Analysis of Pressure Vessel for a Storage Application using FEA

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Abstract - The use of pressure vessels is quickly increasing around the world. In the chemical, petroleum, petrochemical, and nuclear industries, pressure vessels and holding tanks are required to keep fuel stored. The response, division, and storage of raw material all fall under the heading of apparatus. At present study, an efficient finite element model of pressure vessel currently employed for storing high temperature liquid was develop using ANSYS software package. Five different materials are applied as the vessel material i.e., cast iron, structural steel, magnesium alloy, carbon and resin epoxy fibers and compared accordingly. Stresses, strains and deformation are the basic parameters for comparison. Structural and thermal analysis have been applied for higher temperature and load. The carbon epoxy and resin fibers are found more suitable in terms of wight to strength ratio.

Keywords: Thermal analysis, structural analysis, pressure vessels, carbon epoxy, epoxy resins etc.

I. INTRODUCTION

Engineering design is a task that ensures a person's readiness for service. This largely covers strength issues in the context of pressure vessel design. The concept of "total design" has far-reaching implications. Aspects of fuel system design, reactor design, or thermal hydraulic design may be included. The underlying theory, decisions, and calculations linked simply to the strength design are referred to as "pressure vessel design" in our later discussions. Heat transfer and fluid flow needs may still drive early design for certain pressure vessels and related equipment.

We will not go into detail about the element of thermal hydraulic design that is intricately tied to structural design, especially for thermal transient loadings. The temperature distribution associated with a specific thermal transient will be presumed to have been examined in a typical design application. However, the designer must still examine how the required vessel combinations will be created from a structural aspect, as well as how these designs will execute their intended function.

Structural and material considerations

Pressure vessels must be able to tolerate extreme pressure, temperature, and other environmental conditions in order to be used for power production, nuclear or chemical processes, industrial processing, and storage. Corrosion, neutron irradiation, hydrogen embrittlement, and other environmental factors are examples. Pressure vessels must be able to function at temperatures ranging from 600°C to –20°C, with design pressures of up to 140 MPa. Some vessels are made to transport noncorrosive fluids, whereas others are made to survive extreme corrosive and radioactive environments. The type of service, whether continuous or cyclic, might also differ significantly. The pressure vessel material may be required to have certain qualities for each set of operating settings. For example, materials with high notch toughness are required for operation at extremely low temperatures, while materials with high creep strength are required for operation at very high temperatures. Aside from mechanical qualities, the selection process must take into account factors like as manufacturability, commercial availability, and cost. The materials utilized in the building of pressure vessels are:

Steels

- Nonferrous materials such as aluminum and copper.
- Specialty metals such as titanium and zirconium.
- Nonmetallic materials, such as, plastic, composites and concrete.
- Metallic and nonmetallic protective coatings.

The mechanical properties that generally are of interest are:

- Yield strength
- Ultimate strength
- Reduction of area (a measure of ductility)
- Fracture toughness
- Resistance to corrosion

II. LITERATURE REVIEW

Innovative and near-innovative efforts to increase the performance and versatility of spherical and cylindrical pressure vessels have a lengthy history. Some of them are as follows:

The baseline design of a 34,000-tonne subsea shuttle tanker is presented by ***Yucong Ma et al. (2021).*** (SST). For the conveyance of liquid carbon dioxide (CO_2) from current offshore/land facilities to marginal subsea fields, the SST is offered as an alternative to subsea pipelines and surface tankers. Unlike surface tanker operations, which are heavily weather-dependent, the SST can operate in any situation underwater.

The design and strength of prismatic pressure vessels with innovative geometries for usage as fuel tanks in LNG-fueled ships were investigated in a study presented by ***Younseok Choi et al. (2020).*** The plate-stiffened prismatic pressure vessel had a rectangular cross-section, unlike the traditional cylindrical pressure vessel, and its structure could withstand a standing load thanks to the use of a plate inside.

Shahrzad Daghighia et al. (2020) introduced a series of so-called super ellipsoids of revolution that are meant to have bend-free states under uniform internal pressure. When compared to traditional geometries, super ellipsoids of revolution provide various advantages, including improved packing efficiency, smoother stress flow fluctuation, reduced stress concentrations, and lower assembly costs.

Nebe et al. (2020) explore the effects of stacking sequence on laminate quality, structural deformation, and eventually burst pressure in composite pressure vessels. As a result, a known laminate is investigated using a subscale vessel geometry and varying stacking sequences. The specimens are pressed to burst pressures of 166.11 MPa in a specially built chamber.

III. RESEARCH METHODOLOGY

For Exploration of the pressure vessel, the FEA method is cast-off. The finite element method (FEM) is a computational method accustomed to get estimated solutions of boundary value difficulties in engineering. The boundary value difficult can be well-defined as a mathematical problem in which unique or more reliant on variables must meet the expectations of a differential equation in all places or directions within a known domain of independent variables and satisfy particular conditions on the boundary of the domain.

One of the numerical analytic techniques used to obtain the solution of partial differential equations is finite element analysis. The iterative mathematical approaches used to obtain the finite element formulation of the partial differential equation, such as Galerkin's weighted residual method and Raleigh-Ritz methods.

Various steps take place during the analysis through Static Structural- Elements are as:

A. Part Definitions: - Created sketched and then INVENTOR imports Model

B. Material Descriptions: - Based on previous research done by various authors.

C. Boundary Conditions Explanations, Loading, and Rigid bodies

D. Meshing

E. Solution and Simulation Controls

F. Post-processing

G. Restarting

Modeling of Pressure Vessel

The pressure vessel considered for the study is used in energy sector for storing the fluid at higher temperature. The scaled model is used for the analysis. The length of the vessel is 3000mm while its outer diameter is 1500mm respectively. The sheet metal thickness is 2mm.

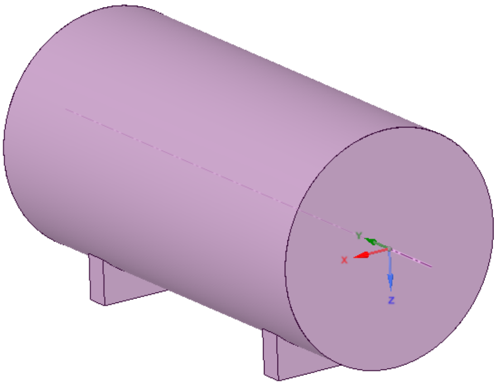

Figure 3.1 Scaled model

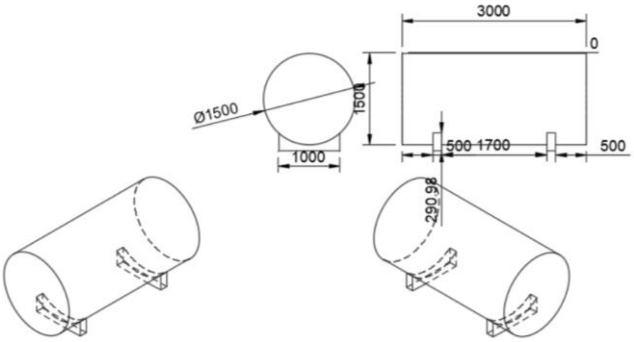

Figure 3.2 Detailed drawing of pressure vessel

Discretization Process (Meshing)

Structured meshing method done in ANSYS Workbench was used for meshing the geometry. 55538 nodes and 27451 elements were created. The mesh model is shown in figure 3.6

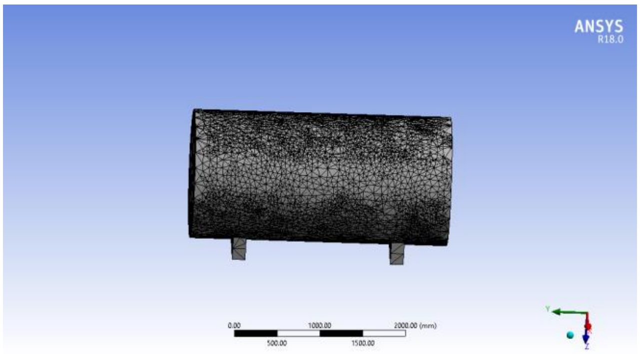

Figure 3.3 The Mesh model

IV. RESULTS & DISCUSSION

The chapter contains the FE results obtained from analysis. There are five materials i.e., structural steel, grey cast iron, magnesium alloy, carbon epoxy and resin epoxy are used for analysis.

Results for Structural Steel

Figure 4.1 to 4.5 shows the results regarding total deformation, Equivalent stress, Maximum Principal Stress, Equivalent elastic strain and Maximum principle elastic strain for structural steel pressure vessel.

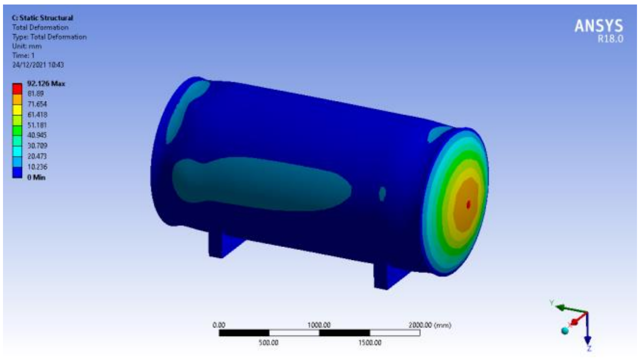

Figure 4.1 Total deformation for structural steel pressure vessel

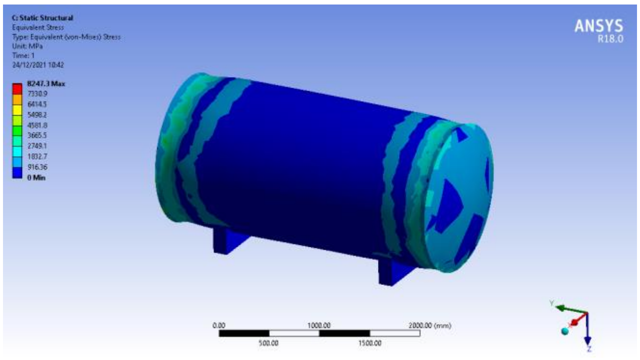

Figure 4.2 Equivalent stress for structural steel pressure vessel

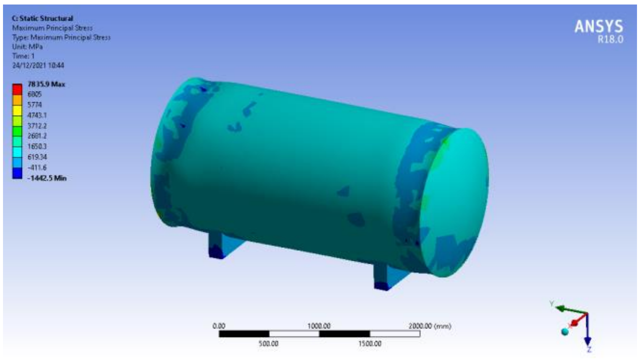

Figure 4.3 Maximum Principal Stress for structural steel pressure vessel

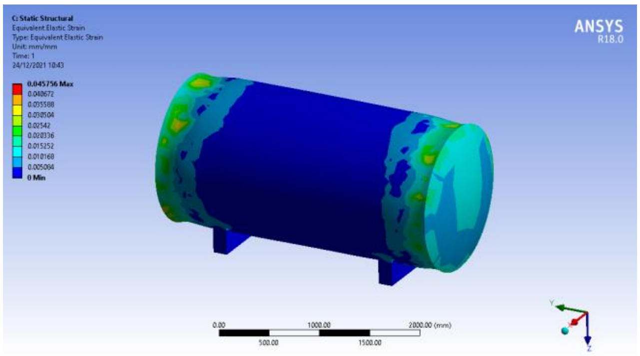

Figure 4.4 Equivalent elastic strain for structural steel pressure vessel

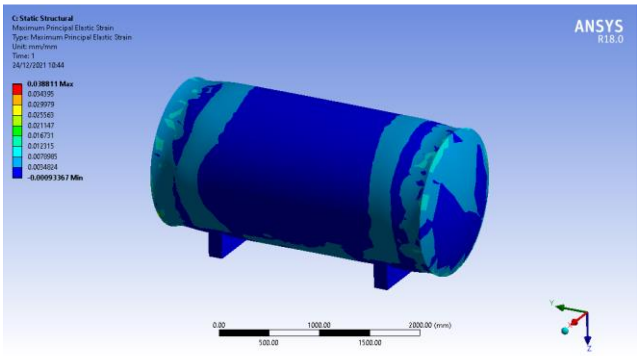

Figure 4.5 Maximum principle elastic strain for structural steel pressure vessel

Discussion

Stresses: Design will fail, if the maximum value of Von Mises stress induced in the material is more than strength of the material. If at some point in the structure the von Mises stress equals the yield stress, then the material is at the failure condition. Figure 4.6 shows the stress generated in all the pressure vessels. The maximum value of Von-Mises stress generated is found in cast iron pressure vessel while it is minimum in carbon epoxy as compared to other four. In all the cases, the maximum value of Von Mises stress is less than the ultimate strength of respective material, thus the design is safe. Von Mises stress theory is applicable and best suited for ductile material.

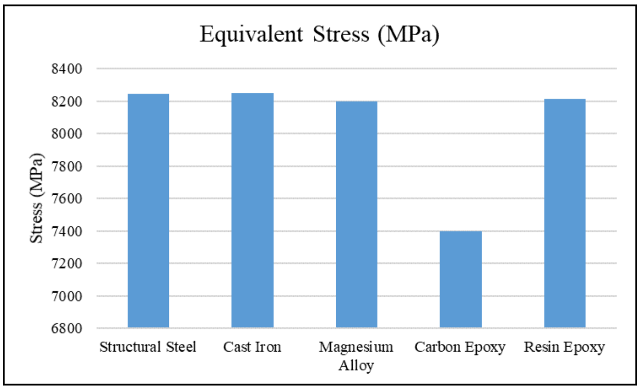

Figure 4.6 Comparison based on equivalent stress

The combination of stresses and strains that causes the onset of yield is of much importance in stress analysis, as the onset of yield is very often related to the ultimate failure of the structure. According to maximum principal stress theory the failure, occur when the maximum principal stress in a system reaches the value of the maximum strength. For the principal coordinate system, all shearing stresses vanish and thus the state includes only normal stresses. The maximum principle stress-based comparison is shown in figure 4.7. The maximum value of principle stress is shown in magnesium alloy pressure vessel. For a good material both the stresses should be low as possible.

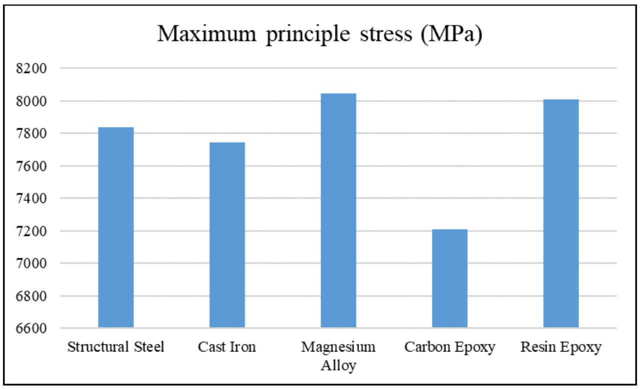

Figure 4.7 Comparison based on maximum principle stress

Strain:

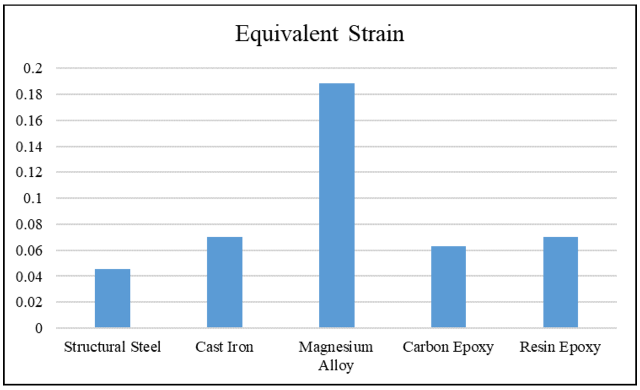

Figure 4.8 Comparison based on maximum elastic strain

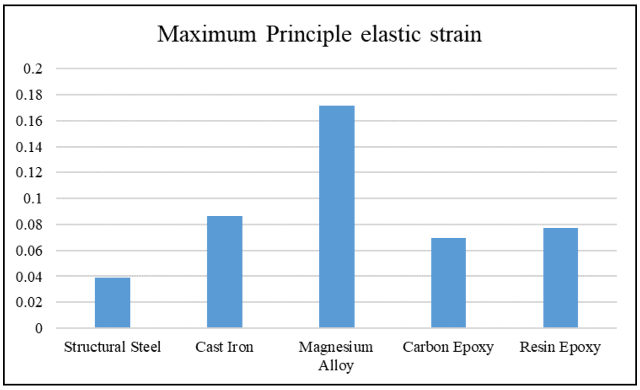

Figure 4.9 Comparison based on maximum principle elastic strain

Figure 4.8 shows the strain induced in all the five-material pressure vessel. It can be observed that it is maximum for magnesium alloy pressure vessel, while it is minimum in structural steel material pressure vessel. Figure 4.9 shows the comparison based on maximum principle elastic strain. The maximum principle elastic strain is also maximum in magnesium alloy material pressure vessel, while it is minimum for structural steel pressure vessel.

Deformation:

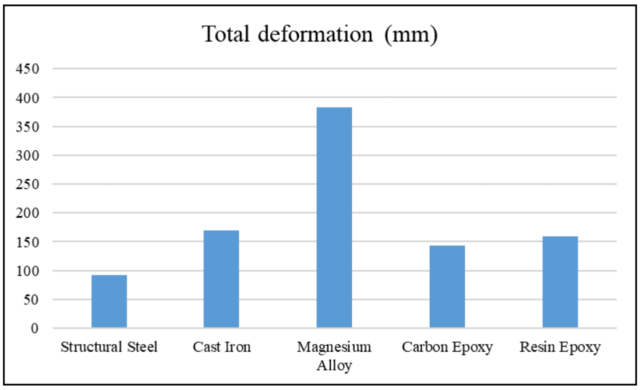

Figure 4.10 Comparison based on total deformation

Figure 4.10 shows the comparison based on total deformation in mm. The deformation is maximum in magnesium alloy material pressure vessel, while it is minimum for structural steel pressure vessel.

V. CONCLUSION

In the present analysis, a pressure vessel currently employed for storing the high temperature liquid is analyzed numerically using ANSYS software package. Following observations are made during the analysis:

- The maximum value of Von-Mises stress generated is found in cast iron pressure vessel while it is minimum in carbon epoxy as compared to other four.
- For all the materials, the maximum value of Von Mises stress is less than the ultimate strength of respective material, thus the design is safe.
- The maximum value of principle stress is shown in magnesium alloy pressure vessel.
- It is observed that strain is maximum for magnesium alloy pressure vessel, while it is minimum in structural steel material pressure vessel.
- The deformation is maximum in magnesium alloy material pressure vessel, while it is minimum for structural steel pressure vessel.
- The maximum stress to weight ratio is shown by Carbon-epoxy and Epoxy resin fibrous material.

On overall conclusions both the carbon epoxy and epoxy resins are found more suitable for the pressure vessel.

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