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Design and Analysis of high pressure composite vessels

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Abstract: Pressure Vessels are used in various indispensable applications such as aerospace, automobile, underwater vehicles and chemical engineering industries etc. Industrially pressure vessels are made of traditional metals like steels and aluminium alloys. Since performance or operating range plays a vital role in weight of the pressure vessel. For getting better performance weight can be reduced by reducing the weight of shell structure. In this work a composite materials is used to improve the strength of pressure vessel.
In this paper design and analyse a high pressure cylindrical composite pressure vessel of various fiber orientation angles is done with the help of APDL ANSYS.
Keywords: Design, Analysis, Composite Pressure Vessel, ANSYS.

1. Introduction:

As the world is suffering from the scarcity of gas, oil/petroleum in the earth. Most of the vehicles, automotive assemblies, power plants are using these reserve resources termed as fuel which is the main cause of polluting and degrading the quality of air in this atmosphere. At present we are in an alarming zone where we are heading towards the disturbance of ecological sustainability. Since natural gas is one of the cost-effective, eco-friendly fuels as well as reliable for safety for such operation, which can help to reduce the fatal causes. The most effective part for storing the compressed natural gas (CNG) storage is designing of high-pressure cylinders. [1] The pressure vessel is a kind of storage device, reservoirs or a closed container designed for storage of gases or liquids at a pressure which is different from the ambient pressure. It is necessary to keep the compressed natural gas at room temperature, and under the filling high pressure in the pressure vessel or tank. High-pressure storage tank must withstand, and crack at the surface or without leakage as well as maximum pressure like a 20MP i.e. Fatigue load cycle, and burst pressure. It occurs during refilling of storage pressure vessel. It is the most important high-pressure vessel. It should maintain high-pressure tightness with fire safety. Storage pressure for compressed natural gas (CNG) used in various applications such as automobile and aerospace are traditionally produced with help of isotropic material such as Aluminium, steel we are using composite material like carbon fibre, Kevlar fibre etc.

2. Types of Pressure vessels:

The pressure holding the capacity of CNG storage vessels ranges from 15N/mm2 to a maximal of 300N/mm2. [1] it can be internally or externally applied pressure on the vessel. In today scenario, there are various types of pressure vessels are present but generally cylindrical and spherical shapes are used for these purposes all around. Spherical vessels are twice stronger than cylindrical, but it is difficult to manufacture so that cylindrical vessel is preferred for industrial application.[15]For the storage of compressed natural gas researchers design various types of storage tanks and describe it into four types:

- **TYPE 1:** These types of vessels are completely made of metal (Aluminium or steel).It is cost- effective but heavier and it also has no covering other than paint on their outer surface of the tank.
- **TYPE 2:** In these vessels Metal liner reinforced by composite wrap around. Partially both liner and composite materials are used where it is applied equally on vessel. Main benefits are it is less heavy, but having a high cost as compared to other two.
- **TYPE 3:** In these Vessels Metal liner reinforced by composite wrap around the entire tank (“full wrapped”). Liner takes the small amount of the stress. It having Light-weight compared to type 2, but are more expensive.
- **TYPE 4:** In these vessels Plastic gas-tight liner reinforced by composite wrap around the entire tank (“full wrapped”). The entire strength of tank is composite reinforcement and having Light-weight, but expensive than others. It is most commonly used nowadays for manufacturing lighter parts such as aircraft components, pressure vessels because it possesses higher strength.

Table: 2.1 Comparable Table on weight w.r.t cost in CNG pressure vessels types

CNG Cylinder Type	Weight	Cost
Type1- Metal Cylinder	100%	40%
Type2- Metal Liner Hoop Wrapped Cylinder	55-65%	80-95%
Type3- Metal Liner-Fully Wrapped Cylinder	25-45%	90-100%
Type4- All Composite Cylinders	30%	90%

2.1 Objective of Project:

The objective of the project is to:

a. Designing and modeling of pressure vessel as per the ASME Code section acceptability to Indian standard.
b. Analysis of Composite pressure vessels using APDL FEA.

The weight of conventional 90L steel storage tank is approx. 85Kg, so it is very difficult to use this tank for multipurpose use. it is presumed that all-composite pressure vessels can be innovative (i.e., Type-4 cylinders) and is the best answer for light weighting of car substantial business vehicles, for example, transports, autos, flying machine and so forth without trading off on security.

3. Modelling of CNG Pressure Vessel:

3.1 Design parameters:

The current weight of conventional steel tank of capacity 90L is approx. 85Kg. so by using a multilayer composite pressure vessel for the same dimension, the weight can be reduced to some extent. The data of problem is:

a. Diameter of cylinder= 318mm
b. Length of cylinder= 1368mm
c. Liner Thickness = 6mm, 7mm, 8mm
d. Pressure = 20N/mm2, CNG

Modeling of CNG pressure vessel will help to check the applicability of selected design parameters.

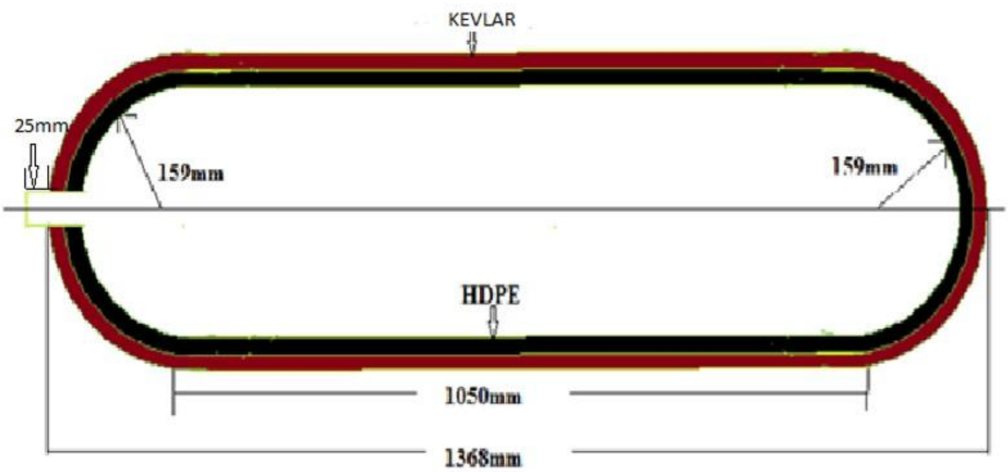


Fig3.1: Dimension of Pressure Vessel

4.2 Material selection:

A number of parameters are considered while selecting the materials such as strength, rigidity, filament winding stability, liner, weight etc. Sometimes geometric and economical viable characteristics are also very much considerable while designing and selecting the material, if weight is optimized then it will make the cost of CNG pressure vessel automatically lesser. Therefore the aim of this study to find the most optimizes design which not makes the pressure vessel light weight and also lesser in cost. In order to achieve this we have selected KEVLAR as base material and HDPE as liner.

Material construction of vessels of KEVLAR Material

Description	**Material**	TS, MPa
Shell liner	HDPE	32 N/MM^2
Shell layers	KEVLAR	2800 N/MM^2

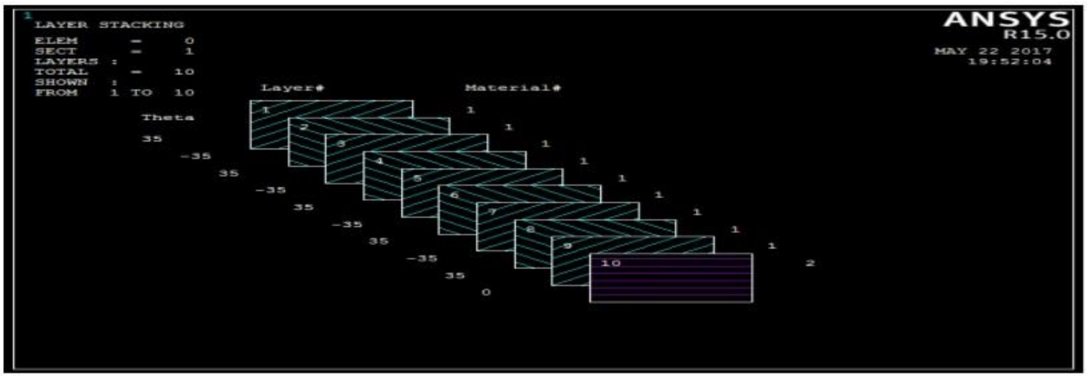
4. Analysis Result:

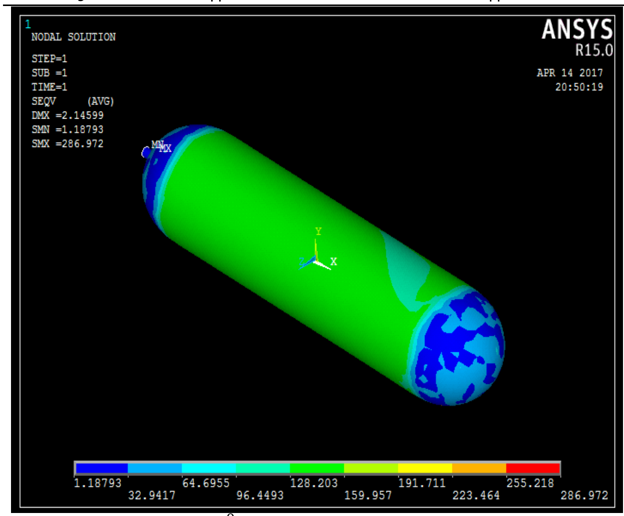
In this report we have analyses a various variant of composite cylindrical pressure vessel of 90L capacity having different thickness and for each variant we have taken various orientation angle ranging from (±25□,±35□,±45□,±55□,±65□,±75□,±85□). The modelling of pressure vessel include the liner is oriented at orientation angle of 0□ while the Carbon/Epoxy is oriented at an angle of (±25□,±35□,±45□,±55□,±65□,±75□,±85□), at different thickness. Now we have to consider different cases of the analysis performed.

VARIANT I-

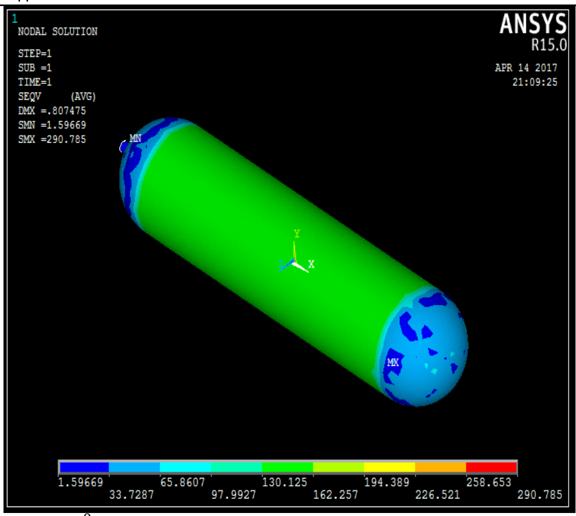
We have used ANSYS 15 software to solve for the Von-Misses stress diagram of composite pressure vessel under specified operating condition with constraints and load applied into the vessel according to actual situation. To verify the stability of pressure vessel. The pressure vessel body section consist of 10 sub layers, among which the first one is plastic sub-layer made of material 2 and is specified as Liner(HDPE) and the other 9 ones are outer Kevlar with helical wound at an orientation of ±25□,±35□,±45□,±55□,±65□,±75□,±85□.

a. Length of Shell (L) = 1368mm
b. Outer Diameter of Vessel (Do) = 318mm
c. Inner Diameter of vessel (Di) = 270mm
d. Thickness of Liner (TL) = 6mm
e. Thickness of Kevlar (TL) = (2mm × 9 Layers) = 18mm

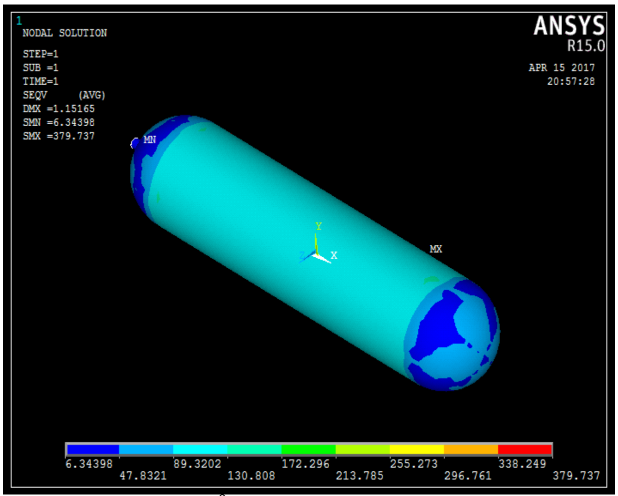




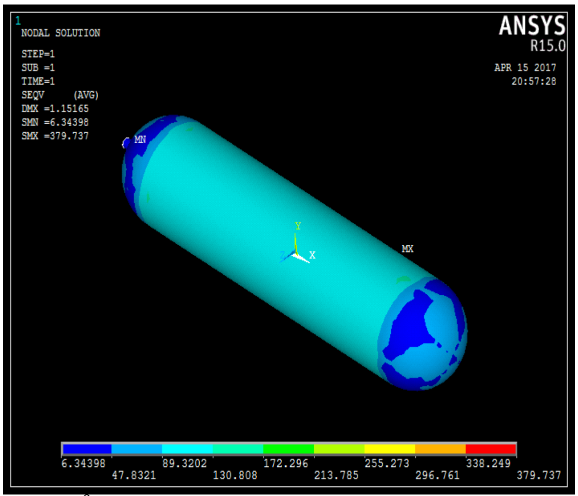
25^0 Orientation



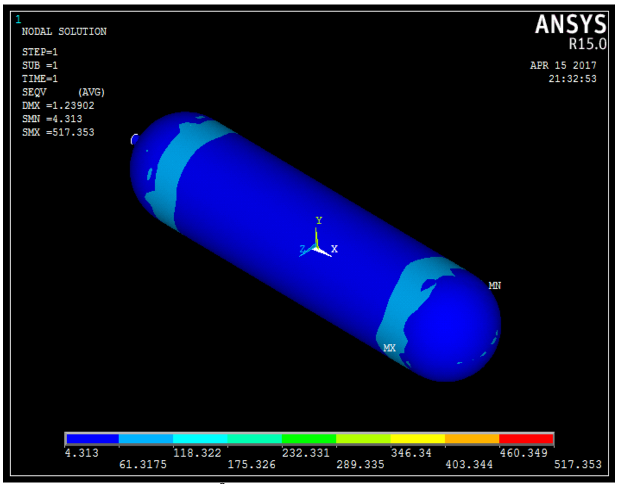
35^0 Orientation



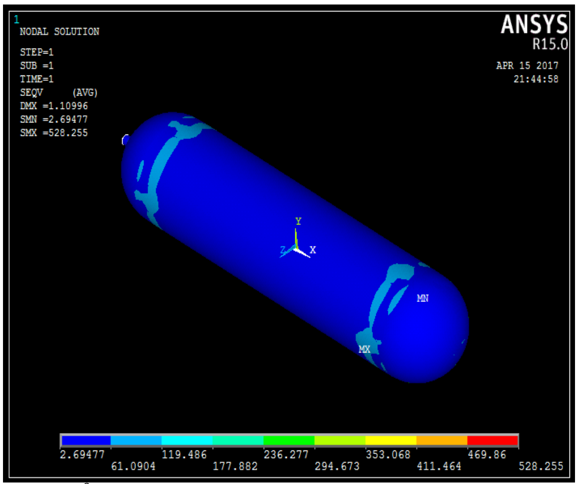
45^0 Orientation



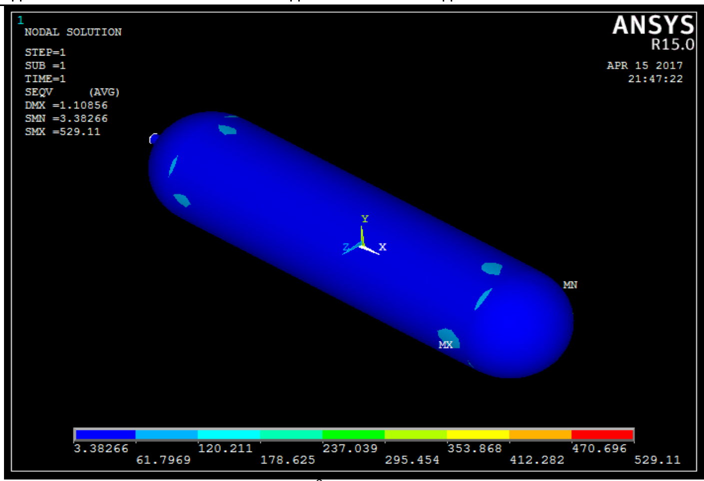
55^0 Orientation



65^0 Orientation



75^0 Orientation



85^0 Orientation

Variants	Deformation (mm)	Orientation (θ)						
		25^0	35^0	45^0	55^0	65^0	75^0	85^0
I	Deformation	2.14599	0.807475	1.15165	1.46821	1.23902	1.10996	1.10856

5. Conclusion:

From this work following conclusion are drawn:

By combining advanced material and technique we can developed high pressure composite vessel that have improved pressure capacity, reduced weight to ensure high performance and more reliable .

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