

Design and Analysis of Pressure Vessel for SA-516 Grade 70, SB-209 Alloy 6061 T6 and E- Glass Epoxy using ANSYS Software

Yashas¹, Nishan A², Yathin Kumar³ and Shreyas M⁴

¹Sahyadri College of Engineering and Management, Mangalore, India

Email: yashasofbajal@gmail.com

²⁻³⁻⁴Sahyadri College of Engineering and Management, Mangalore, India

Email: {sumanasurajmlr, yathinshettigar72, shreyas1999}@gmail.com

Abstract—The pressure vessels, which have a variety of uses, are a crucial part of the process sector. The choice of material and the pressure vessel's design are crucial since the pressure vessel houses highly pressurized liquids. The primary goal of this work is to design a pressure vessel by ASME standards and perform structural analysis on the vessel using Ansys software. It is achieved by selecting three different materials based on the literature survey. The work is concluded by selecting the best material according to the comparative analysis results..

Index Terms—Pressure vessel, ASME standards, structural analysis, Ansys.

I. INTRODUCTION

Normally a pressure vessel is a closed container capable of storing materials at high pressure, above the atmospheric pressure. Pressure vessels according to their usage can be classified into two types- process vessels and storage containers. According to their shape, theoretically, a pressure vessel is divided into any shape such as cylindrical, spherical, or even conical shape. Most commonly used are cylindrical and spherical. Further put into sets, horizontal or vertical pressure vessels may even have coils to vary the fluid temperature [1].

Pressure vessels are found in various sectors of the practical world like the oil industry, the petrochemical industry, gas production industry, nuclear power industry, biotechnology, food industry, and so on. The safety and reliability of the pressure vessels have been instrumental in the usage of pressure vessels in industries which is mainly decided by the selection of the materials. Hence selection of perfect materials has a vital role in the manufacturing of pressure vessels. There are several materials as per the ASME standard grade which is preferred for designing and manufacturing pressure vessels.

A. Introduction to ASME Codebook

- Carbon steel: Carbon steel pressure vessel has a vast range of advantages. Some of the notable properties of carbon steel are high resistance to corrosion, shock and vibration. High tensile strength makes it a preferable material for heavy tank applications [2].
- Nickel alloy: Nickel alloy is obtained in a large range of grades, to make nickel alloy more heat resistant

chromium is added to it. Copper can also be used for pressure vessels working in an environment surrounded by saltwater. One of its most important uses of it is pressure vessels used in Liquefied Natural Gas (LNG) sectors [2].

- Aluminium: For various applications of pressure vessel aluminium are preferred as the standard material. As it is three times less dense than stainless steel, aluminium can keep up high strength under extreme tension with a specific process of heating and cooling. Among all the benefits one of the most important advantages of using aluminium as materials for pressure vessels is its low cost and easy machinability [2].

- Stainless steel: It offers high strength at relatively low compactness similar to the likes of carbon steel. Also, it is highly recyclable which serves as a major advantage for using it in manufacturing and designing a pressure vessel. There are several different types of stainless steel. Among them, Type 304 is recognized for high chemical resistance and imperviousness. Whereas Type 304L very has low carbon content due to which it exhibits excellent weld-ability [3].

- Hastelloy: These pressure vessels are widely used in the chemical, oil, gas and petrochemical sectors. With numerous advantages, on-hand properties like resistance to oxidation, high-temperature strength and very good stress corrosion resistance make it preferable for manufacturing pressure vessels. Good maintenance of these pressure vessels helps them to retain for decades, leading to great cost-efficiency. Their built-in reliability reduces maintenance-related downtime [4].

- Composite materials: They are also used in pressure vessel manufacturing. A composite material can be interpreted as a combination of two or more materials resulting in better properties than their counterparts. Each material maintains separate mechanical, physical and chemical properties. Their two main elements are reinforcement and matrix. Advantages of such material composition are the high strengths, stiffness levels and low densities resulting in lower weight of the finished part. A layer, ply or lamina of composite material is made up of a large number of parallel fibres that are embedded within a matrix, in most cases, the reinforcement which is usually the fibre or particulate demonstrates hardness and strength. The composites made from particulates usually have a lower volume fraction (0.4 to 0.5) in comparison to fibre-based composites this is mainly due to processing difficulties as a result of brittleness. Fiberglass Reinforced Plastics (FRP) also known as Glass Reinforced Plastics (GRP). It is the latest composite material used for construction in chemical plant equipment like vessels and tanks. The equipment has proportions ranging from less than one meter to a maximum of twenty meters and is fabricated with the help of FRP materials [5]. Composite materials offer engineers the opportunity to lighter and stronger structures compared to bulk materials. With the ability to alter the orientation in the fibre angle, engineers can design pressure vessels that are highly adaptable to specific requirements. Other advantages of composite materials are the extended lifetime as they do not corrode.

B. Introduction to ASME Codebook

There are many rules developed by different countries escorted by experienced technical experts in their respective fields, the code which is recognized internationally and widely in use is ASME Section VIII, for Boiler and Pressure Vessel Code (BPVC). Designing a pressure vessel that follows ASME's BPVC has a major role for a variety of reasons mainly for quality and safety [2]. The main factors that should be considered while designing a pressure vessel as per the American Society of Mechanical Engineers (ASME) Section VIII requires the s following minimum considerations: maximum allowable working pressure (MAWP), design temperature, design pressure minimum design metal temperature (MDMT), service and process purpose/ description, corrosion allowance, joint efficiency, nominal thickness, head types, site data for seismic and wind parameters, loads and its combinations, the material of construction, stress analysis, vessel orientation (vertical or horizontal). The motive of the usage of design codes is to evade catastrophic events that can strike the lives of workers. The BPVC is studied and written by various volunteers, who are selected to the council based on their technical expertise and their ability to contribute to the writing, revising, converting, and issuing of the document. The ASME BVPC code is a standard set of codes and rules for design specifications purposes and inspection, installation, fabrication, verification, and certification [3]. It has three Divisions in ASME Section VIII: Divisions 1, 2, and 3. Division 2 for pressure below 10,000 PSIG. Division 3 is used in the computation and scale drawing of high-pressure equipment, which is around 703 kg/cm²g (10,000 PSIG), while Division 1 has pressure generally up to 3,000 PSIG and Division 1 has a set of rules for designs, which do not require a detailed evaluation of the stresses involved. High bending stress is present, but with safety factors being moderate, stresses are recouped. With designing having reference to Division 2 more vivid analysis can be achieved, the person putting up the design has to take into account the higher allowable stresses to get much more real and valid results. This codebook consists of certain rules for the design method, allowable stress, specific material, fabrication, design load, inspection, and certification requirements for vessel design and

construction. This is also known as "design by the rule". It uses design pressure, allowable stress, and a design formula appropriate to the geometry of the part to calculate its thickness. This method decreases the amount of analysis required making sure that the vessel will not fracture by having a specific vessel thickness. The code also contains many details regarding construction that need to be followed step by step. When vessels are subjected to loadings such as thermal, cyclic, or confined loads. This can also be termed the "design by analysis" method [15].

C. Introduction to ANSYS Software

The use of several software packages for simulation leads to inefficiency and an increase in cost. The software used is ANSYS, Analysis of systems which offers a flexible suite of amalgamated analysis outcomes that allows users, irrespective of their domain, in collaborating, to allocate simulation data and approved methods without the loss of any information of the user. The Ansys amalgamated FEA software offers a potent solution for both procedural and complicated engineering problems which covers a varied range of applications in industries. In the automotive industry, it is used to analyze dynamic vibration and other factors. Ansys software will show if a product will collapse, wear out or work in the way it was designed. The action of each element can be predicted by using mathematical equations [4].

II. LITERATURE SURVEY

A. M. SenthilAnbazhagan and M. DevAnand studied "Design and Crack analysis of pressure vessel saddles using Finite Element Method". The work aims to design a model which is used as a fuel carrying tank using FEA software and a selection of appropriate materials for the given pressure vessel [5].

A. Devaraju and K. Pazhanivel worked on "A Study on Stress Analysis for Design of Pressure". Investigated the different pressures which lead to stress in a pressure vessel. Learned about the effect of internal pressure and different loads on a standard pressure vessel. Further, it is designed and stress is applied at different parts for calculation and compared using FEA software [6].

K. S. Naser et al. examined "Structural & Thermal Analysis of Pressure Vessel by using Ansys". The work sheds light on the various substance stored in pressure vessels and the industries they are used in. Modelling is done with the help of Pro-E modelling software and ANSYS is used for analysis. Finally, the theoretical and Design calculations are compared and verified [7].

S. Patel studied "Design and Analysis of Vertical Pressure Vessel using ASME Code and FEA Technique Design and Analysis of Vertical Pressure Vessel using ASME Code and FEA Technique". In this work, the modelling is done using Hyper mesh 6.1, and analysis using ANSYS Software 11. Finally, it is confirmed with the theoretical calculations [8].

M. A. M. Iqbal et al. studied the "Design and Stress Analysis of FRP Composite Pressure Vessel". This work shows the importance of composite pressure vessels and the process of manufacturing composite pressure vessels. FEA model is done through ANSYS 12. It aims to analyze stresses in a Glass filament wound FRP pressure vessel and find the burst pressure by applying suitable failure criteria. It also focuses on developing an E-Glass composite pressure vessel [9].

P. M. Rao et al. examined "Design and Static Structural Analysis of Pressure Vessel using Finite Element Technique". The work highlights the pressure vessel and its various parts. The design is of an axially symmetrical pressure vessel done using CATIA V5 R19 and meshing is done through ANSYS Fluent [10].

M. Nomura et al. examined "A Critical review and analysis of pressure vessel structures". The work gives the history and brief overview of the pressure vessel. It further touches upon applications, main components, geometry, materials, and pressure vessel fabrication. Knowledge of ASME codes is known [11].

J. Jegatheesan and Z. Zakaria studied "Environment & Ecosystem Science (EES)". The work is based on ASME VIII Division I, PD 5500, and EN 13445, and the storage tank is designed using PV-Elite. Finally, they conclude that American Standard is the better of the three [12].

Patel Nikunj S examined "Engineering modelling and Thermal analysis of reactor pressure vessel by using advance CAE Tools". The work gives an idea of the effects of unwanted stresses, defects in shapes, and creeping on various parts of pressure vessels, which tends to reduce the life-cycle of a pressure vessel, leading to an increase in costs. This paper uses advanced CAE tools for the design of a model and thermal analysis of a pressure vessel and an analytical method is used for cost prediction [13].

S. Chattopadhyay investigated "Material selection for a Pressure Vessel". It elucidates the uses of pressure vessels' uses and leaks before break (LBB) concept. Material selection is done based on elastic-plastic fracture toughness and material strength Analysis is carried out based on the Leak before Break methodology [14].

A. Objectives

From the above literature survey, the following objectives have been selected,

- To select the materials for the pressure vessel based on a literature survey.
- To design a standard pressure vessel using the required parameters from ASME Codebook.
- To analyze the designed pressure vessel using FEA (Ansys) software.
- To compare the analysis result with the theoretical values and to come up with the conclusion for the best material suitable for the implementation of a pressure vessel.

III. MOTIVATION

With the interest in design and analysis, the motivation for this project is to apply the knowledge gained during our curriculum and highlight the importance of analysis before implementation.

IV. PROBLEM DOMAIN

Modelling and simulation concepts in manufacturing.

V. PROBLEM DEFINITION

To compare the pressure vessels of different materials and their importance in industries to choose the appropriate material.

VI. STATEMENT

Design and Analysis of Pressure Vessel for SA-516 Grade 70, SB-209 Alloy 6061 T6, and Glass Epoxy FRP using ANSYS Software.

VII. INNOVATIVE CONTENT

The comparative study was done by selecting materials from SA-516 Grade 70 (Carbon Steel), SB-209 Alloy 6061 T6 (Aluminium alloy), and E Glass Epoxy (Fibre Reinforced Polymer).

VIII. PROBLEM FORMULATION OR REPRESENTATION OR DESIGN

This project is mainly concerned with designing pressure vessels using ASME codes and analysis of pressure vessels using analysis software. The flowchart for the same is shown in Fig.1.

The steps are as follows,

- Identification of Problem statement and planning: The problem statement for the project was selected by consultation with the project guide and team members. The project is further divided into different parts and planned accordingly to complete it within the given time frame.
- Literature survey and material selection: Based on the problem statement, a literature survey was done to know more about the problem statement and to find the appropriate materials for the continuation of the project.
- Design calculations: The design of the pressure vessel was done by following the standards set in the ASME Codebook, and the same is modelled with the help of modelling software
- Modelling and analysis: The complete model is then further tested for various conditions with the help of Ansys software.

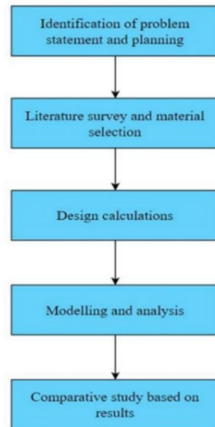


Fig.1: Flow chart for methodology

A. Conceptual Design

The conceptual design of three pressure vessels is shown below,

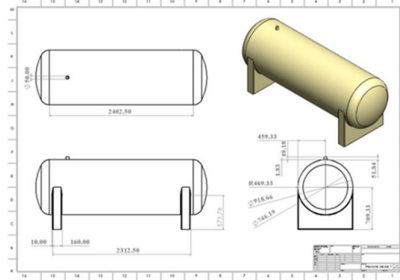


Fig.2: Conceptual design of pressure vessel for material SA-516 Grade 70

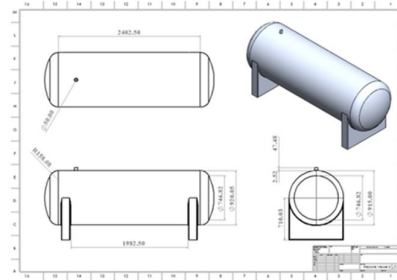


Fig.3: Conceptual design of pressure vessel for material Alclad 6061 T6 class

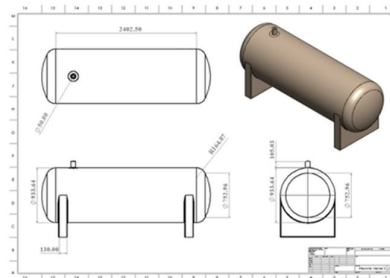


Fig. 4: Conceptual design of pressure vessel for E-Glass Epoxy

IX. SOLUTION METHODOLOGIES OR PROBLEM SOLVING

A. Analysis

The analysis of the pressure vessel was carried out using Ansys Workbench considering the three materials that have been selected. The analysis process is carried out by first applying the material to the model, meshing the model, inserting various parameters and solving the model. The results obtained are compared among themselves according to the parameters chosen. The better material out of the three is selected

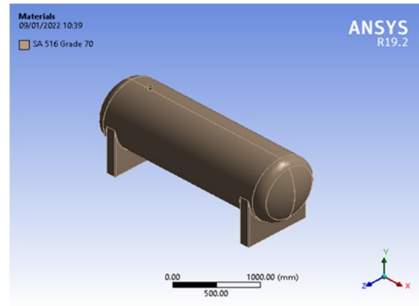


Fig. 5: Three-dimensional view of the pressure vessel for SA-516 Grade 70

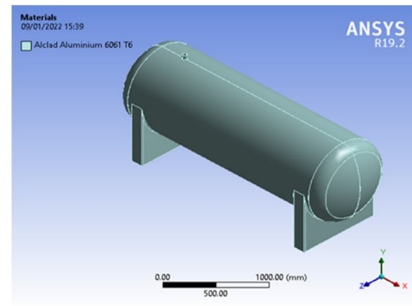


Fig. 6: Three-dimensional view of the pressure vessel for Alclad 6061 T6 class alloy

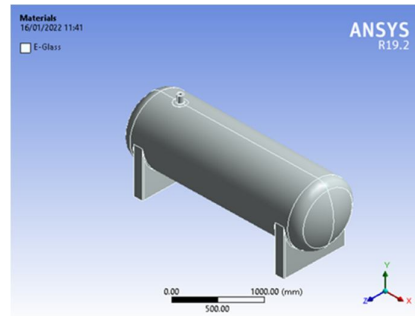


Fig. 7: Three-dimensional view of the pressure vessel FRP E-Glass epoxy

B. Design of Shell

TABLE NO. I: PARAMETERS USED FOR THE DESIGN OF SHELL

Sl. No.	Notation	Values
1.	P, Internal pressure in MPa	0.25
2.	T, Internal temperature in $^{\circ}\text{F}$	32
3.	L, length in mm	2,250
4.	R, Inside Diameter in mm	457.5
5.	E, Joint Efficiency	1
6.	S, Allowable Stress in MPa for Pressure vessel 1	137.9
7.	S, Allowable Stress in MPa for Pressure vessel 2	75.15
8.	E_1 , Tensile modulus in the longitudinal direction in MPa	44,815.92
9.	E_2 , Tensile modulus in the circumferential direction in MPa	12,410.56

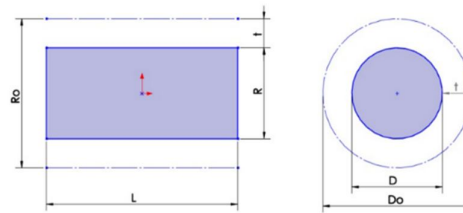


Fig. 8: Schematic representation of the shell

Cylindrical Shells: The minimum Thickness or maximum allowable working pressure of cylindrical shells shall be the greater thickness or lesser pressure as given by (1) or (2) below.

Circumferential Stress: When the thickness does not exceed one-half of the inside radius, or P does not exceed 0.385SE, the following formula shall apply,

$$t = PR / (SE - 0.6P) \quad (1)$$

Longitudinal Stress: When the thickness does not exceed one-half of the inside radius, or P does not exceed 1.25SE, the following formula shall apply

$$t = PR / (2SE + 0.4P) \quad (2)$$

Case study 1 (SA-516 Grade 70):

For case study 1 the chosen material for the pressure vessel is Carbon steel SA-516 Grade-70,

Product form: Plate section II Materials.

2015 ASME Boiler and Pressure Vessel Code Section II materials

Allowable stress from table 1A (cont'd) - Pg. No 18

For metal temperature F maximum allowable stress value δ for ferrous materials.

Allowable stress, S = 20 ksi

$$S = 137.9 \text{ MPa}$$

From Eqn. (1) the thickness of the shell for case study 1 is,

$$t = \frac{0.25 * 457.5}{(137.9 * 1) - (0.6 * 0.25)}$$

$$t = 0.83 \text{ mm}$$

$$t = 0.83 \text{ mm} + 1 \text{ mm (allowance)} = 1.83 \text{ mm}$$

From Eqn. (2) the thickness of the shell for case study 1 is,

$$t = \frac{0.25 * 457.5}{(2 * 137.9 * 1) + (0.4 * 0.25)}$$

$$t = 0.41 \text{ mm}$$

$$t = 0.41 \text{ mm} + 1 \text{ mm (allowance)} = 1.41 \text{ mm}$$

1.83 > 1.41, hence 1.83 mm is taken as the thickness value for case study 1.

Case study 2 (SB- 209 Alclad 061 T6):

For case study 2 the chosen material for the pressure vessel is SB- 209 Alclad 061 T6,

Product form: Plate section II Materials.

2015 ASME Boiler and Pressure Vessel Code Section II materials

Allowable stress from table 1A (cont'd) - Pg. No 18

For metal temperature F maximum allowable stress value δ for ferrous materials.

Allowable stress, S = 10.9 ksi

$$S = 75.15 \text{ MPa}$$

From Eqn. (1) the thickness of the shell for case study 2 is,

$$t = \frac{0.25 * 457.5}{(75.15 * 1) - (0.6 * 0.25)}$$

$$t = 1.525 \text{ mm}$$

$$t = 1.525 \text{ mm} + 1 \text{ mm (allowance)} = 2.525 \text{ mm}$$

From Eqn. (2) the thickness of the shell for case study 2 is,

$$t = \frac{0.25 * 457.5}{(2 * 75.15 * 1) + (0.4 * 0.25)}$$

$$t = 0.76 \text{ mm}$$

$$t = 0.76 \text{ mm} + 1 \text{ mm (allowance)} = 1.76 \text{ mm}$$

2.525 > 1.76, hence 2.525 mm is taken as the thickness value for case study 2.

Case study 3 (E-glass Epoxy):

For case study 3 the chosen material for the pressure vessel is E-glass Epoxy,

1) Circumferential Stress

$$t_1 = \frac{PR}{0.001 * E1} \quad (3)$$

$$t_1 = \frac{0.25 * 457.5}{0.001 * 12410.56}$$

$$t_1 = 9.32 \text{ mm}$$

2) Longitudinal Stress

$$t_2 = \frac{PR}{2(0.001 * E2)} \quad (4)$$

$$t_2 = \frac{0.25 * 457.5}{2(0.001 * 44815.92)}$$

$$t_2 = 1.280 \text{ mm}$$

9.32 > 1.280, hence 9.32 mm is taken as the thickness value for case study 3.

C.Design of Ellipsoidal Head for Pressure Vessels

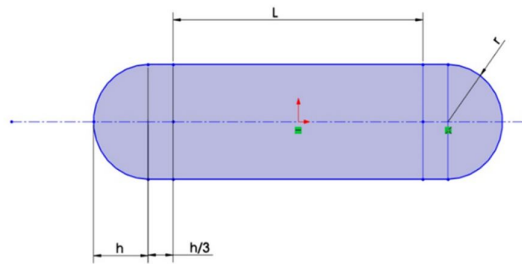


Fig. 9: Schematic representation of shell with ellipsoidal head

Depth of head

$$h = \frac{D}{4} \quad (5)$$

$$h = \frac{915}{4}$$

$$h = 228.75 \text{ mm}$$

$$\frac{h}{3} = \frac{228.75}{3}$$

$$\frac{h}{3} = 76.25 \text{ mm}$$

From ASME BPVC Section VIII Div. 2 2019 Pg. No 210, the knuckle radius formula is as follows.

$$r = D \left(\frac{0.5}{k} - 0.08 \right) \quad (6)$$

$$k = \frac{D}{2h} \quad (7)$$

$$k = \frac{915}{2 * 228.75}$$

$$k = 2$$

Where k should be $1.7 \leq k \leq 2.2$

$$r = 915 \left(\frac{0.5}{2} - 0.08 \right)$$

$$r = 155.55 \text{ mm}$$

D. Design of Nozzle

TABLE NO. II PARAMETERS USED FOR THE DESIGN OF THE NOZZLE

Sl. No.	Notation	Values
1.	D_{in} , Inner diameter in mm	50
2.	R_n , Inner radius in mm	25
3.	L_{pr1} , Projection	50
4.	S_s , Secondary bond strength in shear in MPa	6.89476
5.	F, Design Factor	10
6.	L_c , Longest cord length in mm	50

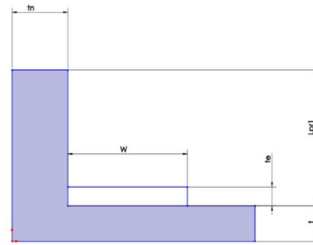


Fig. 10: Schematic representation of nozzle

To find the thickness for case study 1,

1) Circumferential Stress:

$$t_n = \frac{PRn}{SE - 0.6P} \quad (8)$$

$$t_n = \frac{0.25 * 25}{(137.9 * 1) - (0.6 * 0.25)}$$

$$t_n = 0.045 \text{ mm}$$

$$t_n = 0.045 \text{ mm} + 1 \text{ mm (allowance)}$$

$$t_n = 1.045 \text{ mm}$$

2) Longitudinal Stress:

$$t_n = \frac{PRn}{2SE+0.4P} \quad (9)$$

$$t_n = \frac{0.25 * 25}{(2 * 137.9 * 1) + (0.4 * 0.25)}$$

$$t_n = 0.022 \text{ mm}$$

$$t_n = 0.022 \text{ mm} + 1 \text{ mm (allowance)}$$

$$t_n = 1.022 \text{ mm}$$

1.045 > 1.022, hence 1.045 mm is taken as the thickness value for case study 1.

To find (w) width of the added reinforcing element

From ASME BPVC 2001 Section VIII Div. 2 Pg. No 108

$$t_e = 1.5t \text{ or } 1.73w$$

$$t_e = 1.73w$$

$$w = \frac{1.83}{1.73}$$

$$w = 1.057 \text{ mm}$$

$$t_e = 1.73 * 1.057$$

$$t_e = 1.82 \text{ mm (Assuming } t_e \text{ should not exceed } 1.5t)$$

$$1.5t = 1.73w$$

$$w = 1.58 \text{ mm}$$

To find the thickness for case study 2,

1) Circumferential Stress: From Eqn. (8) we know that

$$t_n = \frac{PRn}{SE - 0.6P}$$

$$t_n = \frac{0.25 * 25}{(75.15 * 1) - (0.6 * 0.25)}$$

$$t_n = 0.0833 \text{ mm}$$

$$t_n = 0.0833 \text{ mm} + 1 \text{ mm (allowance)}$$

$$t_n = 1.0833 \text{ mm}$$

2) Longitudinal Stress: From Eqn. (9) we know that

$$t_n = \frac{PRn}{2SE + 0.4P}$$

$$t_n = \frac{0.25 * 25}{(2 * 75.15 * 1) + (0.4 * 0.25)}$$

$$t_n = 0.041 \text{ mm}$$

$$t_n = 0.041 \text{ mm} + 1 \text{ mm (allowance)}$$

$$t_n = 1.041 \text{ mm}$$

1.083>1.041, hence 1.045 mm is taken as the thickness value for case study 2

To find (w) width of the added reinforcing element

From ASME BPVC 2001 Section VIII Div. 2 Pg. No 108

$$t_e = 1.5t \text{ or } 1.73w$$

$$t_e = 1.73w$$

$$w = \frac{2.525}{1.73}$$

$$w = 1.459 \text{ mm}$$

$$t_e = 1.73 * 1.459$$

$t_e = 2.524 \text{ mm}$ (Assuming t_e should not exceed 1.5t)

$$1.5t = 1.73w$$

$$w = 2.189 \text{ mm}$$

To find the thickness for case study 3,

The shear length of the nozzle is given as,

$$L_b = \frac{Pr}{2S_s F} \quad (10)$$

or 75mm (whichever is greater)

$$L_b = \frac{0.25 * 25}{2\left(\frac{6.89476}{10}\right)}$$

$$L_b = 4.532 \text{ mm}$$

75 mm < 4.532 mm therefore $L_b = 75 \text{ mm}$

The thickness of Secondary Overlay on Nozzle (t_b)

$$t_b = \frac{Pr}{S_a} \quad (11)$$

or 6 mm (whichever is greater)

Where S_a = Allowable stress of secondary overlay, defined as the lower of $0.001E_1$ or $0.001E_2$

$$S_a = 0.001 * 44815.92 = 44.815 \text{ MPa}$$

$$S_a = 0.001 * 12410.561 = 12.41 \text{ MPa}$$

Therefore $S_a = 12.41 \text{ MPa}$

$$t_b = \frac{0.25 * 25}{12.41}$$

$$t_b = 0.5036 \text{ mm}$$

6 mm < 0.5036 mm therefore $t_b = 6 \text{ mm}$

To find the thickness of the reinforcing pad (t_p)

$$t_p = \frac{PR}{0.001E_2} \quad (12)$$

$$t_p = \frac{0.25 * 25}{(0.001 * 12410.56)}$$

$$t_p = 0.5036 \text{ mm}$$

To find the length of the pad (L_p)

$$L_p = \frac{\pi L_c P}{4 \left(\frac{S_c}{F} \right)} \quad (13)$$

$$L_p = \frac{\pi * 50 * 0.25}{4 \left(\frac{6.89476}{10} \right)}$$

$$L_p = 14.239 \text{ mm}$$

E. Meshing the Model

Meshing is the process of turning irregular shapes into more recognizable volumes called “Elements.” The goal of meshing in the Ansys workbench is to provide robust, easy-to-use meshing tools that will simplify the mesh generation process. When the meshing application is launched from the Ansys workbench project schematic, the physics preference will be set based on the type of system being edited for the analysis system, the appropriate physics is used for the mechanical model system the mechanical physical preference is used.

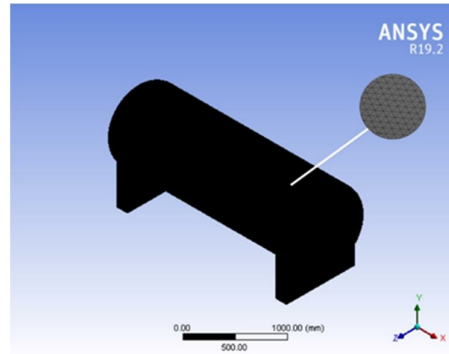


Fig. 11: Pressure vessel view after meshing

F. Parameters Inserted For Analysis

The parameters that we used are gravity, pressure, and fixed support. Here the gravity acts downwards which is in Y- the direction. Pressure acts on the internal side of the pressure vessel. Fixed support is fixed to the. Pressure acts on the internal side of the pressure vessel. Fixed support is fixed to the leg of the pressure vessel which holds the pressure vessel in place.

X. RESULTS AND SENSITIVITY ANALYSIS

- Appropriate materials for designing pressure are selected based on a literature survey.
- Pressure vessel is designed and modelled for these materials based on the ASME section VIII codebook.
- Analysis of the pressure vessel using Ansys software.
- Out of the three materials selected, the better material in terms of economical value and analysis results compared with theoretical values is chosen.

Model is analyzed for different element sizes, and size is selected wherein satisfactory accuracy is obtained having less computation time. The three-dimensional geometry model is meshed using an element size of 4 mm.

A. Evaluation of Longitudinal and Hoop Stresses of Pressure Vessels

The stresses acting on pressure vessels are principal stresses, hoop stress or circumferential stress (σ_H) and longitudinal stress, (σ_L). Circumferential stress is the stress which is set up in resisting the bursting effect of the applied pressure and can be most conveniently treated by considering the equilibrium of the cylinder.

The formula for hoop stress is given by

$$\sigma = \frac{Pd}{2t} \quad (14)$$

Where, P= Pressure in MPa

d= Diameter of the pressure vessel in mm

t= Thickness of the pressure vessel in mm

The formula for longitudinal stress is given by

$$\sigma = \frac{Pd}{4t} \quad (15)$$

Where, P= Pressure in MPa

d= Diameter of the pressure vessel in mm

t= Thickness of the pressure vessel in mm

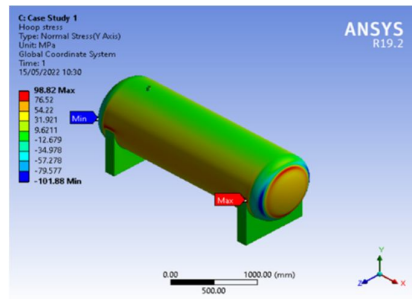


Fig. 12: Hoop Stress analysis of SA 516 Grade 70 Pressure vessel

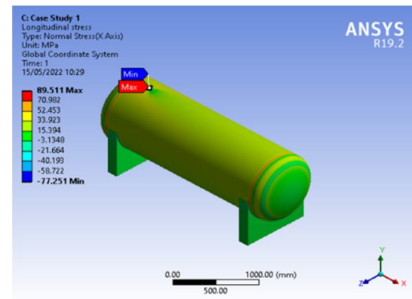


Fig. 13: Longitudinal stress analysis of SA 516 Grade 70 Pressure vessel alloy

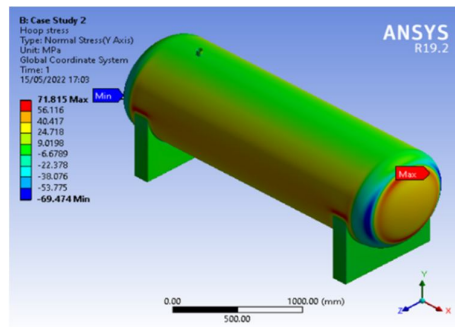


Fig. 14: Hoop Stress analysis for Alclad 6061 T6 class Pressure vessel

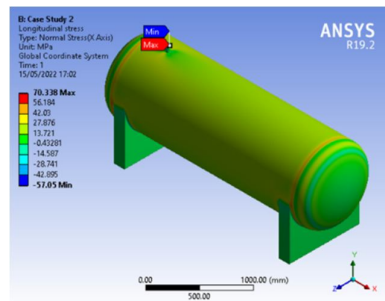


Fig. 15: Longitudinal stress analysis for Alclad 6061 T6 class Pressure vessel

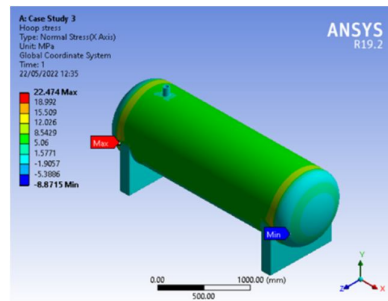


Fig. 16: Hoop Stress of FRP E-Glass epoxy Pressure vessel alloy

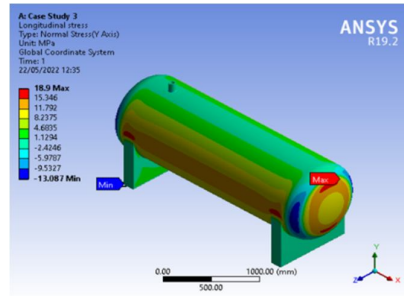


Fig. 17: Longitudinal stress of FRP E-Glass epoxy Pressure vessel

XI. DATA MODEL

A. Materials Selection

Based on the literature survey and after going through various reports three materials are selected for analysis and comparison of results. These materials are standard materials listed in the ASME codebook and are as follows,

1.SA-516 Grade 70:

- It's a carbon alloy that is a mixture of phosphorous, manganese, silicon and Sulphur.
- Its density is 7.80 g/cc and thermal conductivity is 52.0 W/m-K.
- It provides more excellent notch toughness.
- It is widely used in low to moderate temperature boilers. Hence, they are highly preferred in the petrochemical industries, infrastructure and automotive industries.

TABLE NO. III: CHEMICAL COMPOSITION OF SA-516 GRADE 70

Sl. No.	Chemical Composition	Percentage (%)
1.	Carbon	0.31
2.	Iron	98.315
3.	Manganese	0.85-1.2
4.	Phosphorus	0.035
5.	Silicon	0.15-0.40
6.	Sulphur	0.040

2. SB-209, Alloy Designation/UNS Number- Alclad 6061 T6 class:

- It is an Aluminium alloy with 2.5% manganese, and 0.25% chromium alloy.
- It has a density of 2.70 g/cc and thermal conductivity of 167 W/m-K.
- It has the advantage of greatest strength compared to its other alloy counterparts with high fatigue strength and excellent corrosion.
- Used in oil gas industry, chemical industry and marine atmosphere.

3. FRP E-Glass epoxy:

- It is a composite material made up of Glass fibre.
- They are usually employed in places of high temperature. They are light in weight compared to the conventional material used.
- Hence, they have a wide range of applications in the field of aerospace and automotive industry.

TABLE NO. IV: MECHANICAL PROPERTIES OF SA-516 GRADE 70

Sl. No.	Mechanical Properties	Values in MPa
1.	Tensile Strength, Ultimate	485-620
2.	Tensile Strength, Yield	260
3.	Modulus of Elasticity	2,00,000

TABLE NO. V: CHEMICAL COMPOSITIONS OF SB-209

Sl. No.	Chemical Composition	Percentage (%)
1.	Magnesium	0.8-1.2
2.	Silicon	0.4-0.8
3.	Iron	0.7
4.	Copper	0.15-0.4
5.	Manganese	0.15
6.	Chromium	0.04 - 0.35

TABLE NO. VI: MECHANICAL PROPERTIES OF SB-209

Sl. No.	Mechanical property	Values in MPa
1.	Tensile Strength	310
2.	Yield Strength	276
3.	Modulus of Elasticity	68,900

TABLE NO. VII: PROPERTIES OF GLASS EPOXY

Sl. No.	Property	Values
1.	Longitudinal Elastic Modulus	50,000 MPa
2.	Transverse Elastic Modulus	15,200 MPa
3.	Major Poisson's Ratio	0.254
4.	Shear Modulus	4,700 MPa

XII. COMPARISON OF RESULTS

TABLE VIII: COMPARATIVE RESULTS FOR 0.25 MPA INTERNAL PRESSURE

Sl. No.	Materials	Hoop Stress in MPa		Longitudinal Stress in MPa	
		Theoretical	Analytical	Theoretical	Analytical
1.	SA-516 Grade 70	62.5	52.453	31.25	31.921
2.	Alclad 6061 T6 class	45.29	42.03	22.64	24.718
3.	FRP E-Glass epoxy	12.27	12.026	6.135	4.6835

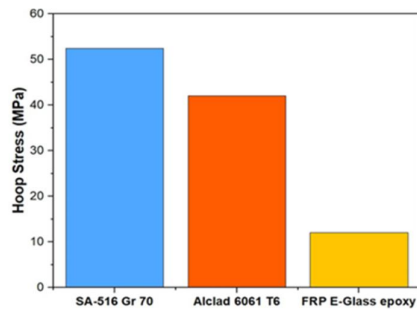


Fig. 18: Comparative results of Hoop stress graphically

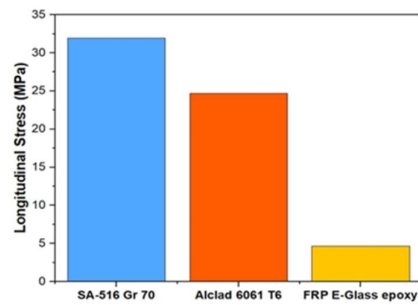


Fig. 19: Comparative results of longitudinal stress graphically

Out of the three materials compared above for Hoop stress, SA-516 Grade 70 has the highest value of 52.43 MPa. Out of the three materials compared above for Longitudinal stress, SA-516 Grade 70 has the highest value of 31.921 MPa.

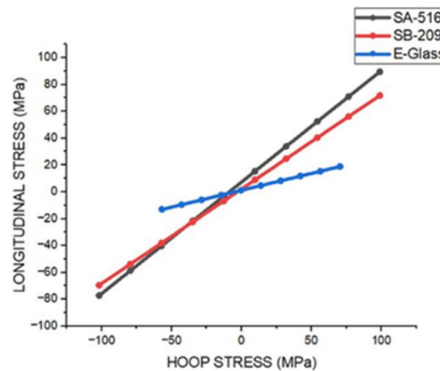


Fig. 20: Comparative results graphically

B. Evaluation of materials based on cost used for Pressure Vessels

Comparison of each material according to their economic value considering only the mass of the pressure vessel (The input parameter for the following is taken from m.indiamart.com on 21/05/2022 at 8:00 PM).

- SA-516 Grade 70: Rate/Kg is ₹275 and the mass of the vessel is 318.79 Kg. Therefore, the total price according to the given parameter is ₹87667.25.
- Alclad 6061 T6 class: Rate/Kg is ₹52.9 and the mass of the vessel is 871.4 Kg. Therefore, the total price according to the given parameter is ₹46097.06.
- FRP E-Glass epoxy: Rate/Kg is ₹110 and the mass of the vessel is 470.041 Kg. Therefore, the total price according to the given parameter is ₹51745.1.

XIII. JUSTIFICATION OF RESULTS

The analysis result obtained is cross-verified by the theoretical calculations. The design errors are also reduced because the codebook referred to is widely accepted in pressure vessel manufacturing.

XIV. CONCLUSIONS

Major conclusions that are obtained from the work are listed down below:

- The design of the pressure vessel is done according to the requirements in terms of standard technical specifications mentioned in the ASME Codebook for the safety protocols.
- The design of a pressure vessel is more of a selection procedure considering the materials. The selection of materials plays a vital role in implementing a specific pressure vessel in a practical world.
- From the analysis results obtained, carbon steel of SA 516 Grade 70 is proven to be better out of the two materials selected. But presently Aluminium alloy Alclad 6061 T6 is found to be better economically.
- Hence, it is concluded that even though Aluminium alloy Alclad 6061 T6 may be economically better but while considering the safety aspect involved in it then SA 516 Grade 70 is chosen as a better option among the three.

A. FUTURE WORK

- The work is concluded according to the requirements. It gives a conclusion considering only the three specific materials and also neglecting external pressure.
- The methods used to find the solution is hoop and longitudinal stress, this limits the quality of the solution obtained.
- The above constraints were only included as the values could be compared theoretically with the values obtained from the Ansys software. By conducting comparative studies one can save time when choosing the required materials for practical usage.

- The world is only going to be more industrialized and pressure vessels will continue to grow with it. In the long run, new materials may be discovered and new alloys may be made and a comparative study will help in minimizing wastage by helping the industry people to choose the better material and help them to cut costs.

ACKNOWLEDGMENT

We wish to extend our gratitude to all faculty and staff members of the Department of Mechanical Engineering who rendered necessary help in carrying out this work.

REFERENCES

- [1] J. Tirenti, "Pressure Vessels, Part I: Pressure Vessel Design, Shell, Head, Nozzle and Basic Flange." [Online]. Available: www.Arvingconsulting.Com
- [2] Honiron, "Choosing the Right Material for Your Pressure Vessel," Jan. 18, 2017. <https://www.Honiron.Com/Choosing-Right-Material-Pressure-Vessel/> (Accessed Dec. 19, 2021).
- [3] The International Nickel Company Incorporated, "Low-Temperature Data Sheet of Types 304 And 304L Stainless Steels".
- [4] B. S. Yilbas, I. Ul H. Toor, And A. Al-Sharafi, "Anti-Corrosive Materials," *Compr. Energy Syst.*, Vol. 2–5, Pp. 913–943, Jan. 2018, Doi: 10.1016/B978-0-12-809597-3.00256-X.
- [5] SaurabhRanjan, "How Fibre Reinforced Plastics Used to Make Tanks and Vessels." <https://Polymeracademy.Com/Fibre-Reinforced-Plastics-Used-To-Make-Tank-And-Vessels/> (Accessed Dec. 19, 2021).
- [6] Heating Equipment Codes & Standards, "What Is Asme Code, Why Does It Matter, And Insight on ASME Industrial Heaters," *Heating Equipment Codes & Standards*, Dec. 16, 2021. <https://www.Americanheatingco.Com/Blog/What-Is-Asme-Code/> (Accessed Dec. 19, 2021).
- [7] M. Webster Et Al., "Asme Standards and Certification." [Online]. Available: <https://www.Engineeringforchange.Org>
- [8] Ansys, "Ansys Workbench Release 10.0," Ansys Work. Release 10.0, 2005, [Online]. Available: <http://Kashanu.Ac.Ir/Files/Content/Ansys-Workbench.Pdf>
- [9] A.M. SenthilAnbazhaganand M. DevAnand, "Design and Crack Analysis of Pressure Vessel Saddles Using Finite Element Method," *Indian J. Sci. Technol.*, Vol. 9, No. 21, Pp. 2–4, 2016, Doi: 10.17485/Ijst/2016/V9i21/90567.
- [10] [4] DevarajuAnd K. Pazhanivel, "A Study on Stress Analysis for Design of Pressure Vessel," Vol. 1, No. 11, Pp. 98–101, 2015.
- [11] K. S. Naser, Mohammed Q, And Gupta, "Structural & Thermal Analysis of Pressure Vessel by Using Ansys," *Int. J. Sci. Eng. Technol. Res.*, Vol. 2, No. 8, Pp. 740–744, 2013.
- [12] S. Patel, "Design and Analysis Of Vertical Pressure Vessel Using Asme Code And Fea Technique Design And Analysis Of Vertical Pressure Vessel Using Asme Code And Fea Technique," No. May 2020, 2018, Doi: 10.1088/1757-899x/376/1/012135.
- [13] M. A. M. Iqbal, M. Hasham, And A. Mohammed, "Design and Stress Analysis of Frp Composite Pressure Vessel," No. May 2016.
- [14] P. M. Rao, T. J. P. Kumar, P. G. Krishnaiah, K. A. Francy, And K. Venkateswara, "Design and Static Structural Analysis Of Pressure Vessel Using Finite Element Technique," Vol. 12, No. 1, Pp. 1288–1299, 2021.
- [15] M. Nomura Et Al., "A Critical Review and Analysis Of Pressure Vessel Structures," 2019, Doi: 10.1088/1757-899x/469/1/012009.
- [16] J. Jegatheesanand Z. Zakaria, "Stress Analysis On Pressure Vessel," Vol. 2, No. 2, Pp. 53–57, 2018.
- [17] Patel Nikunj S, "Engineering Modeling and Thermal Analysis of Reactor Pressure Vessel By Using Advance Cae Tools Patel Nikunj S Abstract Keywords: Reactor Pressure Vessels, Modeling, Thermal Analysis, Fea Or Fem, Costing," No. 2277, Pp. 82–85, 2013.
- [18] S. Chattopadhyay, "Material Selection for A Pressure Vessel SomnathChattopadhyay, Pennsylvania State University," No. February 2018.
- [19] ASME Codebooks