaning and maintenance requirements. It maintains strength and rigidity even at lower thicknesses and facilitates more efficient heat-transfer than many other types of metal as well. Titanium is also known for its ability to maintain its structural properties over long periods of time. It is widely used in power station condensers and similar applications.

1.4 Limitation of existing material

- Poor corrosion resistance
- General cost, steel structures are not economical
- Easily exposed to environmental contaminants
- Heavy construction

Table 1. material properties of PEEK

Properties	Value
Density (Mg/m^3)	1.32
Elastic modulus (GPa)	4.34
Melting point (C)	346.85
Tensile strength (MPa)	103
Yield strength (MPa)	95.2
Hardness (MPa)	285
Poisson's ratio	0.395

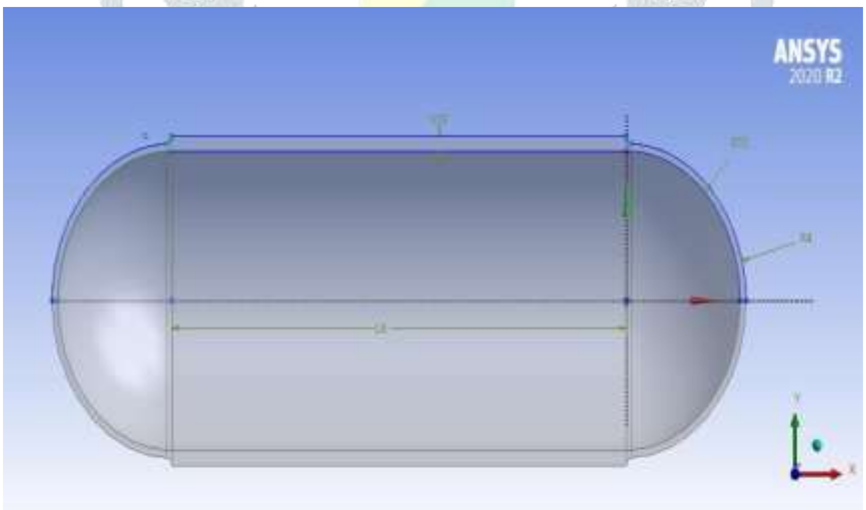

Fig. 2. Dimension of Pressure vessel

Internal diameter of shell	120mm
Thickness of the shell	6mm
Length of the shell	240mm
Internal diameter of the head	120mm
Thickness of the head	3mm

Table.2. Dimensions of the vessel

1.5 PEEK (Polyether ether ketone)

Polyether ether ketone (PEEK) is a colorless organic thermoplastic polymer in the polyaryletherketone (PAEK) family, used in engineering applications. PEEK is a semi crystalline thermoplastic with excellent mechanical and chemical resistance properties that are retained to high temperatures. The processing conditions used to mold PEEK can influence the crystallinity, and hence the mechanical properties. It is highly resistant to thermal degradation as well as attack by both organic and aqueous environments. It is attacked by halogens and strong acids as well as some halogenated compounds and aliphatic hydrocarbons at high temperatures. It dissolves completely in concentrated sulfuric acid at room temperature. (victrex-peek-450G, 2019) Because of its robustness, PEEK is used to fabricate items used in demanding applications, including bearings, piston parts, pumps, HPLC columns, compressor plate valves, and cable insulation. It is one of the few plastics compatible with ultra-high vacuum applications. It is extensively used in the aerospace, automotive, and chemical process industries.

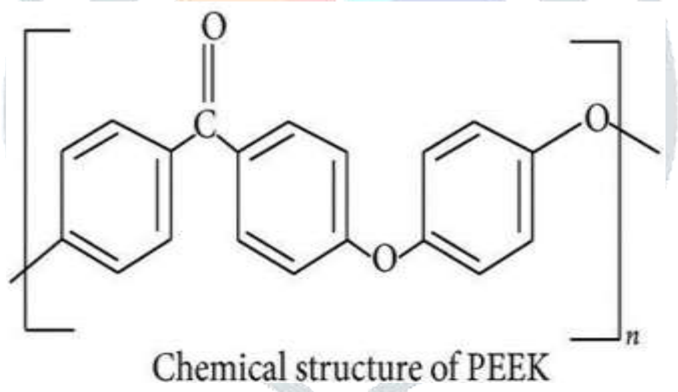

Fig. 3. Chemical Structure of PEEK

1.6 Literature review

Devaraju and Pazhanivel (2015) have studied stress analysis on pressure vessels by considering the inner pressure, self-weight and also the fluid weight. They designed the pressure vessel manual calculations and compared these computed stress values with the results obtained from the ANSYS software package. They all over states that the stress working on the shell of the pressure vessel designed is much less than that of the allowable stress of the material. Thus, the pressure vessel is safe for the usage.

Anandhu P D (2017) has done design and analysis on horizontal pressure vessel and thickness optimization. This Pressure vessel was designed in CATIA and analyzed in ANSYS software. They changed the thickness and analyzed the change in the deformation of the material. This model was designed in CATIA software as per the dimension that has been obtained after the design procedure done using ASME Section VIII division 1,2013.

Sadanandam (2017) has done analysis on design and analysis of pressure vessel using finite element method. They sub-divided the vessel into smaller components and applied the inner pressure so as to check the strain. They used principal stress theory and distortion energy theory for corroboratory their design and also the calculated results which were compared with the results from the FEA software. They ended that the utmost principal stress as per manual calculation was in line with the FEA results and hence the pressure vessel design was safe.

Sandeep Gond (2004) has done analysis on the pressure vessel. The choice of the fabric, style and stress calculation of the pressure vessel was done as per the ASME standards. they need additionally supposed to prove that the multi-layered pressure vessels area unit capable of withstanding a better internal pressure instead of that of the solid wall. They have done the analysis of the pressure vessel considering totally different materials so as to cut back the price of construction. They ended that the utmost stress developed in pressure vessel was inside the yield stress of the fabric.

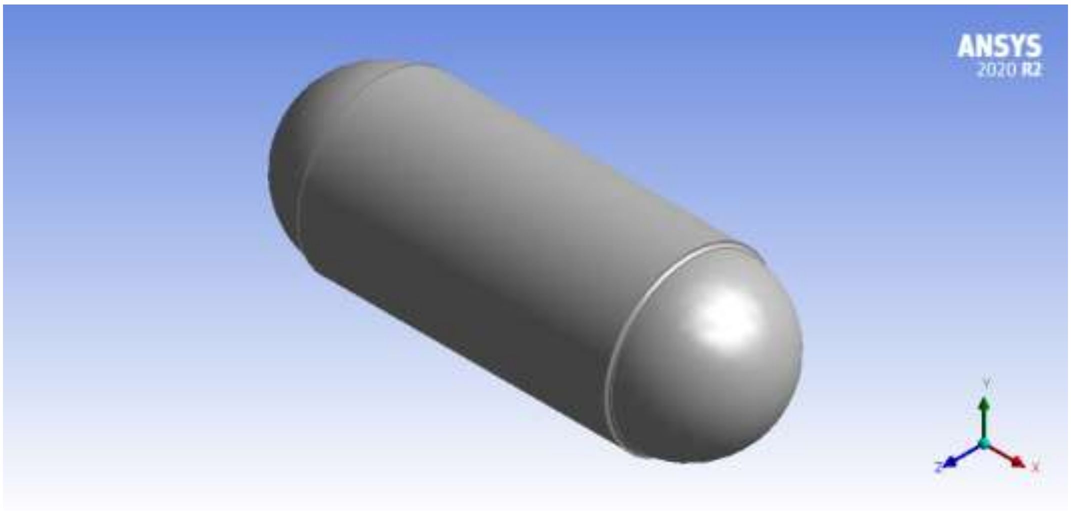

Fig. 4. Isometric view

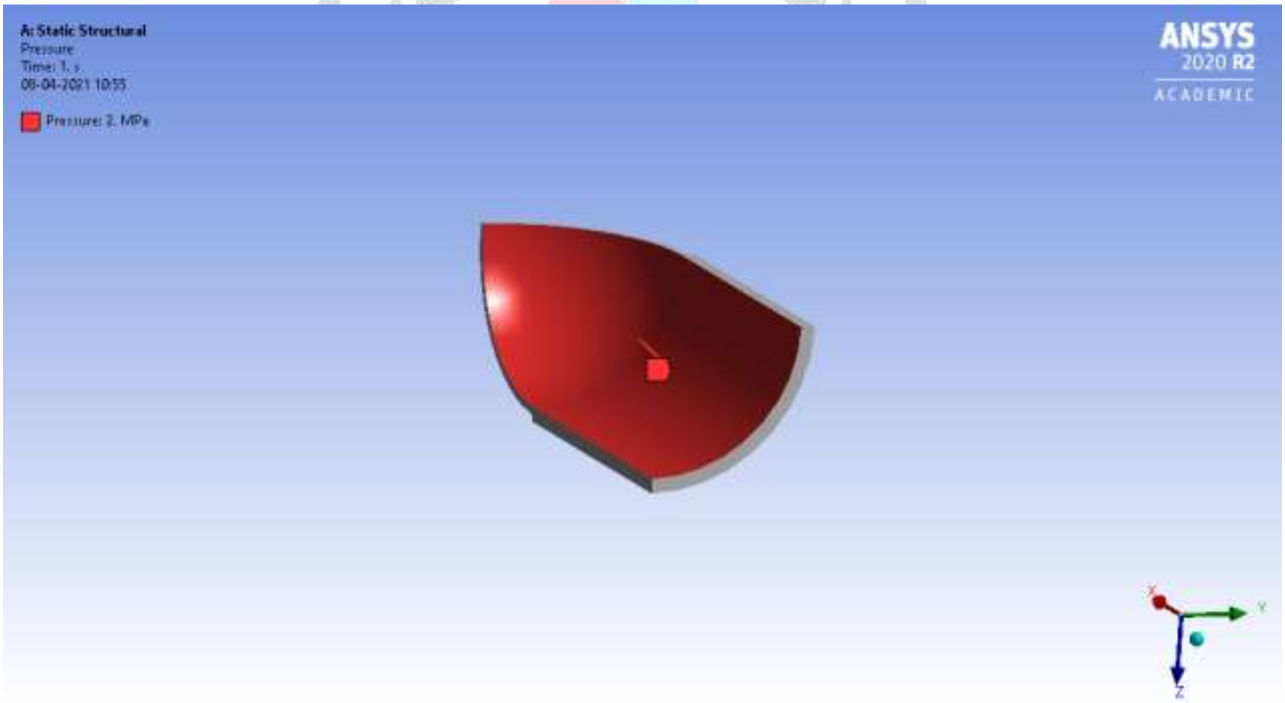

Fig. 5. Boundary conditions for pressure vessel.

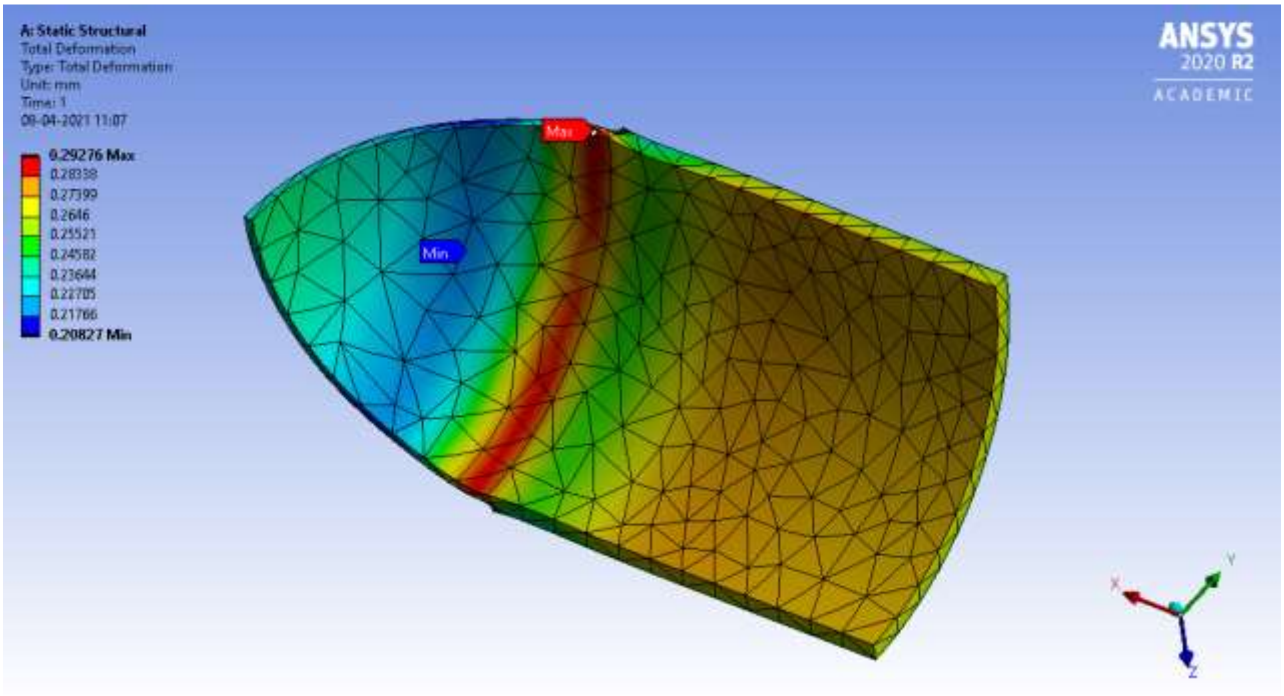

Fig. 6. Total Deformation

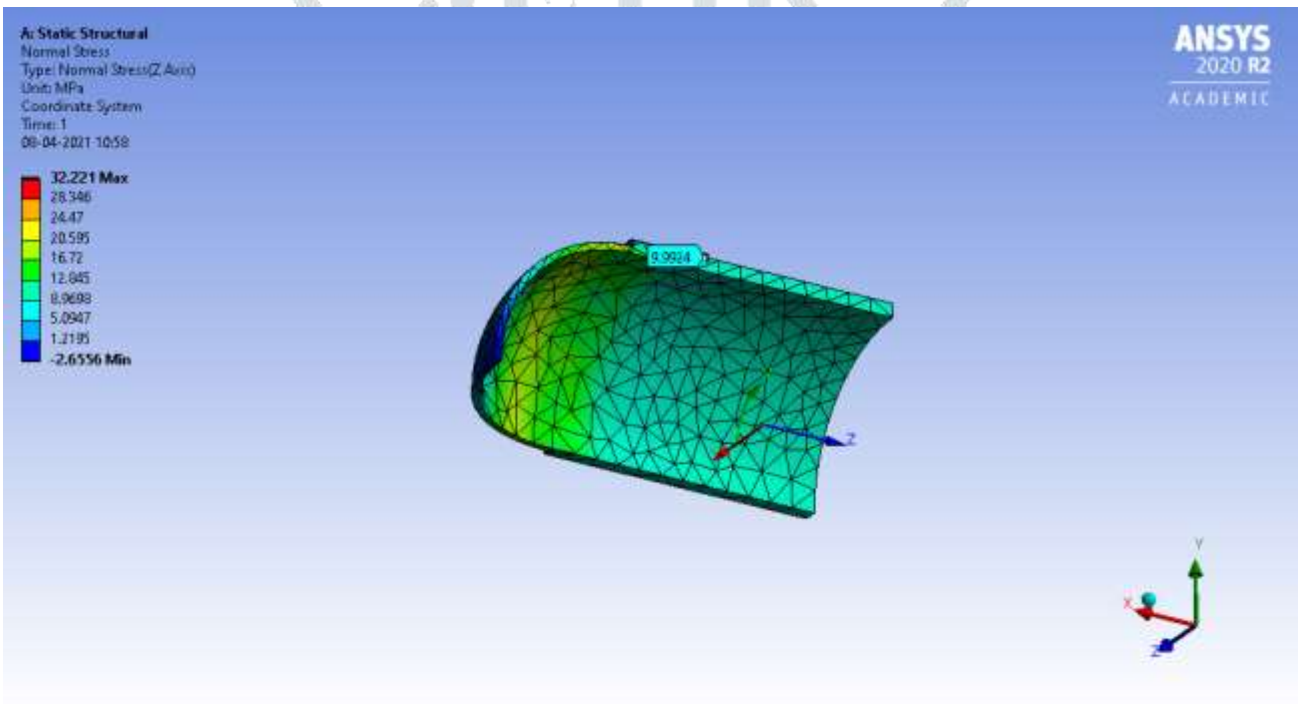

Fig. 7. Longitudinal stress

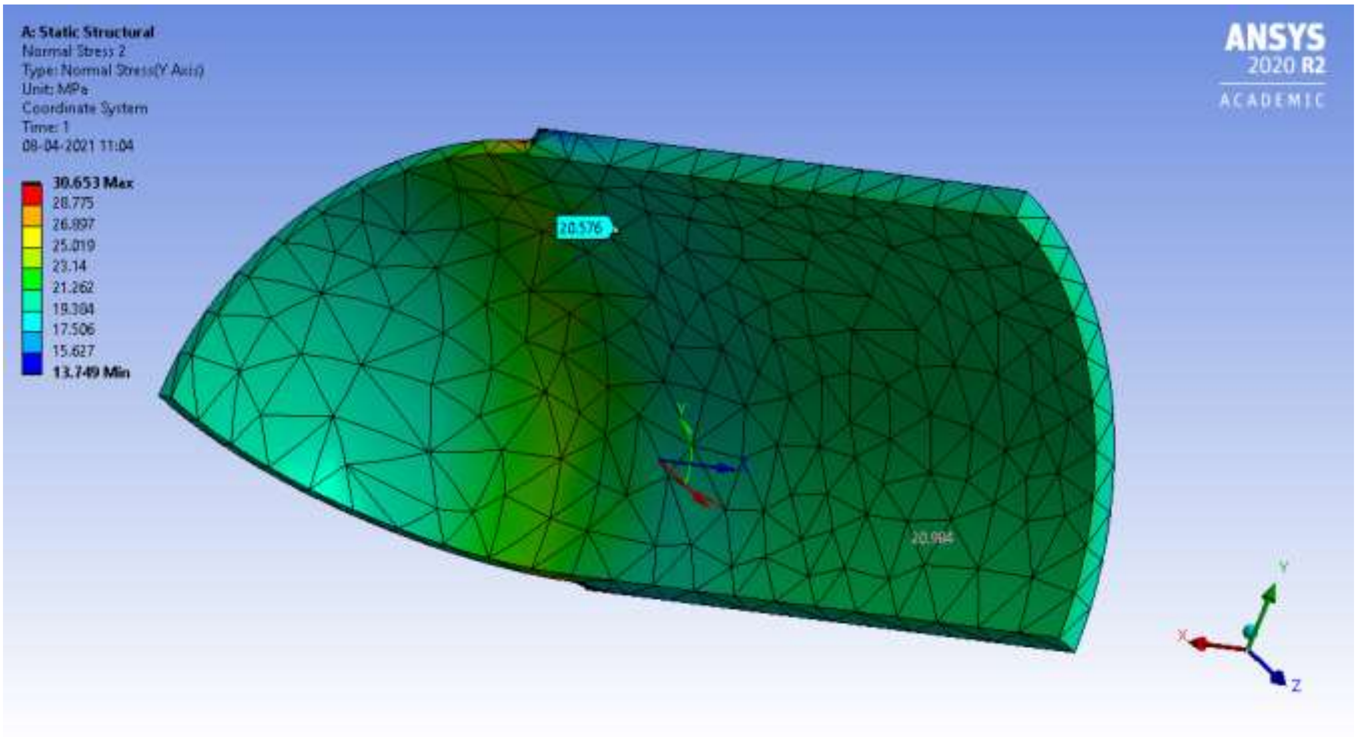

Fig. 8. Circumferential stress

2 Methodology

This section highlights the research methodology for the present study. It explains the research objectives and a suitable methodology to achieve those objectives. The various stages of present research and methods used for the analysis are as follows. (Khobragade & Gandhe, 2017)

- Study of material properties of Polyetheretherketone (PEEK) material
- Selection of pressure vessel for analysis purpose with its technical specifications.
- Static stress analysis of pressure vessel with hemispherical end.
- For static analysis, analytical equations based on design of machine elements are used. For numerical analysis, finite element method is used.
- Finite element method is used to determine the longitudinal and circumferential stresses in pressure vessel.
- For CAD modelling of pressure vessel, modelling software Design Modular and for finite element analysis, ANSYS 2020R2 from ANSYS, Inc. is used.

2.1 Design Calculations

The dimensions for the vessel are calculated using ASME Boiler and Pressure Vessel Code (BPVC). The code used for unfired pressure vessels is Section VIII of the ASME boiler and pressure vessel code. It is usually necessary that the pressure vessel equipment be designed to a specific code in order to obtain insurance on the plant in which the vessel is to be used. Regardless of the method of design, pressure vessels within the limits of the ASME code specification are usually checked. The pressure vessel is designed to meet all the requirement of ASME standards. (Prashanth & Sachidananda, 2019).

2.2 Shell thickness calculation:

- The minimum thickness required of any pressure retaining component is;

tu = 1.5 mm

  - Where P is the internal design pressure, R is the inner radius of the shell,
  - S is the maximum allowable stress value of the material and
  - E is the joint efficiency of the vessel (Quality factor).

- The minimum thickness of the shell required to handle circumferential stress due to internal pressure considering cylindrical shells was estimated using;

tc = **PR / (SE - 0.6×P) + corrosion allowance**

- The minimum thickness of the shell required to handle longitudinal stress due to internal pressure was estimated using;

tl = PR / (2×SE + 0.4×P) + corrosion allowance

- The shell thickness excluding corrosion allowance (t) is the highest of the thickness amongst tc, tl, tu:

t = max (tu, tc, tl)

2.3 Thickness calculation of hemispherical head

- The minimum thickness of the hemispherical head was calculated using;

  t = PR / (2×SE – 0.2×P)

- Outer Radius = R + t

2.4 Modelling and Analysis

Ansys is used to analyze the stresses and deflections in the vessel walls due to the internal pressure. The vessel is axially symmetric about its central axis. In addition, the vessel is symmetric about plane through the center of the cylinder. Thus, only a quarter section of the vessel needs to be modelled. Analysis will be performed using three-dimensional, 10-node tetrahedral elements (SOLID187).

2.5 Modelling

- The pressure vessel model is modelled using Design Modular modelling software.
- The cylindrical vessel has an inner diameter of 120 mm with spherical end caps.
- The end caps have a wall thickness of 3 mm, while the cylinder wall is 6 mm thick.
- We used the basic drawing commands like point, line, circle, revolve, etc to build the model in design modular software.
- By using the revolve method, we created 3-D model with the 2-D outline of the vessel.
- At first, we created full 3-D model of the cylinder then modified that into one fourth model as shown in the figure.

2.6 Analysis

ANSYS 2020 R2 is the finite element analysis software which is used for the analysis of pressure vessels. Suitable material properties were assigned to the 3-D CAD model designed. The material properties like modulus of elasticity and poisons ratio are assign to the vessel in engineering data in Ansys. We carried out the static–structural analysis for pressure vessel with PEEK material.

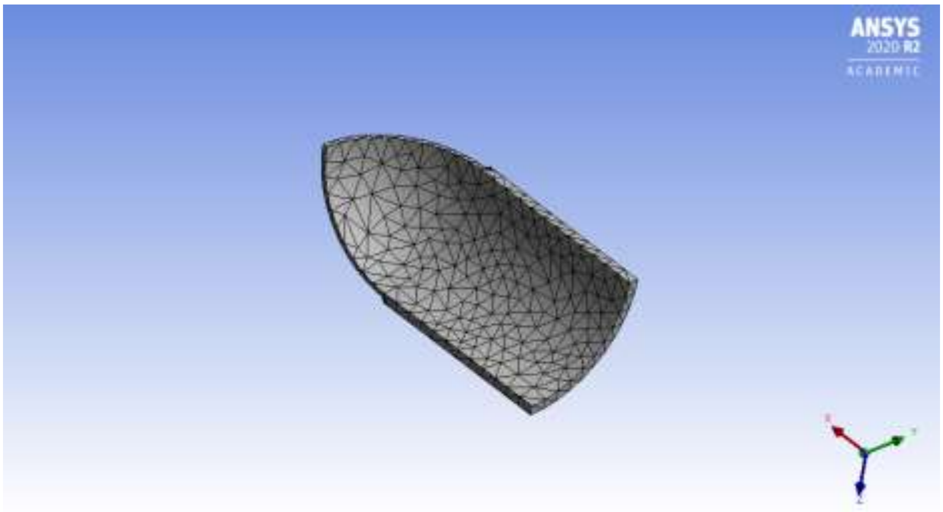

Fig. 9. Mesh

After that the model was ed by using tetrahedral elements. In design simulation 10-node tetrahedral SOLID187 element is used for meshing of three-dimensional vessel. (N P G, Imran, & Haneef, 2015)
A SOLID 187 is defined by 10 nodes (Fig. 8.) having three degrees of freedom at each node: translations in the nodal x, y, and z directions. The element has plasticity, hyper elasticity, creep, stress stiffening, large deflection, and large strain capabilities. It also has mixed formulation capability. The boundary condition was applied to the model. So, boundary condition was defined to corresponding to each side surfaces by using Loads- pressure on areas functions.
Pressure of 2 MPa is applied to the internal surface. (**Fig. 5**.). Then analysis was run and the solutions were observed with plot results, nodal solutions. After the solution has been obtained (**Fig. 6, Fig.7,** and **Fig. 8**), there are many ways to present ANSYS' results, choose from many options such as tables, graphs, and contour plots.

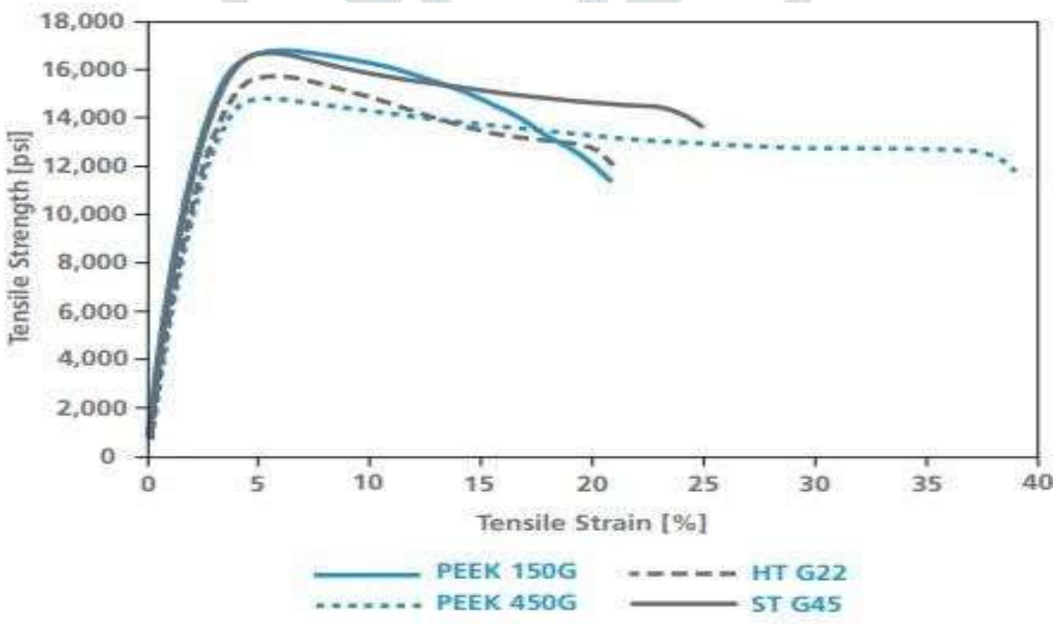

Fig.10. Stress vs Strain graph of PEEK

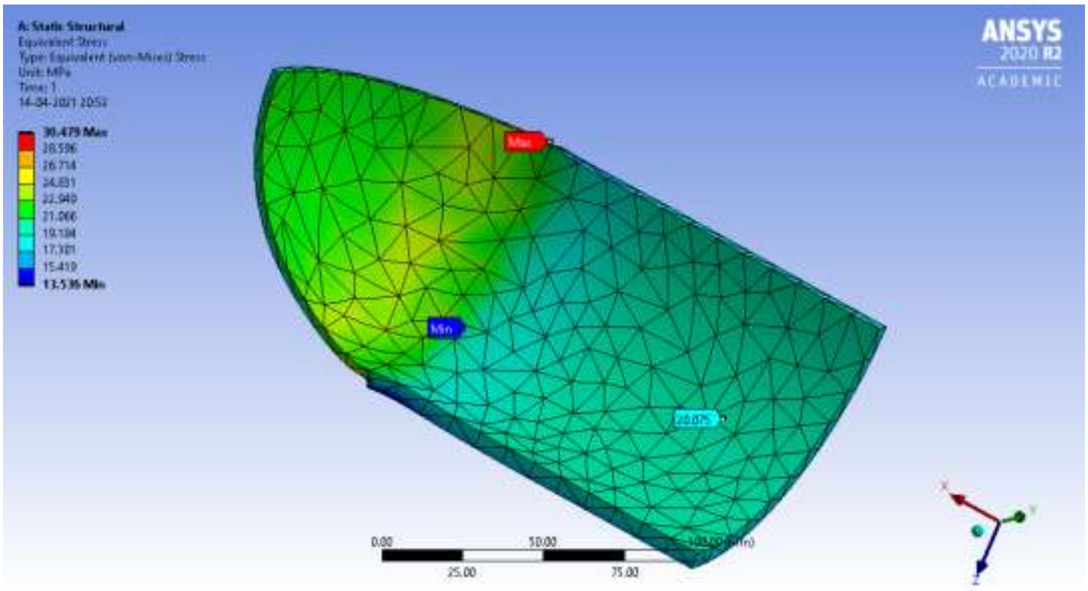

Fig. 11. Von-Mises Stress

2.7 Post Processing

Post processing includes the validation and verification of the result we are getting from the analysis. The post processing of the result from Ansys will make sure whether the analysis and model we chosen is right and the result is reliable. For this part we will manually calculate the stress values, which was our required output with the available derived equations. These values will be compared with results from Ansys and verified.

1. The equation for circumferential stress (Hoop stress) om a thin wall cylindrical pressure vessel is expressed by

$$\sigma c = PD/2t$$

where:

- σc is the hoop stress
- P is the internal pressure
- t is the wall thickness
- D is the mean diameter of the cylinder

2. If the cylindrical vessel has closed ends, the internal pressure acts on them to develop a force along the axis of the cylinder. This stress is known as longitudinal or axial stress. Usually, it is less than the circumferential stress,

   Longitudinal stress is calculated using the equation;

$$\sigma l = PD/4t$$

where:

σl is the longitudinal stress

3 Results and Discussion

Modelling of the pressure vessel using ANSYS software, **Figure 2,** and **Figure 4** revealed the modelling of the pressure vessel. **Figure 2**. revealed the dimension and **Figure 3** shown the chemical structure of PEEK material. The Experimental result that are made in the finite element analysis using ANSYS software are provided from **Figure 6-8**, **and Figure 11.** (Mohanvel, Prashanth, Arunkumar, Pradeep, & Babu, 2020) **Figure 10**, reveals the stress-strain diagram for unfilled PEEK material which is named as PEEK 450G comparing with other filled PEEK materials. With diagrams, graphs pressure vessel with PEEK material showing various analyses like stress, total deformation, longitudinal and circumferential stress and mesh. The **Figure 1.** compared tensile strength and Von-Mises strength of PEEK material with existing and commonly used material mild steel. Analyzed longitudinal stress and circumferential stress using ANSYS and manual calculation, both shown the same value. (El-Qoubaa & Othman, 2015).

Table.3. Results from Ansys and Manual Calculation

	Ansys Result	Manual Calculation
Maximum Deformation	0.27mm	
Longitudinal Stress	9.99MPa	11MPa
Circumferential Stress	20.57MPa	22MPa

4 Conclusion

In this investigation result gives most extreme estimations of stress and strain which has increasingly precise worth. It expands the life and administration life of material. PEEK (Polyether Ether Ketone) based pressure vessels are light weight, high strength, less wear and good corrosive resistance. PEEK based pressure vessels have low weight compared to the existing steel material. The analysis result gives maximum values of stress, strain, deformation which has more accurate value compared to the existing material. It increases the life and service life of material. PEEK pressure vessels are light weight, high strength, less wear, and good corrosive resistance.

5 References

[1] El-Qoubaa, Z., & Othman, R. (2015). *Tensile Behavior of Polyetheretherketone over a Wide Range of*. Hindawi Publishing Corporation.

[2] Ji, S., Sun, C., Zhao, J., & Liang, F. (2015). Comparison and Analysis on Mechanical Property and Machinability about Polyetheretherketone and Carbon-Fibers Reinforced Polyetheretherketone. *www.mpdi.com*.

[3] Akkimaradi, K., & Khadabadi, U. (2016). *DESIGN AND ANALYSIS OF COMPOSITE CYLINDER.* a. IRJET.

[4] Mohanvel, V., Prashanth, S., Arunkumar, M., Pradeep, G., & Babu, S. S. (2020). Modeling and stress analysis of aluminium alloy based composite pressure vessel through ANSYS software. *Materials Today: Proceedings*.

[5] *victrex-peek-450G.* (2019, November). Retrieved from victrex: https://www.victrex.com/~/media/datasheets/victrex_tds_450g.pdf

[6] *victrex peek-polymer.* (2019). Retrieved from victrex: https://www.victrex.com/en/products/polymers/peek-polymers

[7] Khobragade, R. P., & Gandhe, R. R. (2017). *Design & Analysis of Pressure Vessel*

with Hemispherical & Flat Circular End. IJIRST.
[8] N P G, K., Imran, M., & Haneef, M. (2015). *Design Development Analysis on Pressure Vessel under Different End Conditions using Ansys.* IJERT.
[9] P, S., U, R., & Tamera, S. (2017). *Design and Analysis of Pressure Vessel Using Finite.* IJLTEMAS.
[10] Prashanth, D., & Sachidananda, H. (2019). *DESIGN AND ANALYSIS OF PRESSURE VESSEL.*
a. IJMPERD.
[11] Riddhish, C., Rahul, D., Anurag, B., Prashant, B., & Bhosale, R. (2019). *"Design and Analysis of Pressure Vessel Using Software".* IRJET.
[12] Wadkar, V., Malgave, S., Pratil, D., Bhore, H., & Gavade, P. (2015). *DESIGN AND ANALYSIS OF PRESSURE VESSEL USING ANSYS.* JMET.