Design & optimization of LNG-CNG cylinder for optimum weight

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Abstract— In current automobile sector, the weight of the vehicle is too important to increase the efficiency of the vehicle. There are too many component or subassemblies are in the automobile vehicle. In this paper the weight of the HYDROGEN fuel tank is optimized by applying the composite material concept with the existing material of the fuel tank. Initially the dimensional calculation for the existing pressure vessel and compare with the existing cylinder and then the FEA (Finite Element Analysis) applied on the cylinder and material optimize up to the stress reaching equivalent to the stress of the existing cylinder. After that the dimension of the cylinder are finalize. The analysis yields a weight reduction of fuel tank.

Keywords— LPG/CNG cylinder, finite element analysis, composite material, weight.

I. INTRODUCTION

The intemperate use of fossil fuels has led to gradually increasing drastic environmental pollution and energy crisis. Numerous research works have recently been carried out on looking for renewable resources as replacement for conventional fossil fuels. Safe, high-efficiency and economical HYDROGEN storage technique is a key to ensure favorable run of HYDROGEN fuel cell vehicles. Among many HYDROGEN storage patterns including high pressure gaseous storage, cryogenic liquid storage and chemical HYDROGEN storage, high-pressure gaseous storage has become the most popular technique [1–4]. The basic requirements for design of storage vessels are safety, reliability and economy. However, the composite pressure vessels may work under the high- pressure and high-temperature environment. Conventional metallic pressure vessels cannot longer be competent for the rigorous need of high strength and stiffness weight ratios. Therefore, the composite filament wound technology was introduced to improve performance of the storage vessels [5]. Generally, the composite materials are used for fabrication of pressure vessels by placing them in different orientations for different layers and in a common orientation within a layer. These layers are stacked in such a way to achieve high stiffness and strength [6]. The design of the composite vessel as a fundamental research work relates the physical and mechanical properties of materials to the geometric specifications [7].

In the literature, numerous research works have been carried out on design and analysis of composite pressure vessels. Nunes et al. [8] investigated the production of large composite pressure vessels. They were made of thermoplastic liner, glass fiber and polymer resin. They showed that there is a good agreement between experimental results and elasto-plastic modeling for mechanical behavior of high density polyethylene liner under internal pressure. Koppert et al. [9] conducted experimental investigation along with finite element modeling on the composite pressure vessels made by dry filament winding method. They represented that the results of finite element model for vessels with one or two layers is consistent with experimental results but there are high errors for vessels with three or four layers. Chang [10] theoretically and experimentally analyzed failure of the first laminate of composite pressure vessels. He studied proximity of the theoretical and experimental analysis through fracture strength of the first laminate on the symmetrical laminate of composite pressure vessels using different materials with different number of layers under uniform internal pressure. The experimental results were compared with theoretical results based on the Hoffman, Hill, and Tsai-Wu maximum stress criterions which accurately predicted the pressure in which the failure of the first layer occurs.

Vasiliev et al. [11] studied the filament wound composite pressure vessels that have commercial applications. Su et al. [12] used the nonlinear finite element method to calculate the stresses and the bursting pressure of filament wound solid-rocket motor cases which are a kind of composite pressure vessel. The effects of material performance and geometrical nonlinearity on the relative loading capacity of the dome were studied. Kim et al. [13] presented an optimal design method of filament wound structures under internal pressure. They used the semi-geodesic path algorithm to calculate possible winding patterns taking into account the windability and slippage between the fiber and the mandrel surface. In addition, they performed a finite element analyses using ANSYS, to predict the behavior of filament wound structures. The optimal dome contour was studied in ANSYS with a trial design. Onder et al. [14] studied burst pressure of filament wound composite pressure vessels under alternating pure internal pressure. The study dealt with the influences of temperature and winding angle on filament wound composite pressure vessels. Finite element method and experimental approaches were employed to verify the optimum winding angles. The hygrothermal and other mechanical properties were measured on Carbon Fiber composite flat layers. Some analytical and experimental solutions were compared with the finite element solutions, in which commercial software ANSYS 12.1 was utilized; close results were obtained between analytical and experimental solutions for some orientations. Liu et al. [7] presented a comprehensive review on recent development of numerical simulation and optimization for designing of composite pressure vessels. The methods on damage modeling for predicting the failure properties and degradation mechanisms of the composite vessel along with research on predicting the burst pressure and lifetime of the composite vessel were reviewed. Zheng et al. [4] firstly reviewed recent progress toward low-cost, large capacity and light-weight on high pressure gaseous HYDROGEN storage vessels.

Then, three important aspects of high pressure gaseous HYDROGEN safety, i.e., HYDROGEN embrittlement of metals at room temperature, temperature rise in HYDROGEN fast filling, and potential risks such as diffusion, deflagration, and detonation after HYDROGEN leakage were introduced. Liu and Zheng [15-16] established parametric finite element model for the cylinder part using ANSYS finite element code. However, the design platform has not been completely established since ANSYS software does not provide an efficient modeling module for composites until now.

Due to various constraints that exist in testing of composite pressure vessels, finite element analysis (FEA) can be considered as a suitable method for analysis of composite high-pressure LPG/CNG storage vessels. This paper studies finite element analysis of a fuel-cell vehicle's composite high-pressure LPG/CNG storage vessel using commercial code ANSYS. Complete structural analysis is performed and effect of some parameters such as fiber angle is investigated. Moreover, fatigue evaluation of composite high pressure LPG/CNG storage vessel is performed which concentrates on the fatigue properties of the aluminum liner.

II. DESIGN CALCULATION

The dimension of the LPG/CNG cylinder are calculated manually and it is compare with the existing dimension of the LPG/CNG cylinder and weight of the same cylinder are also compare to perform the further work in this project.

Design of a Pressure Vessel for the application as a fluid application for the CNG as well as LPG. The existing dimension of the pressure vessel fitted on the vehicle and application criteria for the pressure vessel are as under:

- Capacity of the tank : 20Liters
- Operating Pressure of the CNG : 200 bar
- Inside temperature of the pressure vessel :111 K
- Outside temperature of the pressure vessel :300 K

In this project, for the weight optimization 34CrMo, Carbon Fiber and G11- CR materials are used; the dimensions of the existing cylinder are calculated as under.

The pressure vessel is manufactured from the 34CrMo material. the material property of the material are described as a under :

Property of the 34CrMo Material:

- Density : 7.80 g/cm^3
- Young Modulus (E_s) : 2 x 10^{11} Pa
- Poissions Ratio : 0.30
- Yield Strength (Y_s) : 800 min. MPa
- Tensile Strength (T_s) : 1000 to 1200 MPa
- % Thermal contraction @111K : -0.265%
- Thermal Expansion (10^{-6}/K) : 20.70
- Thermal conductivity (W/mK) : 11.2
- Specific Heat (J/KgK) : 500
- Emissivity : 0.54

Thickness of the pressure vessel are calculated by ASME code and also calculated with the lames theorem. Which are mentioned as under.

According to ASME code thickness required for the inner steel vessel:

$$t_s : \frac{p \times ds}{(2 \times \ s \times \ w) - (1.2 \times p)}$$

Where,

w : Welding efficiency 1.00 for fully but welded with penetration.

$$t_s : \frac{30 \times 178}{(2 \times 800 \times 1.00) - (1.2 \times 30)}$$

t_s : 3.414mm

t_s : 4.00mm

According to the calculated thickness the inner diameter of the pressure vessel is calculated as under:

D : 2 x t + ds
: 2 x 4 + 178
: 186.00mm

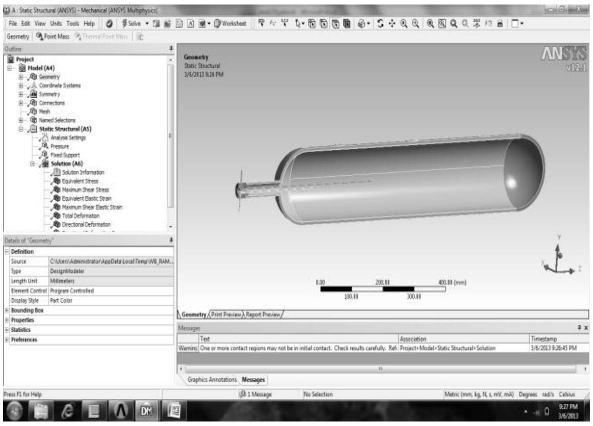
For resisting the 30 MPa internal pressures the total thickness of the inner cylinder with steel of pressure vessel is 4.00mm required. The summary of the material, weight and dimensions are as under :

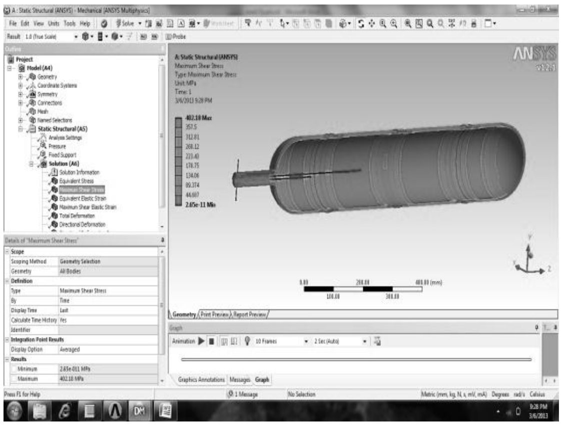
Sr.No.	Material	Inner Diameter(mm)	Thickness (mm)	Weight (Kg)
1	34Cr-Mo	178	4	27.398
2	Carbon Fiber	178	10	11.389
3	G11- CR	178	7	16.93555

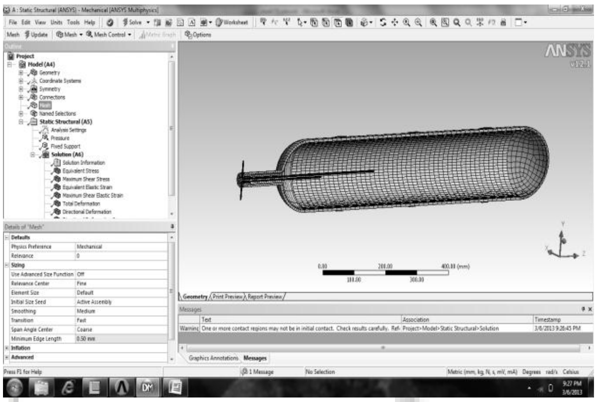
After completing the calculation the analysis of the cylinders are performed.

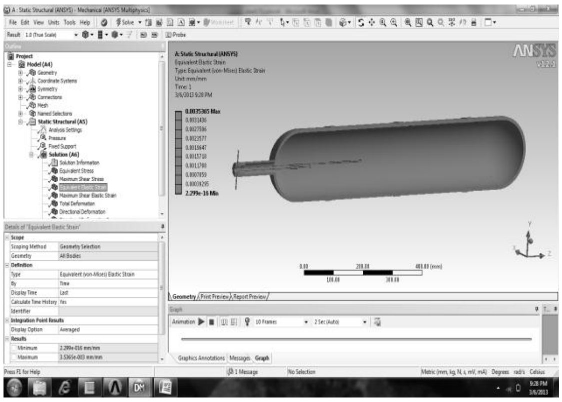
III. ANALYSIS

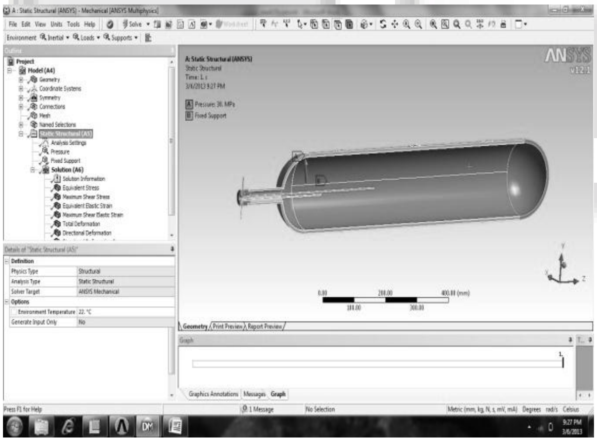
The analyses of the LPG/CNG cylinders are performed on the ANSYS software.

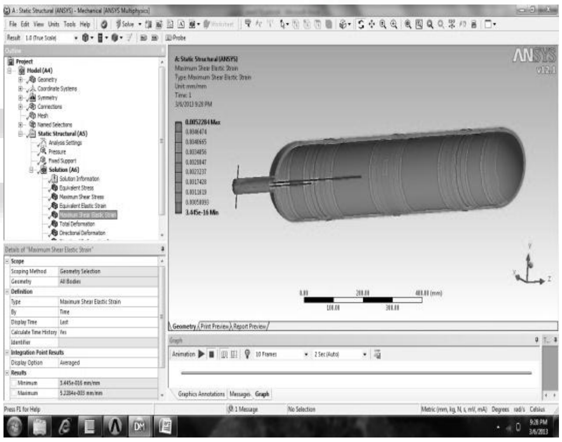


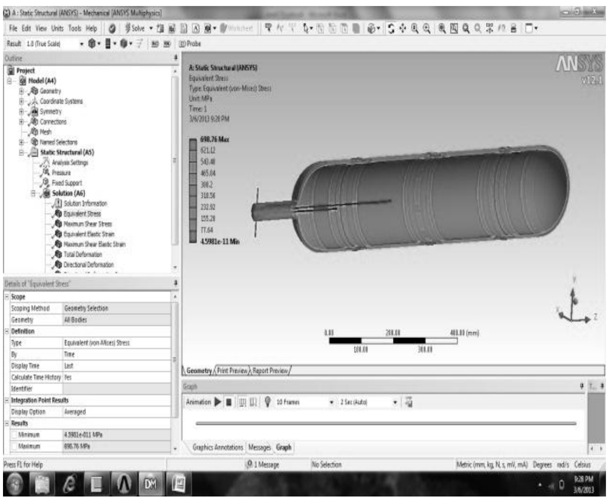


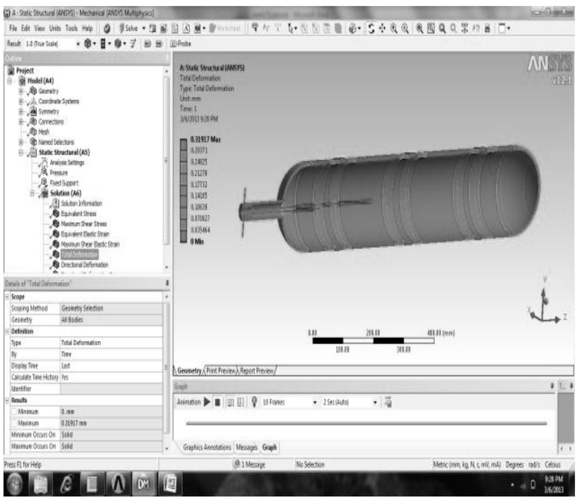


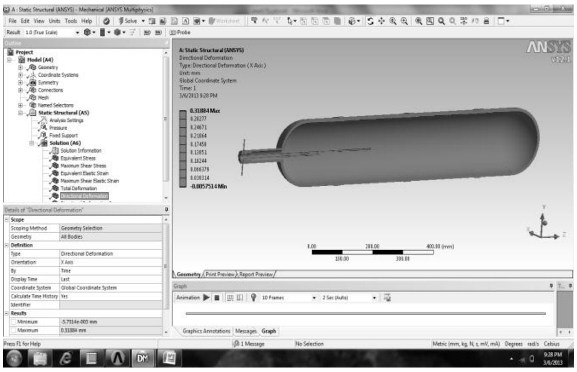


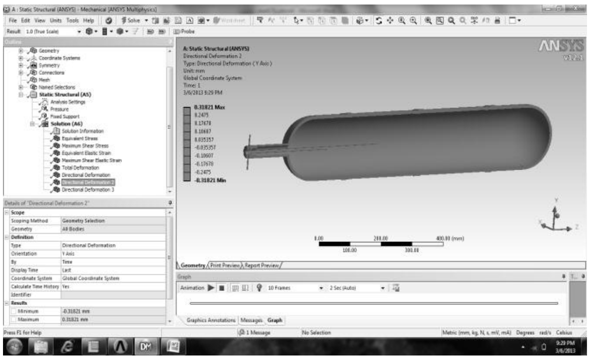


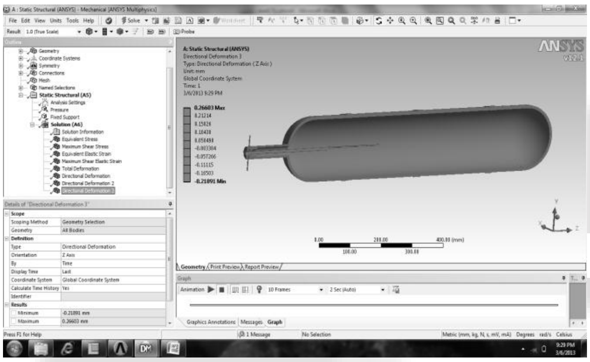












The summary of the analysis for the definite input parameter the stresses and deformation are mentioned as under.

Sr.No.	Material	Inner Diameter(mm)	Thickness (mm)	Stress (N/mm 2)	Deformation (mm)
1	34CrMo	178	4	712.40	0.32
2	Carbon Fiber	178	10	615.02	0.39
3	G11 - CR	178	7	1418.60	1.316

Sr.No.	Material	Thickness	Weight	Von-Misses Stress	Shear Stress	Total Deformation
		mm	Kg	N/mm2	N/mm2	mm
1	SS304	4	19.45	714.6	406.27	0.30677
2	34CrMo	4	19.33	712.4	405.67	0.31648
3	Carbon Fiber	10	10.62	615.02	345.07	0.38988
4	G11-CR	7	8.46	1418.06	811.62	1.316
5	Carbon Fiber + 34CrMo	1.75+4	13.29	698.76	402.18	0.31917

On the based of the above summary the composition of the steel and carbon fiber material will procced.

IV. CONCLUSION

The cylinders with the 34CrMo 1.75mm thickness and carbon fiber with the 4.00mm thickness, the stress is less than the stress achieved in the existing cylinders manufactured from the SS304 steel. The weight of the existing cylinder of SS304 is 19.45 Kg. and that of the new established composite cylinder is reduced by 6.16 Kg (approx 31 % reduction). The lighter weight cylinders are easy to handle and easy to assembled in the vehicle. The ultimate manufacturing costs from the both methods are same.

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