International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

Finite Element Analysis of Hydrogen Storage Composite Fuel Tank

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Abstract: ***Composite materials are engineered or naturally occurring materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct within the finished structure. Composite materials are highly utilized in various fields like aerospace structure, marine, automobile, etc. On-board storage of hydrogen is a major challenge in the advancement of future fuel cell based automobile propulsion system. One standard is the pressurized storage composite tanks. Hydrogen exhibits the highest heating value per mass of all chemical fuels. Furthermore, hydrogen is regenerative and environmentally friendly. There are two reasons why hydrogen is not the major fuel of today's energy consumption. First of all, hydrogen is just an energy carrier. And, although it is the most abundant element in the universe, it has to be produced, since on earth it only occurs in the form of water and hydrocarbons. This implies that we have to pay for the energy, which results in a difficult economic dilemma because ever since the industrial revolution we have become used to consuming energy for free. The second difficulty with hydrogen as an energy carrier is its low critical temperature of 33 K (i.e. hydrogen is a gas at ambient temperature). For mobile and in many cases also for stationary applications the volumetric and gravimetric density of hydrogen in a storage material is crucial. Hydrogen can be stored using six different methods and phenomena: (1) High-pressure gas cylinders (up to 800 bar), (2) Liquid hydrogen in cryogenic tanks (at 21 K), (3) Adsorbed hydrogen on materials with a large specific surface area (at T<100 K), (4) Absorbed on interstitial sites in a host metal (at ambient pressure and temperature), (5) Chemically bonded in covalent and ionic compounds (at ambient pressure), or (6) Through oxidation of reactive metals, e.g. Li, Na, Mg, Al, Zn with water. In present work to reach a design that offers a combination, Aluminum, Aluminium-Epoxy, Aluminium-Carbon Fiber have been tried out for static structural analysis on combinations of metals and composites. Fatigue life estimation of hydrogen fuel tanks have been carried out for above mentioned combination and results have been analyzed and discussed extensively. The numerical study was performed by means of ANSYS finite element analysis method.***

Keywords: cryogenic tanks, Aluminium-Epoxy, Aluminium-Carbon Fiber , metals and composites

1. Introduction

The over utilization of non-renewable energy sources has prompted bit by bit expanding uncommon ecological contamination and vitality emergency. Various research works have as of late been completed on searching for sustainable assets as substitution for ordinary petroleum derivatives. Hydrogen has been perceived as the prevalent alternative for what's to come vitality industry due to the qualities of boundless supply, zero-emanation of greenhouse gases, and high vitality proficiency. Hydrogen stockpiling has turned out to be one of the overwhelming specialized obstructions constraining the across the board utilization of hydrogen vitality. Sheltered, high-effectiveness and sparing hydrogen stockpiling method is a key to guarantee positive keep running of hydrogen power module vehicles. The composite materials are utilized for manufacture of weight vessels by setting them in various introductions for various layers and in a typical introduction inside a layer. These layers are stacked in such an approach to accomplish high firmness and quality. The outline of the composite vessel as a principal inquire about work relates the physical and mechanical properties of materials to the geometric particulars. The present work intends to give a substitute method to build up a situation that can be utilized to store hydrogen. The weight tank proposed is essentially where, under high pressure, hydrogen will be put away in gas frame. An aluminum base chamber must be utilized as a totally composite tank won't be handy as hydrogen has a tendency to respond with the composite material and its properties weaken. Since aluminum is non responsive to hydrogen it gives a perfect base tank. Likewise considering a comparable tank made of steel, an aluminum tank is impressively lighter and gives better weight investment funds equivalent or larger amounts of quality for capacity. The flowchart appeared underneath is a portrayal of the system took after for the finishing of the task and accomplishment of the required destinations. At the point when quick filling is finished utilizing a compressor to expand the weight of the gas it brings about an expansion in the temperature of the gas inside the tank. The base tank material scatters heat better to the environment. The composite wall is for the most part capable to withstand the power of the high weight hydrogen gas put away in the tank and furthermore give the premise to a security factor. The primary composites meant to be utilized as a part of the venture are Carbon Fiber and Carbon Fiber Reinforced Plastic. In a fundamental sense, the thickness of the aluminum chamber can be expanded by additionally thickening the wall and this would likewise bring about getting an appropriate security factor.

A possible alteration of the design can significantly improve the overall performance of this storage technique. This can be done by the amalgamation of materials like carbon fibre.

In present work to reach a design that offers a combination, Aluminum, Aluminium-Epoxy, Aluminium-Carbon Fiber have been tried out for static structural analysis on combinations of metals and composites. Fatigue life estimation of hydrogen fuel tanks have been carried out for above mentioned combination and results have been analyzed and discussed extensively.

2. Literature Survey

2.1 Introduction

On-board storage of hydrogen is a major challenge in the advancement of future fuel cell based automobile propulsion system. One standard is the pressurized storage at 700 bar in composite tanks. A few design including metal or plastic liners are presently a work in progress or in little scale creation. In any case, the regular innovation is far-fetched to satisfy the expanding interest for a moderate item in large scale manufacturing. The extending business sector will offer novel open doors for existing and new providers, however any aggressive arrangement will require an advancement of the tanks as for both basic performance and assembling perspectives like profitability and dependability.

2.2 Composite Pressure Vessels

The run of the composite pressure vessel includes four principle parts as appeared in Figure 2.1 Composite loop windings, composite helical windings, the liner and fittings [6]. The fittings are important to interface valves or funnels. The liner is in charge of the gas snugness and might be made of metal or plastic material. From an applied perspective the metal liner can be thought to be load conveying or non-load conveying (thin metal liner), the plastic liner is for all intents and purposes never stack conveying. On account of a metal liner the fittings might be a fundamental part. In the event that they are not, extraordinary consideration must be paid concerning the best possible association between fitting and liner.

The composite helical windings cover the whole or the majority of the surface territory of the pressure vessel and have unmistakable properties because of the idea of the fiber winding procedure. At long last, the circle windings are just present in the barrel shaped piece of the weight vessel

The composite loop and helical windings together need to take all or a generous piece of the weight load. An effective outline will consider all parts of the pressure vessel – exclusively and regarding their cooperation. In the accompanying we will center around the basic plan of the composite winding and the metal liner.

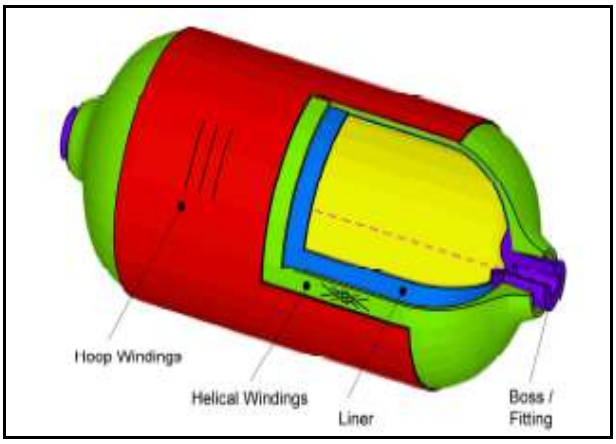


Figure 2.1: Composite Pressure Vessel

2.3 Structure of Composite Pressure Vessels

Cylindrical composite pressure vessels constitute of a metallic inner liner, a composite external shell as appeared in Figure 2.2. The metal liner is important to counteract spilling, while a portion of the metal liners additionally give quality to share inner weight stack.

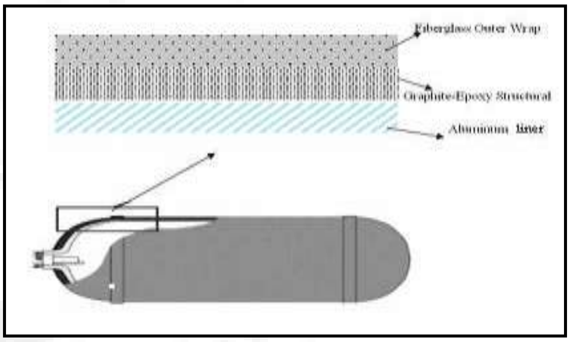


Figure 2.2: Example of Filament Wound Composite Pressure Vessels.

2.4 Structural Behavior

The two superseding concerns for the Safety and economy of high pressure vessels are the blasted pressure and the quantity of cycles to exhaustion disappointment. Besides, the nature of the particular disappointment mode is of significance. In the end, conformance of these properties must be shown by testing to satisfy the Safety prerequisites.

2.5 Modelling Approach

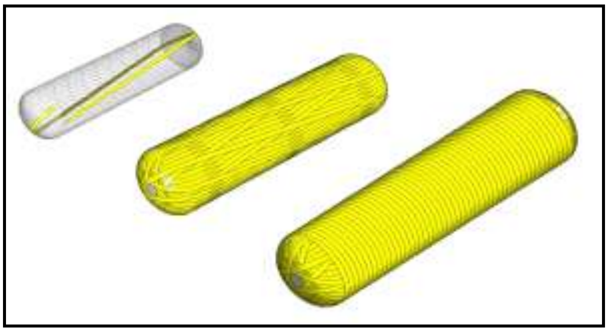


Figure 2.3: Filament Winding Simulation.

Due to the confounded multilayered, anisotropic composite overwrap and the nonlinear flexible plastic conduct of the metal liner just itemized displaying and numerical examination can prompt the required understanding. The limited component strategy is the set up and for the most part acknowledged technique for examination for requesting designing frameworks.

2.6 Hydrogen Storage Techniques

Hydrogen storage issue has been endeavoured to be unravelled with various systems. These distinctions uncover themselves principally in the period of hydrogen to be put away, to be specific vaporous, fluid and in strong mixes; and furthermore in working conditions, producing procedures and materials. Up until now, none of the methods depicted could fulfill the prerequisites to begin the everyday life uses of hydrogen.

2.7 Compressed Gaseous Hydrogen storage

Figure 2.4: Compressed Gaseous Hydrogen storage.

High-pressure tanks for hydrogen capacity are now accessible in the market, which can be pressurized up to 30MPa it is shown in Figure 2.4. Among these, pure steel has been utilized for the most part for weight vessels. High elasticity, low thickness and non-reactivity with hydrogen alongside low diffusivity, are the principle, wanted properties for hydrogen stockpiling tanks.

2.8 Liquid Hydrogen Storage

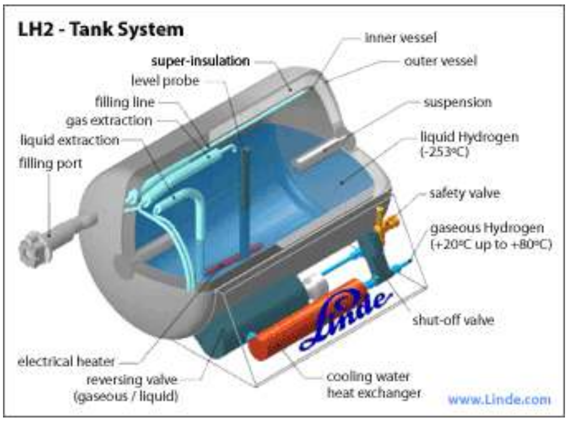


Figure 2.5: Liquid Hydrogen (LH2) Tanks

At typical conditions, hydrogen is in vaporous shape. At the barometrical pressure; hydrogen can be changed to the fluid state under 20.4 ° K, which is underneath the basic point temperature (33 ° K, 1.29MPa).

Summary

The majority of FEA investigation on composite pressure vessels are in light of shell components, which are produced utilizing the traditional cover hypothesis. Most FEA bundles like ANSYS give a thick shell element to reflect the impact of shear, radial and hoop stresses.

The goals of this examination are to explore the distinctive methods for storage of Hydrogen. Pressure vessel comprising of aluminum liner wrapped with a fiber winding glass fiber reinforced polymer network structure in the external layer of vessel. The ANSYS FEM package is utilized to foresee the mechanical behaviour of various deigns of the proposed pressure vessel as appeared in the accompanying chapters.

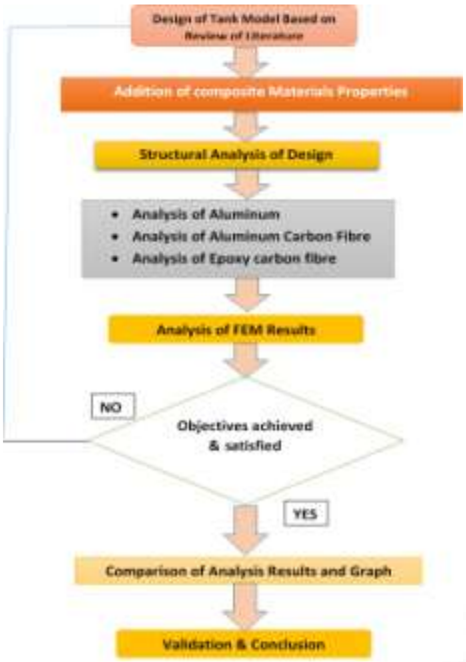
3. Scope of Present Investigation

Hydrogen (H2) is an elective fuel that can be produced from differing local resources. The most straightforward approach to store hydrogen is in a barrel with a weight up to 20 MPa by pressure, yet the vitality thickness is too low to fulfil the fuel request of driving practice. Likewise, these tanks consume up significant room when utilized as a part of automobiles. The Proposed work plan is as shown in Flow chart 3.1.

3.1 Problem statement and Objectives

The main objectives of the present investigation are,

1) To design and analysis of hydrogen fuel tank using Aluminium-Epoxy, Aluminium-Carbon Fibre combination.
2) Static structural linear analysis of hydrogen fuel tank using Aluminium-Epoxy, Aluminium-Carbon Fibre.
3) Thermal analysis of hydrogen fuel tank using Aluminium-Epoxy, Aluminium-CF.
4) Fatigue life estimation of a hydrogen fuel tank using Aluminium-Epoxy, Aluminium-Carbon Fibre.



Flow chart 3.1: Proposed Work plan.

4. Modelling, Design and Analysis

4.1 Methodology for the Study
Numerical Analysis

The utilization of numerical or analytical investigation has been improved the situation numerous hundreds of years preceding the creation and advancement of present day PCs. Numerical Analysis was primarily completed by extraordinary mathematicians and subsequently we have some broadly utilized and exceptionally imperative calculation and conditions like Gaussian Elimination, Euler's Method, Principal Stress Equation, and so on.

4.2 Geometric Modeling

Methods and algorithms for the numerical depiction of shapes are considered through a branch of connected arithmetic and computational geometry called Geometric Modelling. A few dimensional shapes are for the most part contemplated in geometric displaying despite the fact that as to sets of any limited measurement numerous devices and standards can be connected. A Design of base cylinder is as shown in Figure 4.1.

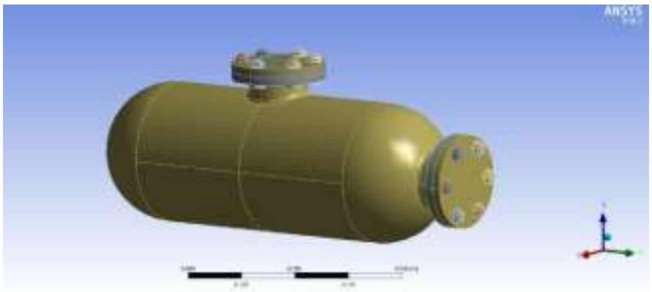


Figure 4.1: Design of Base Cylinder

4.3 Model

Geometric Model mainly deals with shapes that are mostly two or three dimensional and their finite dimensions can be worked upon by multiple design tools and principles. We have refered the base dimensions from a predetermined research paper. The cylinder chosen has the base dimensions as specified below:

- Material Used: T6-6061
- External Diameter=309.5 mm
- Internal Diameter=290 mm
- Total Length=920 mm
- Internal Pressure=35 MPa
- Ultimate Tensile Strength=310 MPa
- Tensile Yield Strength=276 MPa

4.4. Mesh

Tank design dealt with in the project has been meshed in Ansys as shown in Figure 4.2, in which Tetrahedral meshing was used for the cylindrical body while quadrilateral meshing was done for the lids. The conditions for finding the stress can be integrated into the design better and the calculated results are more consistent. The automatic mesh detects the type of surface and accordingly uses the most applicable type of mesh that can be used. Depending on the geometry and structure the mesh applied can be Polyhedral, Tetrahdral, etc. The final mesh had 73643 Nodes and 34643 Elements.

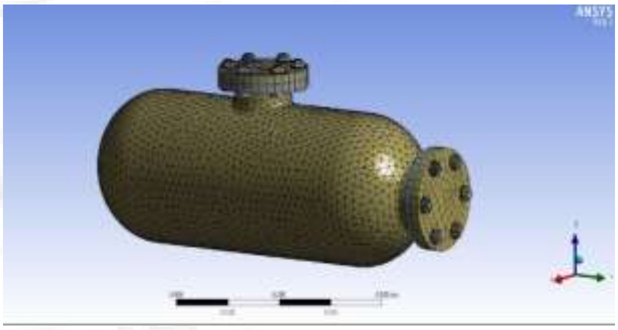


Figure 4.2: Design Meshing.

4.5. Boundary Conditions

The tank design studied in the project is experiences the force from the gas which is stored within the tank. The coordinate references is as shown in Figure 4.3.

A pressure of 35Mpa radially outward from the central axis of the tank on the walls of the tank. The temperature for the entire system to be analysed is varied between 70^{O}C and 120^{o}C at a fixed pressure of 35Mpa at fixed time intervals of one second. The fasteners that are used for the lid have a preloaded condition of 50N.

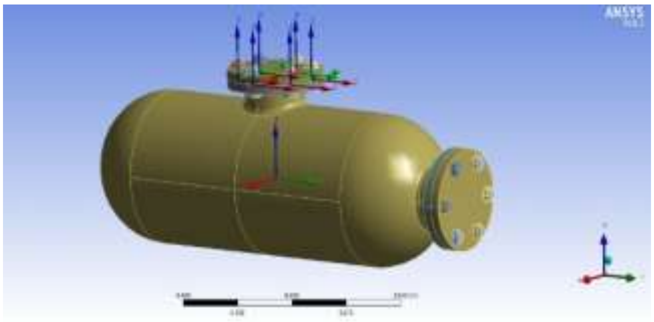


Figure 4.3: Coordinate System Reference

5. Results and Discussions

5.1 Case 1 Aluminum

Table 5.1: Aluminum material

Aluminum material	
Maximum equivalent stress	200.57 Mpa
Maximum Principal Stress	166.58 Mpa
Minimum Principal Stress	48.714 Mpa
Minimum Principal Stress	0.54518 mm

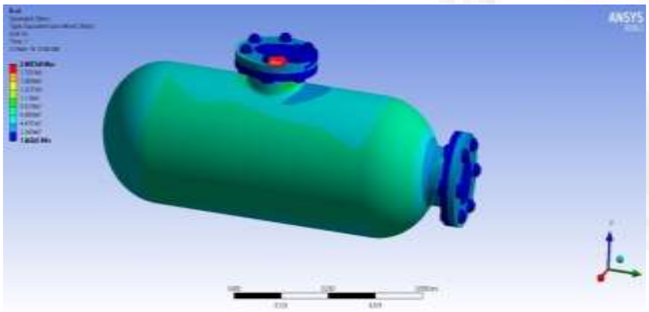


Figure 5.1: Equivalent Stress for Aluminium.

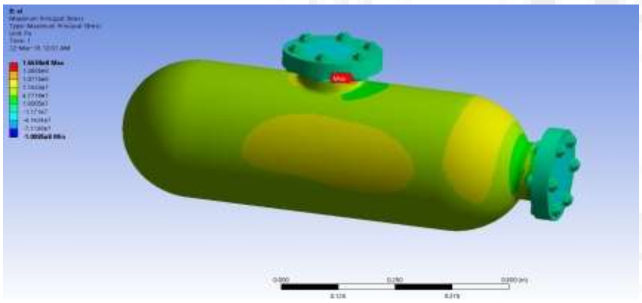


Figure 5.2: Maximum Stress for Aluminium

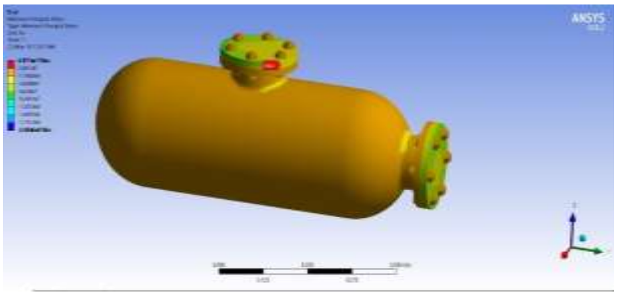


Figure 5.3: Minimum Stress for Aluminium.

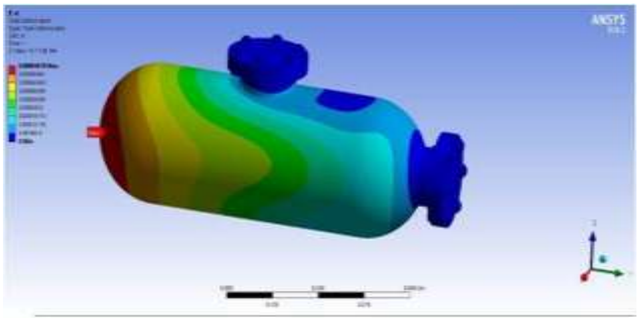


Figure 5.4: Total Deformation for Aluminium

5.2 Case 2-Aluminium with Epoxy

Table 5.2: Aluminum material **with Epoxy**

Aluminum material **with Epoxy**	
Maximum equivalent stress	157.58 Mpa
Maximum Principal Stress	139.07 Mpa
Minimum Principal Stress	39.599 Mpa
Minimum Principal Stress	1.2136 mm

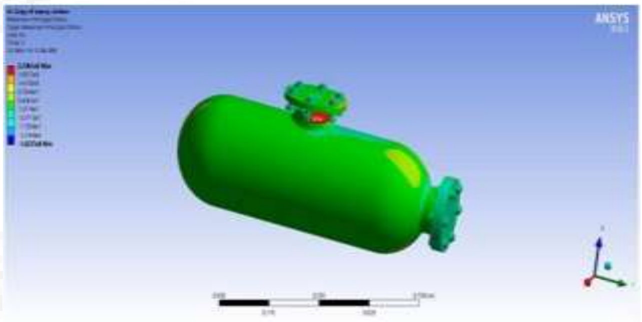


Figure 5.5: Equivalent Stress for Aluminum with Epoxy.

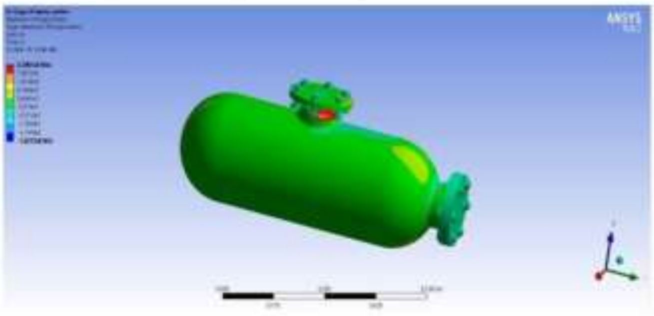


Figure 5.6: Maximum Stress for Aluminum with Epoxy

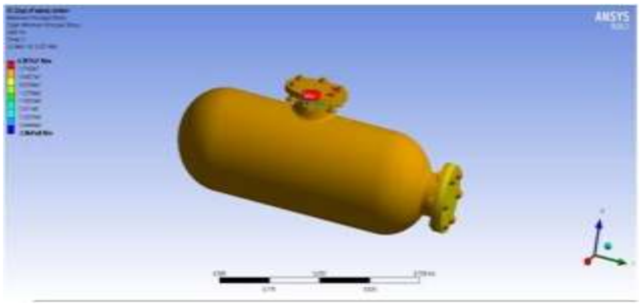


Figure 5.7: Minimum Stress for Aluminium with Epoxy.

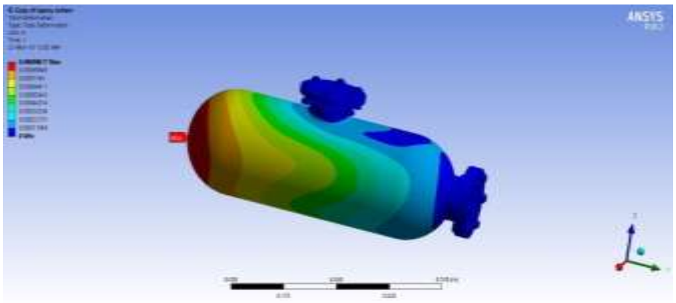


Figure 5.8: Total Deformation for Aluminium with Epoxy

5.3 Case 3-Aluminium with Carbon Fiber

Table 5.3: Aluminum material with Epoxy

Aluminum material **with** Carbon Fiber	
Maximum equivalent stress	296.57 Mpa
Maximum Principal Stress	209 Mpa
Minimum Principal Stress	59.714 Mpa
Minimum Principal Stress	1.14518 mm

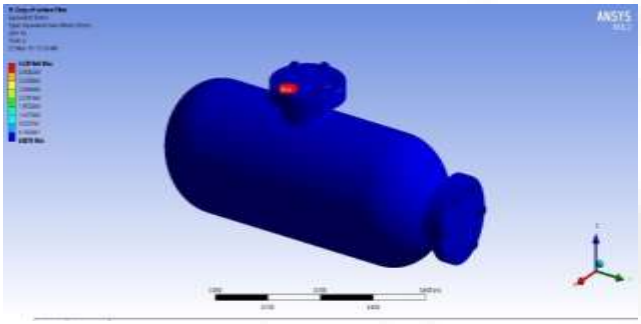


Figure 5.9: Equivalent Stress for Aluminium with Carbon-Fibre

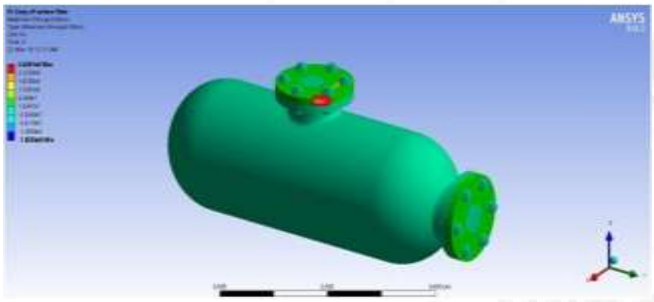


Figure 5.10: Maximum Stress for Aluminium with Carbon-Fibre.

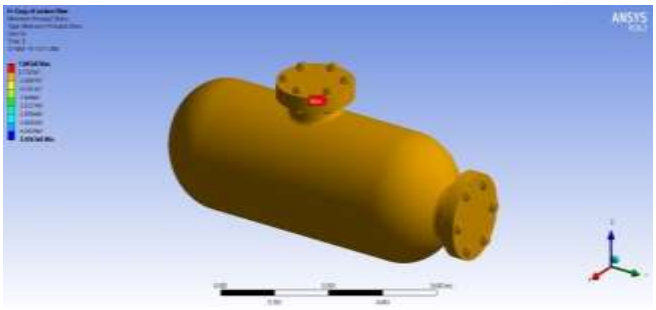


Figure 5.11: Minimum Stress for Aluminium with Carbon-Fibre

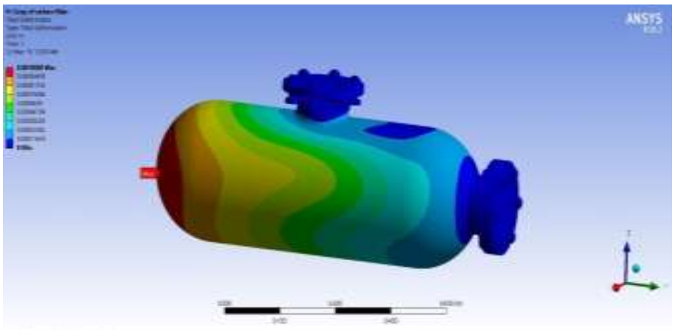


Figure 5.12: Total Deformation for Aluminium with Carbon-Fibre.

5.4. Equivalent stresses

Table.5.4 shows variation of equivalent stresses for different combination of materials with respect to load.

Load	Case 1 (Aluminium)	Case 2 (Aluminium +Epoxy)	Case 3 (Aluminium+ Carbon Fibre)
20 MPa	165.88	177.86	209.75
25 MPa	234.95	251.81	296.95
30 MPa	269.52	288.91	340.7
35 MPa	304.9	326	384.44
40 MPa	338.66	363.1	428.19

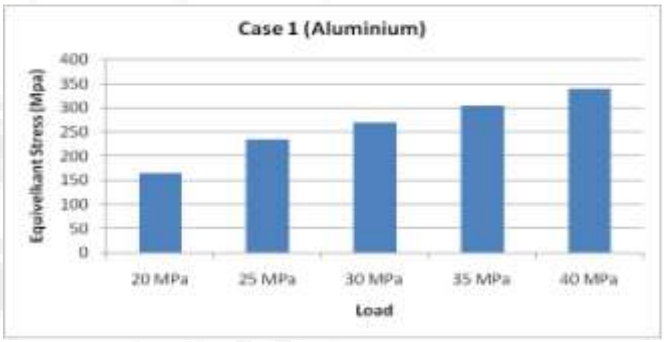


Figure 5.13: Variation of Equivalent Stress with Load for Aluminum

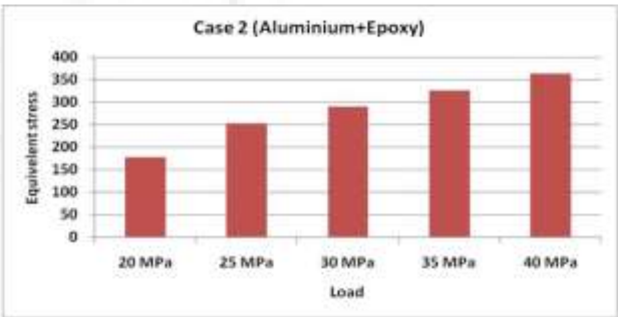


Figure 5.14: Variation of Equivalent Stress with Load for Aluminum+Epoxy

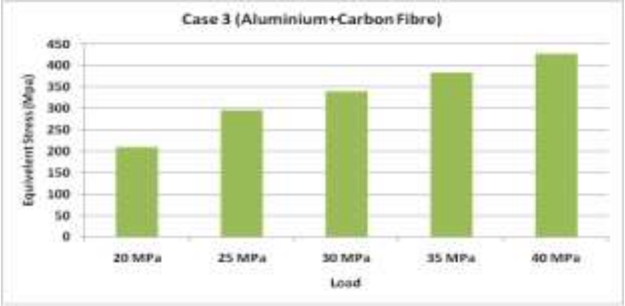


Figure 5.15: Variation of Equivalent Stress with Load for Aluminum+Carbon Fibre

5.5: Total Deformation

Table 5.4: Total deformation for various combinations

Load	Case 1 (Aluminium)	Case 2 (Aluminium +Epoxy)	Case 3 (Aluminium+ Carbon Fibre)
20 MPa	0.45151	0.99617	1.0508
25 MPa	0.639765	1.4118	1.4885
30 MPa	0.73379	1.6192	1.7075
35 MPa	0.82783	1.8266	1.9265
40 MPa	0.92186	2.034	2.1454

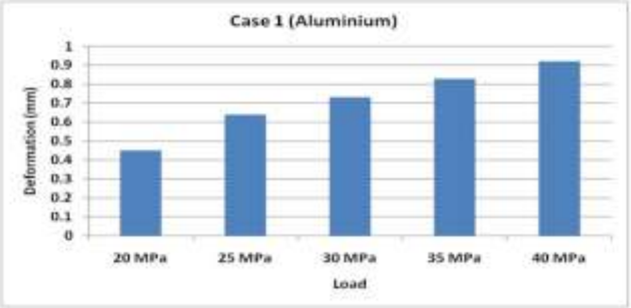


Figure 5.16: Variation of Total Deformation for Aluminium

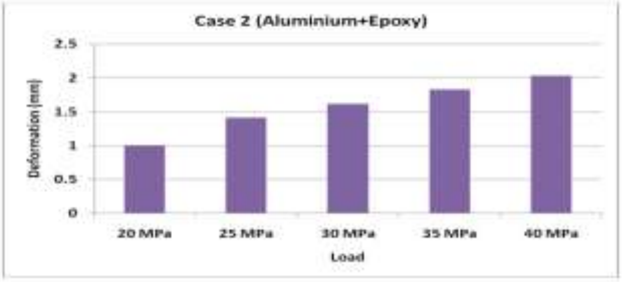


Figure 5.17: Variation of Total Deformation for Aluminum+Epoxy

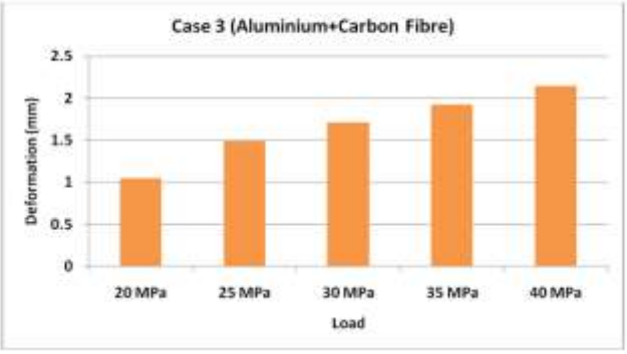


Figure 5.18: Variation of Total Deformation for Aluminum+ Carbon fibre

5.6 Validation of life estimation with analytical method and fem result

Fatigue occurs when a material is imperilled to replication loading and unloading. If the loads are above a certain threshold, microscopic cracks will begin to form at the stress concentrators such as the surface, persistent slip bands (PSBs), interfaces of constituents in the case of composites, and grain interfaces in the case of metals. Eventually, a crack will reach a critical size, the crack will propagate suddenly, and the structure will fracture. Round holes and smooth transitions or fillets will increase the fatigue strength of the structure.

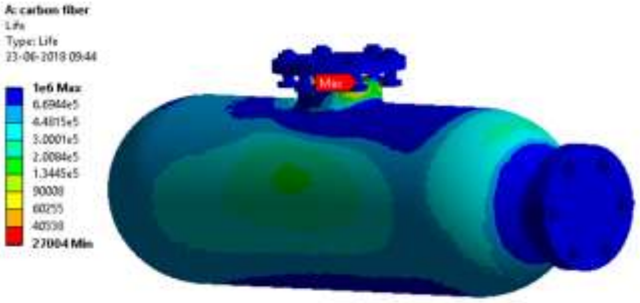


Figure 5.19: FEM estimated that 1e6 mean 1000000 cycle hydrogen tank

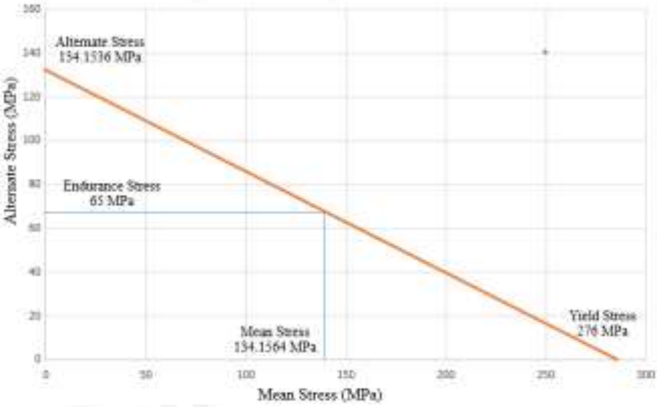


Figure 5.20: Alternate Stress v/s Mean Stress

6. Conclusions and Scope of Future Work

6.1 Conclusion

1) Three dimensional modelling and analysis of a hydrogen gas container with different combination of materials have been successfully carried out.
2) Static structural analysis and fatigue life estimation of hydrogen fuel tank using aluminium, Aluminum + Epoxy, and Aluminium + carbon fibre have been successfully carried out using finite element tool.
3) Equivalent stress and deformation increases with increase in internal pressure for all three combination of materials studied.
4) For a given internal pressure Aluminum carbon fibre combination exhibited higher equivalent stress and deformation compared to aluminum and aluminum+epoxy composite combinations.
5) Fatigue life of hydrogen fuel tank has been successfully estimated for aluminum, Aluminum+Epoxy, and

Aluminum+carbon fibre.

6.2 Scope of Future Work

High storage capacity and safeties needs to be achieved, these parameters are strongly influenced by dynamic wall. In view of this, the temperature effect on performance and fatigue life of the hydrogen fuel tank may be carried out. Further, thickness effect of combination of various materials may be studied by changing the volume fraction of carbon fibre and epoxy and its effect on performance may be evaluated.

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