A Comprehensive Study of Carbon Fibre Composite and Titanium Alloy Composite Pressure Vessel

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***Abstract*— The primary goal of this study is to construct and analyse multi layer high-pressure vessels, as well as their characteristics.-The ANSYS finite element software was used to create finite element model of a carbon fibre reinforced polymer (CFRP) pressure vessel with a titanium liner. Because of the high operating pressure (more than 25 MPa), safety is critical. Every unidirectional layer in the vessel section is considered as a composite laminate in the modelling process, including thickness and wrap angle changes. The winding angle, burst pressure, maximum axial force, and maximum angular speed of the pressure vessel are optimised using several 3D failure theories. Model predictions and experimental results are in good agreement.**

Index Terms: **Design, Analysis, Solid & Multilayer Pressure vessel, Burst Pressure, Composite Pressure Vessel, Tsai– Wu failure Criteria ANSYS**

I.INTRODUCTION

Pressure vessels have extended implementations in manufacturing, thermal and atomic power plants, procedure and chemical industries and, air supply systems. It can be classified into many types, the mainly used types are Horizontal and Vertical pressure vessels. The pressure vessels should be completely sealed and can contain many liquids and gasoline under their breaking point. High pressure is generated in the pressure vessel and it should resist severe forces. High-pressure vessels have a pressure range from a minimum of 15 N/mm2 to a maximum of 300 N/mm2. It makes the design of pressure vessels the most important consideration of mechanical engineering. Reservoirs or containers subjected to internal or external pressures are referred to the term as pressure vessels. As in chemical plants, combined with other reagents, a change of state may undergo inside the pressure vessel in the case of steam boilers. In thermal and nuclear power plants, in ocean and depths, gas and air supply systems in industries pressure vessels it has wide applications. That’s why pressure vessels are considered as the heart of storage for fluid. Hence, after the series of Hydro static tests, a pressure vessel was designed. By using ANSYS analysis the safety and stability of pressure vessels are determined.

Nowadays, for the improvement of material properties composite materials are widely used in producing pressure vessels. The use of pressure vessels has also been increased with this improvement. Pipes, rocket motor cases, fuel tanks are some of the examples of pressure vessels that are made of composite materials. Origin of maximum studies about the analysis of composite pressure vessels is being found from Lethnitskii’s approach[1].The following studies considered environmental and different loading conditions. Recently, some studies show the direct involvement of tubes with internal pressure [2,]. In the study of Xiaetal.[3], The failure analysis of a pressurized FRP cylinder under transverse impact loads was carried out by Tomonori et al [4] While Hou et al. studied many failure mechanisms in CFRP using solely solid parts [5]. Thermo mechanical loading and internal pressure is being merged and taken into consideration. This study is done by developing an analytical procedure to predict and design the behavioural aspect of composite pressure vessels with a combination of mechanical and hydrostatic loading.

II.METHODOLOGY

A. ABOUT ANSYS SOFTWARE

ANSYS could be an analysing program that is utilized for various investigations such as dynamic analysis, structural analysis, a study of heat transfer, and fluid analysis. A certain geometric shape and size (called basic size) are used to study the pressure vessel through ANSYS software. This fundamental size can be derived from standard design. The ANSYS analysis (1) provides multiple solutions for the same design, (2) aids in better modification, and (3) aids in better material utilization. In contrast, in traditional design, a group of people will work to get her and it will take along time. Further more, it necessitates the use of qualified human resources and, clearly does not guarantee the optimal design solution.

On the other hand, the pressure vessel planned by ANSYS programming can make ensuing changes. Consequently, ANSYS analysis permits the originator to make a few fine changes furthermore, to distinguish hand move toward other plan issues which, could someway or another stay covered up or ignored. All the above distinctly shows that the ideal design (by ANSYS programming) undergoes more benefits than traditional design (by human sources).

B.MATERIAL USED AND ITS PROPERTIES

Selected materials for the parts of Pressure Vessel are given in theTable.1.The following metals are to be used during design consideration for Plate for Shell, Dished end and Sealer and other body of vessels

Table.1Materials selected for the PressureVessel

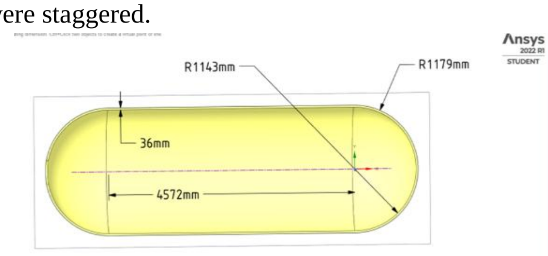
Materials	Properties	Value
Titanium	Density (1000kg/m3)	4420
	Elastic modulus(GPa)	114
	MeltingPoint(^{0}c)	1668
	Tensile Strength (MPa)	1070
	Yield Strength(MPa)	930
	Poisson'sratio	0.36
CarbonEpoxy (T300/LY5052)	Tensile Strength(MPa)(Xt)	1860
	Transverse Tensile Strength (MPa) (Yt)	76
	Compressive Strength(MPa)(Xc)	1470
	TransverseCompressive Strength(MPa)(Yc)	85
	ShearStrength(S) (MPa)	98
	Ultimate Tensile Strength(MPa)	2297
	Modulus of Elasticity (GPa)	86.9
	Poisson'sratio	0.230
	Density (1000kg//m3)	2480
	ElongationatBreak (%)	5.7

C.DESIGNOBJECTIVE

1. To demonstrate that multilayer pressure vessels are better than solid wall pressure vessels at high operating pressures.
2. To demonstrate that using a multilayer vessel instead of a solid wall vessel can result in considerable material weight savings.
3. To demonstrate that there may be a uniform stress distribution across the entire shell, indicating the most efficient use of the material in the shell.
4. To determine the suitability of employing different materials for the Liner shell and remaining layers in order to reduce the vessel's construction costs.
5. To ensure that the stresses do not approach the yield point value during testing and to verify the theoretical stress distribution induced by internal pressure at the shell's exterior surface.
6. Finally, using the ANSYS package, validate the design parameters with FEM analysis to ensure that FEM analysis is suitable for multilayer.

D.DESIGNCONSIDERATIONS

1. ASME Code Section VIII division I is used to build a multilayer vessel.
2. Only in the design of the multi-layer shell is a Safety Factor of on Ultimate Tensile Strength considered. Other parts should be kept at room temperature.
3. For longitudinal seams, a joint efficiency of100 % is required. It is taken from the liner shell.
4. For longitudinal seams, a joint efficiency of100 % is required. It is taken from the liner shell
5. Dished end plates are subjected to a full ultrasonic examination.
6. After attaching the boss, nozzle, and other components, the dish ends will be tension eased.
7.In a multi-layered shell, the longitude in a lwelds were staggered.



8.

Figure1:Drawing of Multilayer Pressure Vessel

E. DESIGN DATA OF THE VESSEL:

Inner diameter (Di) = 2.286 m Outer diameter (DO) = 2.402m

Design Pressure, P=25N/mm^2, Hydrogen.

Design Temperature, T=22ºC

Hydro static Pressure PH=32.5N/mm2

F. CALCULATION OF BURSTING PRESSURE:

Ultimate tensile strength of material (titanium) = 1070mpa

K=Outer diameter/Inner diameter (K)=1.1417

$$\text{Titanium bursting pressure} = U.T.S \times \left[\frac{k^2-1}{K^2+1}\right]$$

$$=140.9\text{N/mm2}$$

Ultimate tensile strength of material (carbon) = 2297 mpa

$$\text{Carbon bursting pressure} = U.T.S \times \left[\frac{k^2-1}{K^2+1}\right]$$

$$=302.6\text{N/mm2}$$

III.MODELING AND ANALYSIS

a) STRUCTURAL ANALYSIS AND RESULTS (CARBON+TITANIUM):

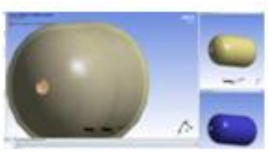
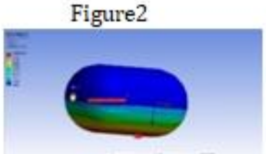


Figure2

Figure3



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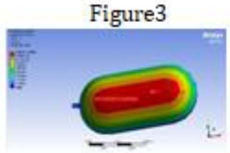

Figure5

Total No. of layers =7, (5 shell layers + 1Liner) Total Thickness = 162mm Liner

Epoxy Carbon shell thickness of each layer =40 mm

Epoxy Carbon shell layer number=18

Titanium layer thickness t= 12mm

Fig.No.	Title of the Figure
Fig.No.1	Finite Element meshed Model of solid wall pressure vessel
Fig.No.4	Applicationofhydrostaticpressure14.3Mpa
Fig.No.3	Vector sum displacement
Fig.No.5	Von-Mises Stresses

Deformation over three axes

Deformation	Minimuminmm	Maximuminmm
Vector sum deformation	0.mm	1.3367e+005 mm
X–axis deformation	-31607mm	31350mm
Y–axis deformation	-4934.7mm	989.94mm
Z–axis deformation	-1.3358e+005 mm	1913.9mm

Equivalent VonMises stresses over three axes

Stresses	Minimum,MPa	Maximum,MPa
Von Mises Stresses	880.09MPa	1.8499e+006MPa
X –axis deformation	-1.0207e+006MPa	8.4803e+005MPa
Y –axis deformation	-1.2056e+006MPa	1.1687e+006MPa
Z – axis deformation	-2.6609e+006MPa	2.6281e+006MPa

b) STRUCTURAL ANALYSIS AND RESULTS (CARBON)

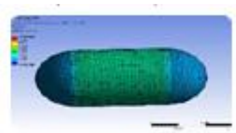

Figure5

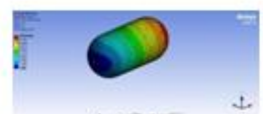

Figure6

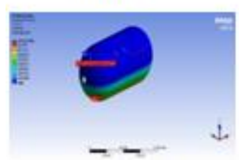

Figure7

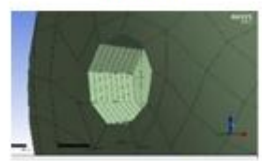

Figure8

Total No. of layers =5

Each layer thickness 8 mm

total thickness= 5*8=40mm

Fig.No.	Title of the Figure
Fig.No.7	Applicationofhydrostaticpressure32.5Mpa
Fig.No.8	Meshed modelfor6-layers
Fig.No.5	Vector sum displacement
Fig.No.6	Von-Mises Stresses

Deformation over three axes

Deformation	Minimuminmm	Maximuminmm
Vector sum deformation	0.mm	199.31mm
X–axis deformation	-26.795mm	52.687mm
Y–axis deformation	-16.555mm	34.567mm
Z–axis deformation	-2.3998mm	197.8mm

Equivalent VonMises stresses over three axes

Stresses	Minimum,MPa	Maximum,MPa
Von Mises Stresses	74.876MPa	1239.1MPa
X –axis deformation	-277.17MPa	986.83MPa
Y –axis deformation	-29.764MPa	1222.9MPa
Z –axis deformation	-104.81MPa	157.18MPa

c) STRUCTURAL ANALYSIS AND RESULTS (TITANIUM)

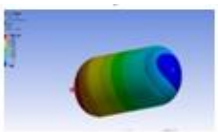

Figure 9

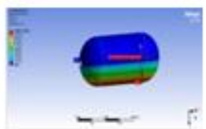

Figure10

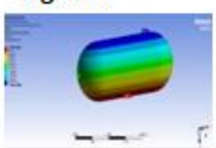

Figure11

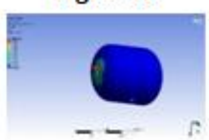

Figure12

Fig.No.	TitleoftheFigure
Fig.No.9	FiniteElementmeshedModelofsolid wallpressurevessel
Fig.No.10	Applicationofhydrostaticpressure32.5Mpa
Fig.No.11	Vectorsumdisplacement
Fig.No.12	Von-MisesStresses

Deformation over three axes (table)

Deformation	Minimuminmm	Maximuminmm
Vector sum deformation	0.mm	4.4767e+007 mm
X –axis deformation	-7.8243e+006 mm	7.5529e+006 mm
Y –axis deformation	-1.3958e+005 mm	1.4187e+005 mm
Z –axis deformation	-4.4766e+007 mm	44438mm

EquivalentVonMisesstressesoverthreeaxes

Stresses	Minimum,	Maximum,
Von MisesStresses	19392 MPa	8.6516e+008 MPa
X –axis deformation	-2.4487e+008 MPa	2.7976e+008 MPa
Y –axis deformation	-5.623e+008 MPa	4.7518e+008 MPa
Z –axis deformation	-4.9516e+008 MPa	4.2989e+008 MPa

IV. RESULTSANDDISCUSSION

In this project work, we are mainly used two types of materials; Carbon Epoxy (T300/LY5052) and Titanium alloy. And we also get a new composite material by mixing of these two materials, after that we have analysed all these three materials on Ansys workbench and find out the best suit for making of a high-pressure vessel. As shown in Figure 9 and 10, Carbon fibres are the typical fragile materials with a high tensile strength and low elongation. The composite pressure vessels will initially fail at the point where there is a significant strain under internal pressure. As for the 40mm thick pressurevessel,theequivalentstressoftheCarbonEpoxy(T300/LY5052)is1239.1MPa,undertheworkingpressure25MPaisappliedandtheburstpressure of the material 302.6 N/mm2. Titanium, the workhorse of the reactive metals, is readily accessible and is utilised in higher numbers than all of the other reactive metals combined in the production of corrosion-resistant equipment. in Figure 13, 14 and 15 an equivalent stress of titanium alloy based solid pressure vesselis 8.6516e+008MPa and total deformation of the material is shown in table6 under the working pressure 25 mpa and burst pressure is 140.9N/mm2. Hydrostatic Pressure is same for both pressure vessel that is 32.5 N/mm2. Due to high tensile strength of carbon epoxy and superior corrosion resistant metal titanium, we combine them both in proper manner and make a new composite pressure vessel by the help of ANSYS and analys is it an equivalent stress of new composite (carbon epoxy and titanium) based The solid pressure vessel has a pressure of 8.6516e+008MPa, and the total deformation of the material is indicated in table6 at a working pressure of 25 mpa and a burst pressure of 140.9N/mm2. All components of the CFRP layer and inner metal layer are meshed using nonlinear layered shell elements and linear layered shell elements, respectively. The work proposes a technique for analysing such vessels exposed to internal pressure stress. The vessel's burst pressure is anticipated using the maximum stress criterion. There is high agreement between model prediction and experimental measurement.

V.CONCLUSION

1. Nowadays, compared to solid wall pressure vessels, multi-layered pressure vessels are now widely employed in numerous sectors. Because of the large disparity in vessel weight and uniform stress distribution a cross the vessel wall thickness.
2. This reduces not just the overall weight of the component, but also the cost of the material used to make the pressure vessel. This is justoneoftheimportantcomponentsofthedesignerinordertokeeptheweightandcostaslittleaspossible.
3. The pressure vessels are designed to be safe. The safety factor that we consider permissible and by which the design is deemed safe. The bursting pressure is below the allowed stress, preventing the design from failing. And because the analysis is so near to the analytical design, both data are validated, the design is deemed safe, and no failures in the pressure vessel occur.
4. Use of a CFRP composite gives good impact and tensile strength and increases the material life. It gives good stability and good stiffness and less deformation of the pressure vessel.
5. It is concluded that multi layered pressure vesselsaresuperiorforhighpressuresandhightemperatureoperatingcircumstancesduetotheadvantages of multi layered pressure vessels over traditional single walled pressure vessels.
6. Following this experiment, we came to the following conclusions: first, titanium is the best metal for making a high-pressure vessel; however, titanium is very expensive, making it impossible or impractical to make a pressure vessel out of titanium. As a result, we devised a new composite metal that is a mixture of two metals: carbon epoxy and titanium. So, we can say that this material is the best because of titanium's corrosion resistance, as well as high stiffness, high tensile strength, low weight, and several advantages, of carbon epoxy. For all of these reasons, we can say that this new composite metal is the best for making a high-pressure vessel.

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