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Design and Analysis of Plastic Fuel Tank for Three Wheeler CNG Passenger Vehicle

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ABSTRACT

The current trend is to provide weight/strength effective and reliable products which satisfy the stringent requirements. The fuel tank is used in automobile industries to carry fuel and supply fuel to the engine via fuel filter, fuel pump. The aim of this project is to design plastic fuel tank for three wheeler vehicles. This study aimed at to make a new design of plastic fuel tank for three wheeler vehicles in order to reduce production cost of fuel tank and make most secure and safe fuel tank. The project involves geometry and finite element modeling of plastic fuel tank design. Study the existing fuel tank and then begins the attempt to make plastic fuel tank. Geometrical modeling was done using Pro-E; finite element modeling using Hyper mesh software and analysis was done using ANSYS software. Experimental test was conducted to examine the effectiveness of the plastic fuel tank. Result of static load analysis of the existing fuel tank and plastic fuel tank design is compared to prove the design is safe. Similarly experimental result of the existing fuel tank bracket and the plastic fuel tank bracket are compared to prove the design is safe. Plastic fuel tank design gives optimum design for same loading condition with huge amount of weight reduction.

Keywords- **Automobile industries, optimum design, Plastic fuel tank, static load analysis, weight reduction.**

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I. INTRODUCTION

It is said that in early days buoyancy in vehicle sales in India is heartening for the industry and economy. It caused to sever competition in Automobile industry, Market rate challenges to automobile industries. So it becomes a necessary strategy for each and every company to accept this challenge and to make a room in the automobile sector. This market requirement supports the saying that, "This is a competitive era".

1. Price of the vehicle is at the core point of view. So it's become an important objective of each company is that to pay their attention on the market price rate and should attempt to minimize the price of the vehicle. It found that each and every part of engine, vehicle body and its necessary accessories and equipment's, are the assessors and they are directly affecting the total price of the vehicle. There is a chance to minimize the cost of the vehicle through its designing aspects this overall assessment taking into consideration and it is decided that there is a chance and these needs of reassessment of three wheeler vehicle in connection to reduce its price.

1.2 Need of study

Three wheeler vehicle worlds are also not an exception to the competition on price. A careful assessment has been done to find out the chances of improvement. Detailed assessments of three wheeler vehicle come to the conclusion that fuel tank can be made from plastic and it can be moved forward following purpose. Existing secondary fuel tank had required a large space compared to its fuel carrying capacity and the cost of the existing fuel tank is much more than the plastic fuel tank. The fuel tank can move from vehicle right side long member of the vehicle body. There is an unused remaining space in engine cabin that would be utilized by changing the mounting position of the fuel tank. All above things imply that there is a need to minimize the cost of the fuel tank in order to get more comfortable in working process. The vehicle should have a suitable range of price and one can enjoy the cost benefit. It is needed to make a new design of a plastic fuel tank in such way which is useful to minimize the cost of the fuel tank in order to get comfortable in the working process and it would be more secure and safe.

1.3 Problem statement

A detailed study of three wheeler vehicle comes to the following conclusion. The manufacturing cost of the existing fuel tank is higher than the plastic fuel tank. It occupies unnecessarily large space in the engine cabin compare to its fuel carrying capacity and it is resulting in congestion in engine cabin. It is comparatively heavy weight. There is a remedy to solve these problems is that to make new designed secondary (Plastic) fuel tank.

1.4 Aim of project

The aim of this project is to design secondary plastic fuel tank for three wheeler vehicles. For this purpose following things would be possible.

It is possible that mounting position would be change tank can move from vehicle right side long member to vehicle body in engine cabin. It would be suitable for the vehicle and remaining space can use for other purposes to get much more simplified in engine cabin. And the most important thing is that it would get a reduction in weight using strong and rigid light weighted plastic fuel tank instead of a metal one. It reduces manufacturing cost of the fuel tank.

1.5 Objective

1. To design Plastic Fuel Tank solid model using Pro-E wildfire 3.
2. To generate infinite element using Hyper Mesh 11 from 3D model of Plastic Fuel Tank and tank brackets.
3. To analysis the Plastic Fuel Tank with brackets by using Ansys.
4. To test the effectiveness of the plastic fuel tank through experimental test.
5. To compare the result of existing fuel tank referential data and plastic fuel tank.
6. Verify all over utilization of the plastic fuel tank with its bracket validation.

1.6 Methodology

Analytical and Experimental method are used to prove the objectives and validity of plastic fuel tank. The following strategies will be followed to achieve objectives of the study.

1. Benchmarking plastic fuel tank from competitor vehicle.
2. To design the plastic fuel tank by using Pro-E modeling Software.
3. To analysis the plastic fuel tank by using Ansys Software.
4. Manufacture the plastic fuel tank (proto type).
5. Test the effectiveness of the plastic fuel tank through conducting the durability test, hydraulic test, resistance to fire and bracket validation test and compare its result with existing data.

II. LITERATURE REVIEW

Initial assessment through value engineering and comparative study of the reference vehicles has led to the listing out of various parameters and components which affect the price of the vehicle. Literature survey therefore is concentrated towards the study of those parameters which affects the price of the vehicle and the methods of quantifying the parameters of the vehicle and also various testing procedures and standards.

Fatigue Behavior Analysis and Durability Evaluation of Plastic Fuel Tank, by Himeki. H, Kumagai.H and Morohoshi.K Plastic materials are often used for automotive fuel tanks today because of their light weight, freedom for forming complicated shapes and corrosion resistance. The fatigue behavior of the high-density polyethylene applied to fuel tanks was analyzed under the low-level cyclic loading that simulated fuel tank pressure changes. The correlation between fatigue life and stress, temperature and frequency (the major influencing factors) was expressed quantitatively using fatigue test data for test pieces. This formulation was then verified in fatigue tests conducted on plastic fuel tanks. The validity of this equation for predicting the fatigue life of plastic fuel tanks was thus confirmed. [3]

Barrier Technologies Applied to Plastic Fuel Tanks Comparison of Their Performance, by Delbarre. P and Rod. A. Their low density, to their excellent process ability and recyclability, and to their outstanding chemical resistance and specific mechanical strength, polymers are now the best materials to be applied in fuel tank systems. In that field, High Density Polyethylene is regarded as the best compromise between economical and technical requirements. But, basically, because of its chemical nature and structure, HDPE offers a poor barrier to hydrocarbons, especially light ones composing gasoline. Then, in order to meet to more and more demanding regulations on air quality and emissions, professionals from the Fuel Tank System area have developed several technologies in order to cope with that property of HDPE. [4]

Influence of Tank Design Factors on the Rollover Threshold of the Partially Filled Tank Vehicles by Rakheja.S, Sankar.S and Ranganathan. R. This paper gives a brief description on general purpose tank vehicles often carry partial loads in view of variations in the weight density of the liquid cargo and are thus subject to slosh loads during highway man oeuvres. The magnitude of destabilizing forces and moments due to liquid slosh is strongly related to a number of vehicle and tank design factors, such as tires, suspension, articulation mechanism, weights and dimensions, tank geometry and fill level. The rollover threshold of the tank vehicle is compared to that of an equivalent rigid cargo vehicle to demonstrate the destabilizing effects of liquid slosh. The rollover threshold of the tank vehicle is assessed for a number of tank design factors. Influence of tank size and cross-section on the rollover threshold of the tank vehicles is investigated. The study concludes that the lateral load shift and thus the rollover threshold are strongly related to the tank cross-section geometry. The rollover threshold of the articulated vehicle carrying a compartmented tank is investigated and an optimal order of unloading various compartments is presented. [5]

Fuel Tanks for the automotive vehicle by Corrodi, R and Gordon, H Steel tank or plastic tank that is the question. Like Shake spear's "Hamlet, Prince of Denmark" this is probably what all those responsible for fuel tanks have asked themselves, time and time again. [6]

Minimum Weight Design of Tank Structures by Jones. This paper defines the geometry of minimum weight tank structures of giving the enclosed volume. A tank structure is seen to comprise a circular cylindrical shell (monologue or stiffened), bulkheads, and skirt structures. The analyses, starting from established criteria of failure, apply to the loading cases of longitudinal compression and bending moments in combination with internal pressure. The bulkhead geometries are flat, hemispherical, and ellipsoidal. For monologue shells, the analyses yield the radius and wall thicknesses prescribing a minimum total weight of cylindrical tank wall, bulkheads, and skirts (unpressurized cylindrical appendages, for example, interstate structure). For stiffened shells, the analyses yield the tank radius, skin gauge, stringer spacing, and frame spacing prescribing a minimum total tank weight. [7]

Fuel Tank Heat Shield Design by Jordan, C. And Matkovich. D. The placement and design of heat shields are a critical step in the design of today's vehicles. Computer modeling of heat shield configurations can help to optimize shielding performance while minimizing their size and price. In this paper an attempt was made to determine the most effective shielding arrangement between the exhaust system and the fuel tank. It has been determined through numerical experimentation that vehicles fitted with plastic fuel tanks should have tanked shields installed as a first preference over exhaust shielding in most practical applications. [8]

A study of storage tank accidents by James I. Changa, Cheng-Chung Linb. This paper reviews 242 accidents of storage tanks that occurred in industrial facilities over last 40 years. Fishbone Diagram is applied to analyze the causes that lead to accidents. Corrective actions are also provided to help operating engineers handling similar situations in the future. The results show that 74% of accidents occurred in petroleum refineries, oil terminals or storage. Fire and explosion account for 85% of the accidents. There were 80 accidents (33%) caused by lightning and 72 (30%) caused by human errors including poor operations and maintenance. Other causes were equipment failure, sabotage, crack and rupture, leak and line rupture, static electricity, open flames etc. Most of those accidents would have been avoided if better engineering have been practiced. [9]

III. DESIGN OF PLASTIC FUEL TANK

The design process can be viewed as an optimization process to find structures, mechanical systems, and structural parts that fulfill certain expectations towards their economy, functionality, and appearance. Generally, the design process is an iterative procedure consisting of the following components.

- Conceptual design
- Design
- Testing
- Optimization

Today's testing ground is usually the computer. Finite element analysis (FEA) and Multi-body dynamics analysis (MBD) are the most used tools for computational design testing. The results of computational analyses are used to determine design improvements. Changes to the design are introduced in all phases of the process. At a certain stage of this process, changes to the concept become prohibitive. The concept phase plays a fundamental role concerning overall efficiency of the design and the cost of the overall development process.

The definition of the design problem and of the design target is most important. The solution can be left with computational means. Multidisciplinary considerations, especially in the conceptual design, are, in many ways, still active research topics and are being covered by future developments of topology optimization. However, the inclusion of manufacturing constraints into topology and topography optimization is already implemented in Optic Struck. Optic Struck also provides the size and shape optimization to completely support the design process with finite element based structural optimization. Using the advanced interfacing with Hyper Mesh, the generation of input data for structural optimization becomes an easy task. This allows structural optimization to be integrated into the design process seamlessly.

A. Storage tank design calculation

1. Design code API 650
2. Tank

i.	Material	HDPE
ii.	Roof (Open/Close)	Close
iii.	Tank support	self-support

3. Geometrical data
   - i. Tank width = 100 mm
   - ii. Tank height H = 110 mm
   - iii. Tank length = 320mm
   - iv. Specific gravity of operating liquid S. G = 0.95
   - v. Nominal capacity, V = 3.85 m^3
   - vi. Maximum design liquid level, HL = 100 mm
4. Pressure & Temperature
   - i. Design pressure Upper, P_u = 0.4 bar Lower, P_i = 0.3 bar
   - ii. Design Temperature Upper, T_u = 120ºc Lower, T_i = -100ºc

We have chosen 5 mm thickness of fuel tank shell for optimization purpose. [2]

B .Mathematical calculation

Maximum bending stress

The minimum thickness of the shell wall is determined as follows:

The maximum pressure on the side wall due to liquid level is given by

$$P = \rho \times g \times h$$

Where,

p = pressure in N/mm²

ρ = density in kg/m³

h = height from the bottom of the course under consideration to the top of the roof in m.

$P = \rho \times h \times 9.81 \times 10^{-6}$

$P = 950 \times 0.110 \times 9.81 \times 10^{-6}$

$P = 0.00102$ N/mm²

Calculated pressure is 0.00102 N/mm2 < 0.03 N/mm2, so that we have taken design pressure 0.04 N/mm².

If the longest side of the tank is L, then maximum bending stress on the side wall is given by

$$f = \frac{\beta \times p \times L^2}{(t-c)^2}$$

Where,

β = constant (from table)

t = thickness of wall plate

c = corrosion allowance.

The maximum deflection is given by

$$Y_{max} = \frac{\alpha \times p \times L^3}{E\,(t-c)^2}$$

Where,

α = constant (from table)

E = modulus of elasticity

Table.1 Constant for Shell thickness calculation [2]

Ratio (h/L)	0.5	0.667	1.0	1.5	2.0	2.5	3.0
B	0.11	0.16	0.2	0.28	0.32	0.35	0.36
A	0.026	0.033	0.04	0.06	0.058	0.064	0.067

Factory of safety = $\frac{Ultimate\ stress}{Working\ stress}$

For Tank design FOS is taken as 2 & ultimate stress is 37

Working Stress = $\frac{Ultimate\ stress}{FOS} = \frac{37}{2}$ = 18.50 N/mm^2

Stage-1 for thickness 4.5 mm

The maximum bending stress on the side wall is given by

$$f = \frac{\beta \times p \times L^2}{(t-c)^2}$$

$$f = \frac{0.11 \times 0.4 \times 310^2}{(4.5-0)^2}$$

f = 20.88 N/mm²

The maximum bending stress on the side wall is 20.88 N/mm² > 18.50N/mm², so that the design is unsafe.

The maximum deflection is given by

$$Y\ max = \frac{\alpha \times p \times L^3}{E\ (t-c)^3}$$

$$Y\ max = \frac{0.026 \times 0.04 \times 310^3}{600\ (4.5-0)^3}$$

Y max = 0.56 mm

Stage-2 for thickness 5 mm

The maximum bending stress on the side wall is given by

$$f = \frac{\beta \times p \times L^2}{(t-c)^2}$$

$$f = \frac{0.11 \times 0.04 \times 310^2}{(5-0)^2}$$

f = 16.91 N/mm²

The maximum bending stress on the side wall is 16.91 N/mm² < 18.50N/mm², so that the design is safe.

The maximum deflection is given by

$$Y\ max = \frac{\alpha \times p \times L^3}{E\ (t-c)^3}$$

$$Y\ max = \frac{0.026 \times 0.04 \times 310^3}{600\ (5-0)^3}$$

Y max = 0.41 mm

Stage-3 for thickness 5.5 mm

The maximum bending stress on the side wall is given by

$$f = \frac{\beta \times p \times L^2}{(t-c)^2}$$

$$f = \frac{0.11 \times 0.04 \times 310^2}{(5.5-0)^2}$$

f =13. 97 N/mm²

The maximum bending stress on the side wall is 13.97 N/mm² < 18.50N/mm², so that the design is safe.

The maximum deflection is given by

$$Y\ max = \frac{\alpha \times p \times L^3}{E\ (t-c)^3}$$

$$Y\ max = \frac{0.026 \times 0.04 \times 310^3}{600\ (5.5-0)^3}$$

Y max = 0.31 mm

Stage-4 for thickness 6 mm

The maximum bending stress on the side wall is given by

$$f = \frac{\beta \times p \times L^2}{(t-c)^2}$$

$$f = \frac{0.11 \times 0.04 \times 310^2}{(6-0)^2}$$

f =11. 74 N/mm²

The maximum bending stress on the side wall is 11.74 N/mm² < 18.50N/mm², so that the design is safe.

The maximum deflection is given by

$$Y\ max = \frac{\alpha \times p \times L^3}{E\ (t-c)^3}$$

$$Y\ max = \frac{0.026 \times 0.04 \times 310^3}{600\ (6-0)^3}$$

Y max = 0.23 mm

Stage-5 for thickness 6.5 mm

The maximum bending stress on the side wall is given by

$$f = \frac{\beta \times p \times L^2}{(t-c)^2}$$

$$f = \frac{0.11 \times 0.04 \times 310^2}{(6.5-0)^2}$$

f =10. 00 N/mm²

The maximum bending stress on the side wall is 10.00 N/mm² < 18.50N/mm², so that the design is safe.

The maximum deflection is given by

$$Y\ max = \frac{\alpha \times p \times L^3}{E\ (t-c)^3}$$

$$Y\ max = \frac{0.026 \times 0.04 \times 310^3}{600\ (6.5-0)^3}$$

Y max = 0.18 mm

Stage-6 for thickness 7.0 mm

The maximum bending stress on the side wall is given by

$$f = \frac{\beta \times p \times L^2}{(t-c)^2}$$

$$f = \frac{0.11 \times 0.04 \times 310^2}{(7-0)^2}$$

f = 8. 62 N/mm²

The maximum bending stress on the side wall is 8.62 N/mm² < 18.50N/mm², so that the design is safe.

The maximum deflection is given by

$$Y\ max = \frac{\alpha \times p \times L^3}{E\ (t-c)^3}$$

$$Y\ max = \frac{0.026 \times 0.04 \times 310^3}{600\ (7-0)^3}$$

Y max = 0.15 mm

Stage-7 for thickness 7.5 mm

The maximum bending stress on the side wall is given by

$$f = \frac{\beta \times p \times L^2}{(t-c)^2}$$

$$f = \frac{0.11 \times 0.04 \times 310^2}{(7.5-0)^2}$$

f =7. 51 N/mm²

The maximum bending stress on the side wall is 7.51 N/mm² < 18.50N/mm², so that the design is safe.

The maximum deflection is given by

$$Y\ max = \frac{\alpha \times p \times L^3}{E\ (t-c)^3}$$

$$Y\ max = \frac{0.026 \times 0.04 \times 310^3}{600\ (7.5-0)^3}$$

Y max = 0.12 mm

We have chosen 5 mm thickness of fuel tank shell for optimization purpose. [2]

IV. ANALYSIS OF PLASTIC FUEL TANK

Existing fuel tank is consisting of by metal. It has two liter fuel storage capacity. It has been redesigned purposefully in order to keep value engineering. The proposed fuel tank is made of plastic material. It increases fuel storage capacity of one liter means up to three liters. The overall tank thickness is 5 mm. In order to get more space more durability, more security and safety mounting place of the proposed fuel tank is also changed. It adjusted in the engine cabin where the place is fit for the purpose. It is easier to perform the work. Considering all this issue proposed fuel tank is mounted on the vehicle body. These need to be analyzed using hyper mesh software and result to be benchmarked with a proposed fuel tank of the test vehicle.

The 3-D model of the existing fuel tank and proposed plastic fuel tank was modeled in Pro/ENGINEER software as shown in Fig

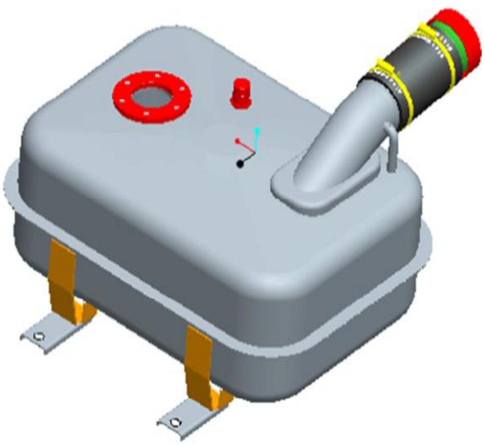


Fig.1 Existing fuel tank

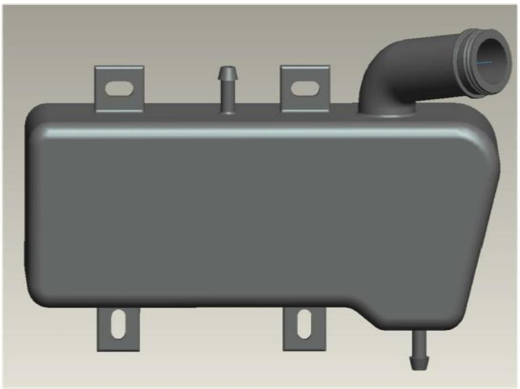
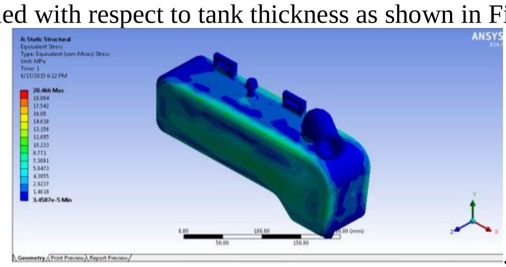
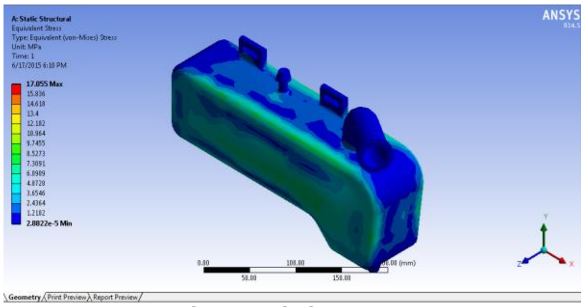


Fig.2 Plastic fuel tank

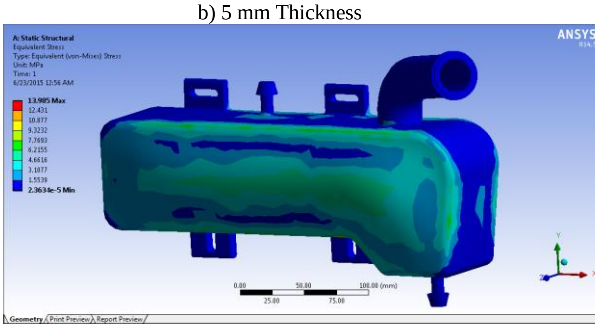
After the solution was achieved the results and the stress plot of the test vehicle and plastic fuel tank where the compared. In the figure above the fuel tank on the left is the existing fuel tank on the right is the plastic fuel tank .The results are as follows: The left side figure representing the existing fuel tank and the figure on the right side represent proposed plastic fuel tank as shown in Fig 1. and the stress is varied with respect to tank thickness as shown in Fig



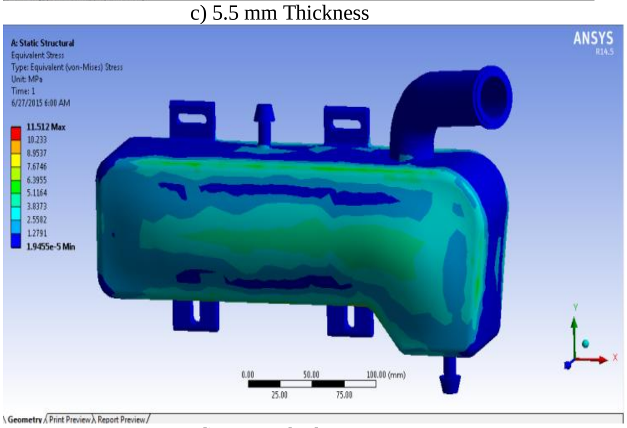
a) 4.5 mm Thickness



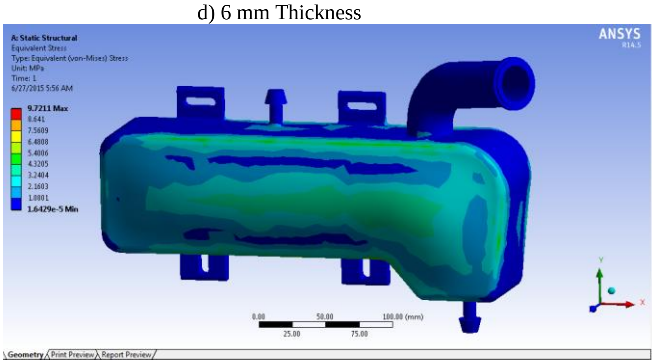
b) 5 mm Thickness



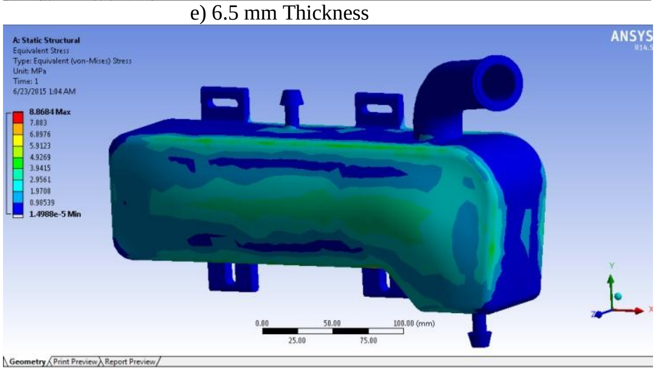
c) 5.5 mm Thickness



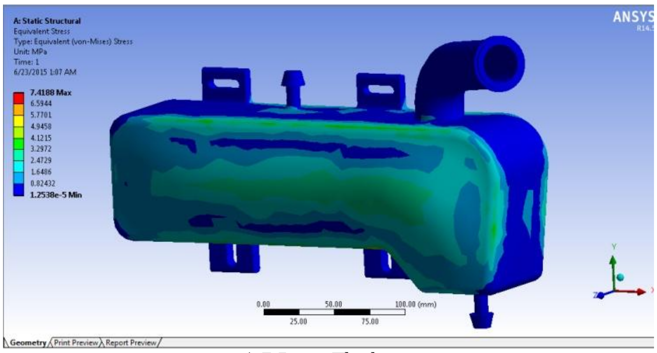
d) 6 mm Thickness



e) 6.5 mm Thickness



f) 7 mm Thickness



g) 7.5 mm Thickness

Fig.3 Stress on different thickness of plastic tank.

V. CONCLUSIONS AND FUTURE SCOPE

A. Conclusions

After the completion of various experimental tests, comparative data of the existing fuel tank and plastic fuel tank have observed following conclusions

i. Reduction in weight: -The weight of the existing fuel tank is 2.5 kg. And the weight of the plastic fuel tank is 0.680 kg. It proved that 80% reduction obtained with weight of the plastic fuel tank. Finite element analysis shows the following results. The tensile stress on the existing fuel tank is 25.45 MPa. Whereas the tensile stresses of the plastic fuel tank is 17.52. MPa.

iii. Finite element analysis shows the following results. The tensile stress of the existing fuel tank bracket is 274.48 MPa. Whereas the tensile stresses of plastic fuel tank bracket is 168.22 MPa. This analysis shows tensile stress is reduced in plastic fuel tank by 106.26MPa.

iv. The existing fuel tank is in square shape. It has two liter fuel storage capacity and it is mounted on vehicle right side long member. Whereas the Plastic fuel tank is in rectangular shape, it has three liter fuel storage capacity i.e. increased by one liter and mounted on the vehicle body in the engine cabin due to this the unused space of the engine cabin came in utilization. It provided enough free space in engine cabin, and it is much more suitable, secure and safety than old one.

v. The existing fuel tank is made of sheet metal it is heavy in weight and at high cost also. The material of the plastic fuel tank is high density polyethylene (HDPE) which is light weighted and reduce the cost of the fuel tank.

It is observed that there is very small difference in analytical and FEM results, i. e. FEM gave virtually similar results as the analytical results. The difference between analytical results and ANSYS results is below 4 % with respect to analytical results. This difference is due to numerical techniques of Finite Element Method in ANSYS. Since analytical results are validated by FEM calculations, the design methodology proposed in this project can be successfully applied in the real-world mechanical applications for minimizing the weight of the fuel tank to assure the best utilization of material.

vi. Analytical results and FEM (ANSYS) results are summarized in Table 2 as shown in below.

Tank thickness in mm	Result	Results Tensile stress f (Mpa)
4.5	Analytical	20.88
	ANSYS	20.46
5.0	Analytical	16.91
	ANSYS	17.98
5.5	Analytical	13.97
	ANSYS	13.98
6.0	Analytical	11.74
	ANSYS	11.51
6.5	Analytical	10.00
	ANSYS	9.72
7.0	Analytical	8.62
	ANSYS	8.45
7.5	Analytical	7.51
	ANSYS	7.38

Table 2. Comparison of Analytical and ANSYS results for 7 different plastic fuel tank thicknesses

B. Future scope

i. Presently the plastic fuel tank is designed by using material high-density polyethylene (HDPE), but it's also possible to design by using material Fiber reinforced plastic (FRP).

ii. In this study analysis the stress on the fuel tank in various directions takes into consideration. However vibrations on fuel tank will have to consider.

iii. In this study linear static analysis is observed to test the plastic fuel tank. However dynamic analysis also required to test use fullness of plastic fuel tank.

iv. Presently secondary fuel tank is designed in plastic material. There is an opportunity to design the primary fuel tank also in plastic material.

VI. ACKNOWLEDGMENT

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