iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 11 **Issue:** XI **Month of publication:** November 2023

DOI: https://doi.org/10.22214/ijraset.2023.56610

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 11 Issue XI Nov 2023- Available at www.ijraset.com

Fabrication and Experimental Investigation of Composite Pressure Vessel

Y. Srinivasa Reddy[1], Dr. K. Rajendra Prasad[2], V. Mukesh Reddy[3]
[1, 3]Asst.Professor, [2]Professor, Dept. of Mechanical Engineering, CMR Engineering College, Hyderabad, India

Abstract: Composite pressure vessels are an important type of high-pressure containers that are widely used in aerospace industries. The pressure vessels develop hoop stresses that are twice the longitudinal stresses. CFRP (Carbon Fiber Reinforced Polymer) composite materials with their higher specific strength and characteristics will result in reduction of weight of the structure when compared with isotropic materials like steel. The present work is aimed in understanding the behaviour of the Composite Pressure Vessel with variation of internal pressure. In this connection, a pressure vessel using CFRP (Carbon Fiber Reinforced Polymer) is fabricated which can hold liquids or gases under pressure and is tested at various pressures. The FEA tool ANSYS 14.5 is used to determine better fiber angle required for liquid storage, when the conventional low carbon steel cylinder is replaced with CFRP Pressure Vessel.
Keywords: Pressure vessel, CFRP (Carbon Fiber reinforced polymer), Ansys 14.5,

I. INTRODUCTION

Starting from the oldest ordinary metals such as copper, cast iron & brass to the recently developed advanced materials like composites and ceramics, engineers have a wide choice for selection of materials required for designing and manufacturing of products for various applications. This has also posed an additional problem of choosing the right material for the right process. Therefore, a wide classification is necessary for simplification and better understanding of the characteristics of the materials.

Materials, based on major characteristics like stiffness, strength, density, and melting temperature can be broadly classified into four main categories as metals, plastics, composites and ceramics.

Each category contains more number of materials with a wide range of properties which results in an overlap of properties with other categories. For example, most common ceramic materials such as silicon carbide (Sic) and alumina (Al_2O_3) have densities in the range of 3.2 to 3.95 g/cc and overlap with the densities of common metals such as iron (7.8 g/cc), copper (6.8 g/cc), and aluminium (2.7 g/cc). The maximum operating temperature in metals does not degrade the material the way it degrades the plastics and composites. Metals generally tend to temper and age at high temperatures, thus altering the microstructure of the metals. Due to such micro structural changes, modulus and strength values generally drop.

II. EXPERIMENTAL SETUP

The first step for manufacturing the pressure vessel is to prepare a mould of considerable length taken on which the fiber is to be pasted and cut according to the required shape. Various moulds and moulding processes are used in the manufacturing of the pressure vessel. A mould for pressure vessel is as shown in Fig-1. The releasing agent and then another layer of gel coat are applied on the mould for better surface finish of the extracted mould.

Fig -1: Cylindrical Mould

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The second step for manufacturing of pressure vessel is to place the stacked Carbon fiber of required dimensions inside the mould and apply the poly epoxide resin with a mixture of 2% of accelerator MEKP (methyl ethyl ketone peroxide) and catalyst as hardener on the Carbon fiber and allow it to get dried up. After that the cylinder is removed from the mould as shown in fig-2

Fig-2 Fabricated glass fiber cylinder

The next step is to prepare two hemi-spherical shapes of carbon fiber with the help of a hemi-sphere pattern and these are attached to either sides of hollow cylinder as shown in Fig-3.

Fig-3: First layer of Pressure vessel

The woven fabric cloth is kept at orientation of 90^0 for better stiffness. Stacking of woven fiber is placed in a proper sequence with proper orientation. A sharp knife is used for cutting fibers in required orientation sequence. The angle of ply is maintained to 90-degrees as shown in the Fig-4.

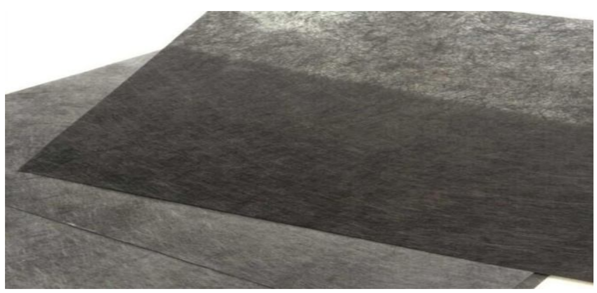

Fig-4: 90^0 orientation of woven fabric cloth on pressure vessel

The poly-epoxide resin and the catalyst are mixed proportionately in a bucket with a mixture of 2% of accelerator MEKP (methyl ethyl ketone peroxide) and catalyst as hardener on the woven fabric cloth. As soon as the resin is applied on the woven fabric cloth, it is fixed on the pressure vessel and finally six layers of woven fabric cloth are laid on the upper layer of the pressure vessel. During the placement of each woven fabric cloth a time gap of 30 minutes is to be maintained for allowing the resin to dry as shown in fig-5

Fig-5: Pressure vessel of 6 layers

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A hole is drilled at one end of the pressure vessel which acts as inlet/outlet. The final coating of the resin with accelerator and catalyst is applied on the upper layer of the pressure vessel. The fabricated pressure vessel is allowed for curing for 18 hours. The final product pressure vessel is shown in Fig-6.

Fig-6: Final fabricated pressure vessel

III. FINITE ELEMENT ANAYSIS USING ANSYS

A. Introduction to FE Analysis

Finite element Analysis is a powerful numerical technique for analysis. FEA is used for stress analysis in the area of solid mechanics. In finite element method, a body or structure is divided into smaller elements called finite elements. The properties of the element are formulated and combined to obtain the solution for the entire body or structure. For a given practical design problem the engineer has to idealize the physical system into a FE model with proper boundary conditions and loads that are acting on the system. Then the discretization of a given body or structure into cells of finite elements is performed and the mathematical model is analyzed for every element and then for complete structure. The various unknown parameters are computed by using known parameters.

B. Steps Involved in ANSYS

1) Preprocessor

All inputs like element selection, real constrain, material properties (young's modulus, poisons ratio, shear modulus) and meshing of the design is given here. And FE analysis is carried out in the solution.

2) General Post Processor

In post processors the results obtain are

- Deformation
- Mechanical Strain (both longitudinal and hoops strain)
- Inter laminate shear stress and shear stress.

3) Designing in ANSYS 14.5

The pressure vessel can be modeled using CATIA software and can be imported into ANSYS or can be modelled directly in ANSYS. Open the Ansys workbench followed by static structural –model –select any one plane, by using center two point arc and lines commands draw the half sketch with required dimensions. The overview of that sketch is as shown below.

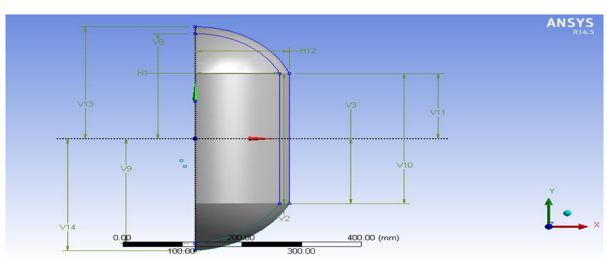

Fig -7: Half design of the pressure vessel

By using symmetry command and with the accurate reference axis the full model of pressure vessel can be obtained.

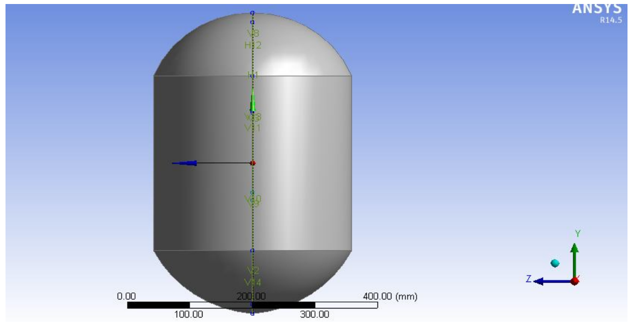

Fig-8: Geometric model of the pressure vessel

4) Meshing and analysis of pressure Vessel

The geometric model of pressure vessel is created in ANSYS 14.5. The element selected for this problem is shell linear layer 99 element. In real constant no. of layers selected for this element type is 12, the thickness of each layer is 1mm and these layers are arranged in balance symmetric laminate process. The orthotropic material properties of the different fiber angles are given in material models. After this the pressure vessel with 12 mm thickness and 620 mm long model is created and this design is meshed. The total no. of elements created after meshing is 3648 elements. After this boundary conditions are applied to the pressure vessel.

5) Boundary Conditions

Open end of the cylinder is fixed in all degrees of freedom and internal pressure applied inside the cylinder is 1.0132 N/mm^2 (10 atm).

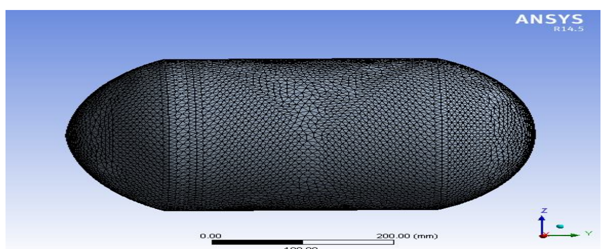

Fig -9: Geometric and meshed model of Pressure Vessel

Meshing is done on the pressure vessel model and a fine mesh generated with an Element size of 3 mm.

C. FE Analysis ON FRP Pressure VESSEL

ANSYS 14.5 has been implemented to solve the present problem considering an internal pressure of 1.0132 N/mm^2 the element selected for performing the analysis is Shell element and the cylinder is made of Carbon fiber and Epoxy resin. The analysis is carried on 12 mm thick cylinder, and the geometric mesh model is shown in figure 9. The simulated results at a pressure of 1.0132 N/mm^2 is shown in figures Strains (both longitudinal and hoop strains).

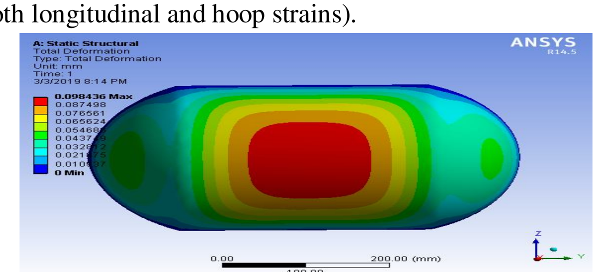

Fig-10: Total Deformation for 90^0 fiber angle

For pressure of 3 Mpa to 8 Mpa is checked and deformation is observed. A deformation of 0.0984 mm is obtained at 6 Mpa for 90º fiber angle

IV. EXPERIMENTAL TESTING OF PRESSURE VESSEL

A. Hydrostatic Testing

Hydrostatic testing is a process of testing for strength and leaks in piping systems, gas cylinders, boilers, and pressure vessels. Hydrostatic testing is done after shutdowns and repairs. The testing is best done using an effective fixed equipment mechanical integrity program. It is considered to be a nondestructive testing method, but the equipment can fail if the inspection exceeds a specified test pressure. Hydrostatic testing is a type of pressure test that works by completely filling the component with water, removing the air contained within the unit, and pressurizing the system up to 1.5 times the design pressure limit the of the unit. The pressure is then held for a specific amount of time to visually inspect the system for leaks. Visual inspection can be enhanced by applying either tracer or fluorescent dyes to the liquid to determine where cracks and leaks are originating.

B. Testing

The pressure vessel is filled with water and attached to hydrostatic equipment through the nozzle of the pressure vessel. The vessel is pressurized slowly to know the burst pressure of the vessel.

Fig-10: Hydrostatic testing of pressure vessel

The pressure is pumped manually in to the vessel. The pressure obtained is around 4.5 Mpa. These pressure vessels with aluminum liner and fibers wounded around the vessel can withstand up to higher pressures up to 70 Mpa and can be used widely for hydrogen storage.

V. RESULTS

From the tabulated results in table-1 & 2 the deformation, von-misses strain and shear strain are compared for every fiber angle (0^0,30^0,45^0,60^0,90^0), It can be observed that 90^0 is the better fiber angle among the all angles.

Orientation sequence of laminate	Young's modulus in x-direction (E_{xx})	Young's modulus in y-direction (E_{yy})	Major poison's ratio (ϑ_{xy})	Minor poison's ratio (ϑ_{yx})	Shear Modulus (G_{xy})
[0]	38.22	8.46	0.1	0.083	5.83
[±30^0]	32.36	9.17	0.1	0.083	6.35
[±45^0]	26.27	16.2	0.1	0.083	7.43
[±60^0]	21.02	17.6	0.1	0.083	8.07
[90^0]	18.5	18.5	0.1	0.083	8.29

Table: 1

Carbon fibers		Epoxy resin with k-6 hardener	
Mechanical properties	Values	Values	Units
Young's modulus	85	4.3	GPa
Tensile strength	350	69	MPa
Density	1.6	1.27	g/cm^3

Table: 2

The ANSYS results are shown below for different fiber angles

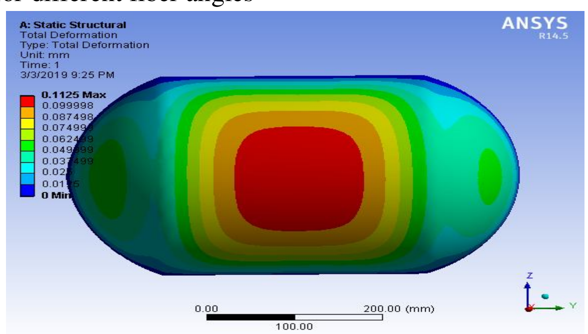

Fig-11: Total Deformation for 0^0 fiber angle

Pressures between 3 Mpa to 8 Mpa are applied and the deformation of 0.1125 mm at a pressure of 6 Mpa is obtained for 0º fibre angle.

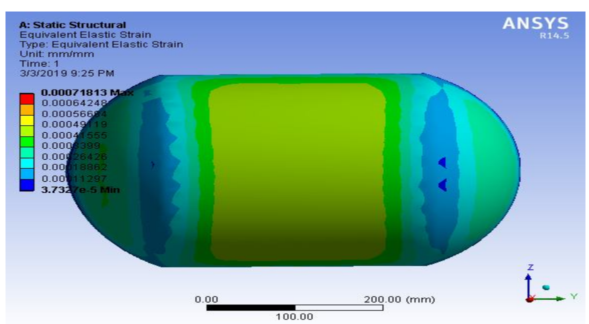

Fig-12: Equivalent Elastic strain for 0^0 fiber angle

A strain of 0.0007 is obtained when 6 Mpa pressure is applied for 0º fiber angle.

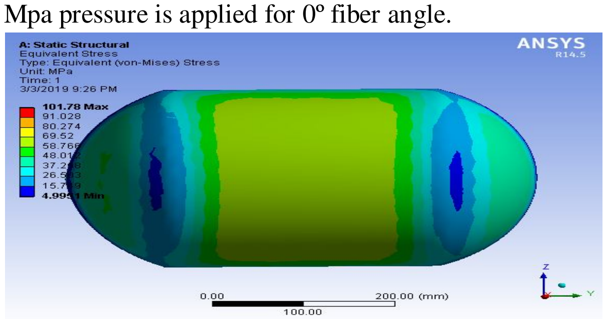

Fig-13: Equivalent (von-misses) stress for 0^0 fiber angle

A Stress of 101Mpa is obtained for 0º fibre angle when 6 Mpa internal pressure is applied

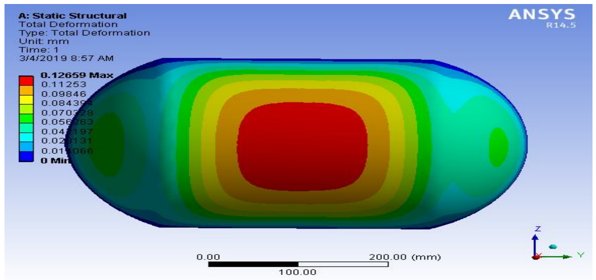

Fig -14: Total Deformation for 30^0 fiber angle

Pressures between 3 Mpa to 8 Mpa are applied and the deformation of 0.1265 mm at a pressure of 6 Mpa is obtained for 30º fibre angle.

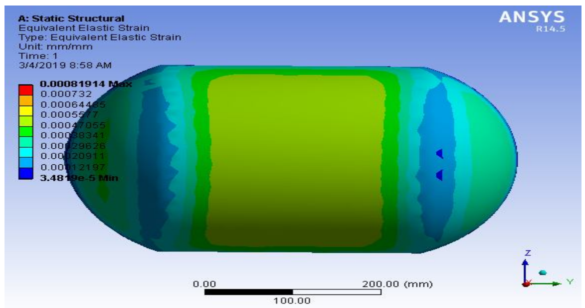

Fig-15: Equivalent Elastic strain for 30^0 fiber angle

A strain of 0.0008 is obtained when 6 Mpa pressure is applied for 30º fibre angle.

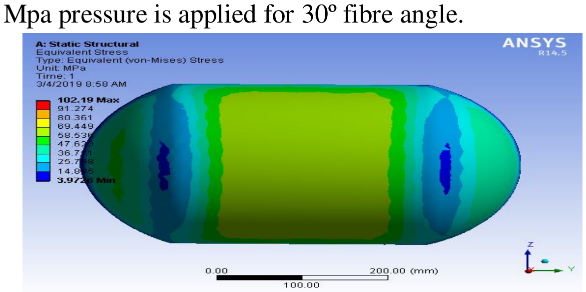

Fig -16: Equivalent (von-misses) strain for 30^0 fiber angle

A Stress of 102 Mpa is obtained for 30º fibre angle when 6 Mpa internal pressure is applied.

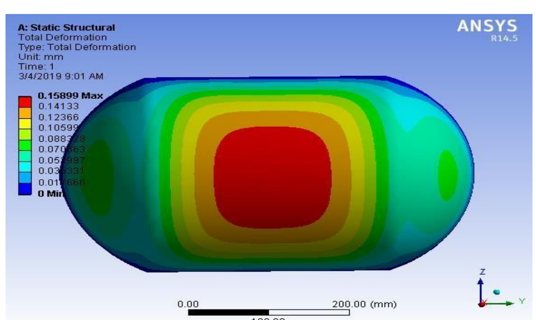

Fig -17: Total Deformation for 45^0 fiber angle

Pressures between 3 Mpa to 8 Mpa are applied and the deformation of 0.1589 mm is obtained at 6 Mpa for 45° fibre angle

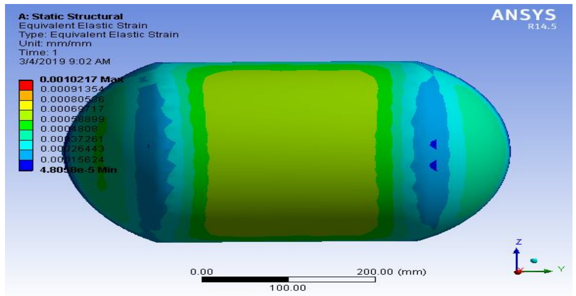

Fig -18: Equivalent Elastic strain for 45^0 fiber angle

A strain of 0.0010 is obtained when 6 Mpa pressure is applied for 45° fibre angle.

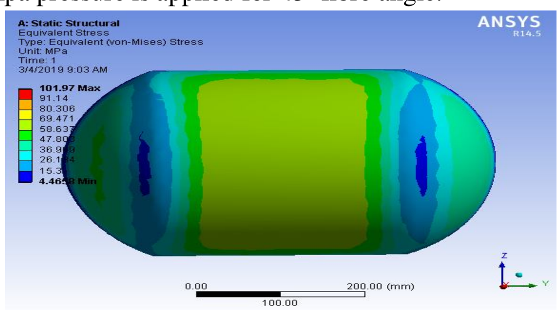

Fig -19: Equivalent (von-mises) for 45^0 fiber angle

A Stress of 101.97 Mpa is obtained for 45° fibre angle when 6Mpa internal pressure is applied.

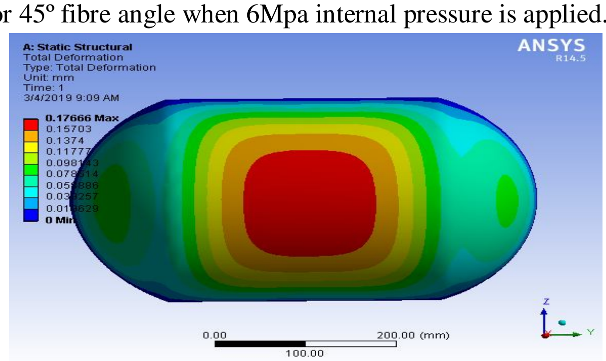

Fig -20: Total Deformation for 60^0 fiber angle

Pressures between 3 Mpa to 8 Mpa are applied and the deformation of 0.1766 mm is obtained at 6 Mpa for 60° fibre angle.

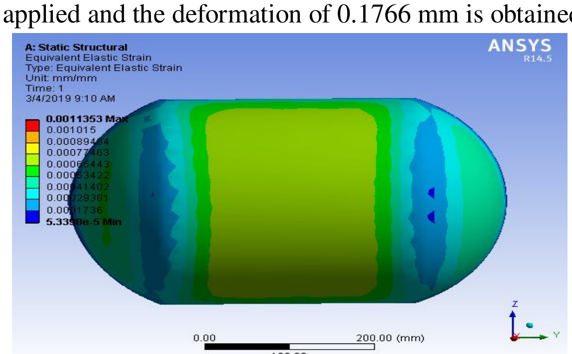

Fig -21: equivalent Elastic strain for 60^0 fiber angle

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A strain of 0.0011 is obtained when 6 Mpa pressure is applied for 60º fibre angle.

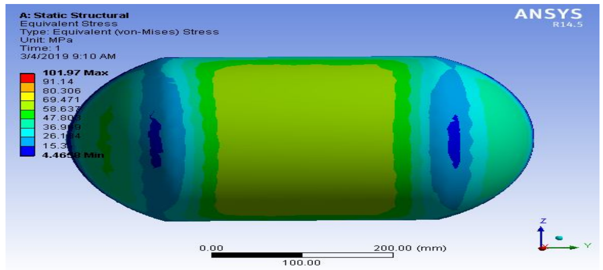

Fig- 22: Equivalent (von-misses) stress for 60^0 fiber angle

A Stress of 102 Mpa is obtained for 60º fibre angle when 6 Mpa internal pressure is applied.

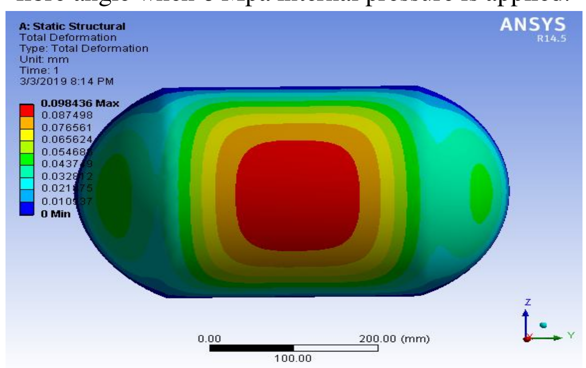

Fig -23: Total Deformation for 90^0 fiber angle

Pressures between 3 Mpa to 8 Mpa are applied and the deformation of 0.0984 mm is obtained at 6 Mpa for 90º fibre angle.

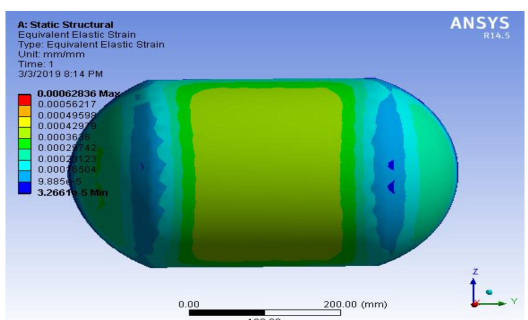

Fig -24: Equivalent Elastic strain for 90^0 fiber angle

A strain of 0.0006 is obtained when 6 Mpa pressure is applied for 90º fibre angle.

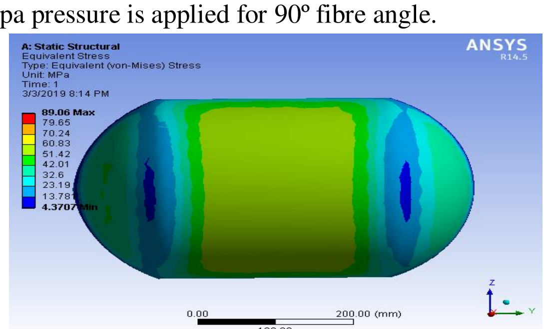

Fig -25: Equivalent (von-mises) stress for 90^0 fiber angle

A Stress of 89 Mpa is obtained for 90º fibre angle when 6 Mpa internal pressure is applied.

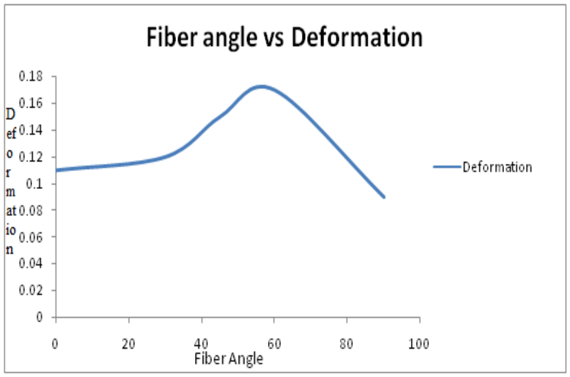

Fig-26: Fiber angle V_s Deformation

From the above results it is clear that the 90^0 fiber angle is the best suited for less deformation. The deformation versus fiber angle graph is plotted as shown below.

X-axis –fiber angles

Y-axis - deformation in mm

A. ANSYS results for KEVLAR material are shown below

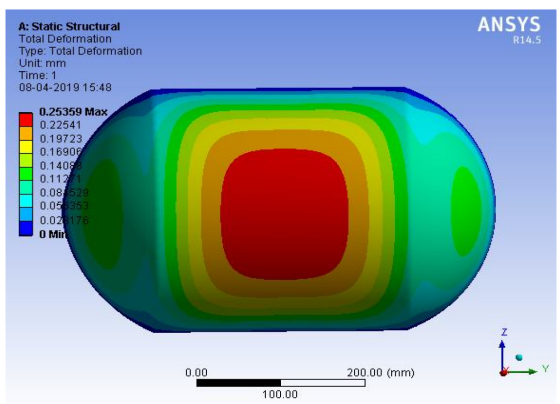

Fig-27: Total Deformation for Kevlar

Pressures between 3 Mpa to 8 Mpa are applied and the deformation of 0.0984 mm is obtained at 6 Mpa for Kevlar material.

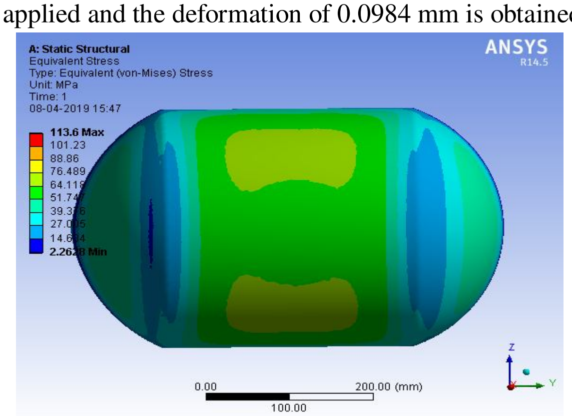

Fig-28: Equivalent stress at 6 Mpa

A Stress of 113 Mpa is obtained for Kevlar Material when 6 Mpa internal pressure is applied.

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Volume 11 Issue XI Nov 2023- Available at www.ijraset.com

B. ANSYS Results for Glass filled Epoxy Material are Shown Below

Glass filled epoxy is a composite material which is made of a polymer matrix reinforced with fibres. The fibres can be glass in fibreglass, carbon in carbon-fiber-reinforced polymer, aramid, or basalt. Also, fibres like paper, wood, or asbestos are also used. The polymer is usually an epoxy, vinylester, or polyester thermosetting plastic, though phenol formaldehyde resins are still in use.

The applications of Glass filled epoxy are in aerospace, automotive, marine and construction industries.

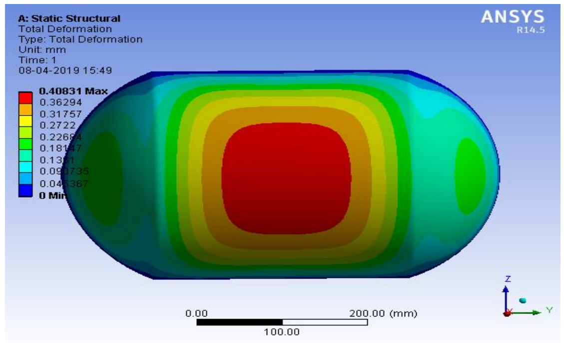

Fig-29: Total deformation at 6mpa for glass filled epoxy

Pressures between 3 Mpa to 8 Mpa are applied and the deformation of 0.408 mm is obtained for Glass Filled Epoxy.

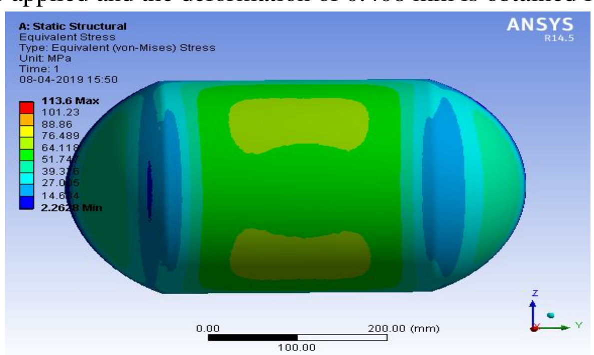

Fig-30: Equivalent stress at 6 Mpa for glass filled epoxy

A Stress of 113 Mpa is obtained for Glass Filled Epoxy Material when 6 Mpa internal pressure is applied.

C. ANSYS Results for CAST IRON-GRADE 20 are Shown Below

The use of iron in day-to-day life began in around 1200 BC. It has a wide range of uses from farming to military weapons. Black smithy is also a profession where, working with iron takes place

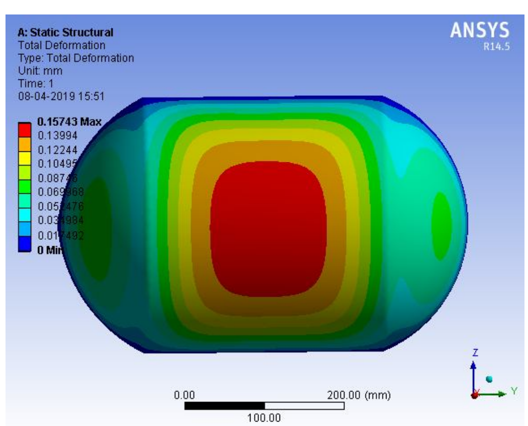

Fig -31: Total deformation of cast iron grade 20 at 6 Mpa

Pressures between 3 Mpa to 8 Mpa are applied and the deformation of 0.408 mm is obtained for the material of Cast Iron Grade 20

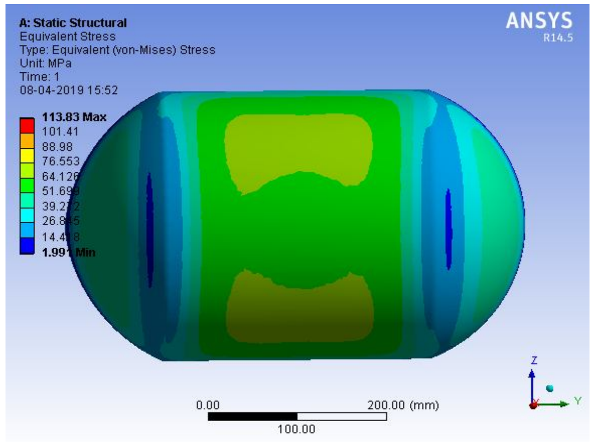

Fig -32: Equivalent stress of cast iron grade 20 at 6 Mpa

A Stress of 113Mpa is obtained for Cast iron Material when 6Mpa internal pressure is applied.
After the simulation the total deformation of the pressure vessel of different materials is compared with the carbon reinforced polymer. The graph is plotted between deformations at 6 Mpa for different materials as shown below.

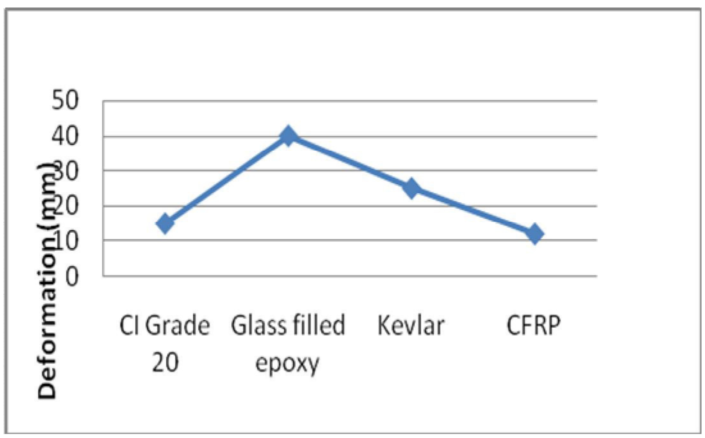

Fig-33 Different materials V_s Deformation

X-axis –different materials
Y-axis-deformation in mm
From the above graph it is clear that the material with lowest deformation is carbon fiber reinforced polymer. The color curve indicates the deformation.

VI. CONCLUSIONS

1) It can be observed from the simulation values that the deformation is minimum for CFRP as compared with Kevlar, Glass filled epoxy and Cast Iron grade 20 because of high strength (785 KN-m/kg) of CFRP.
2) It is found that the 90^0 degree fibre angle is best suited for minimum deformation.
3) The composite pressure vessel which is fabricated is tested using hydrostatic testing is and is found that it can withstand pressure up to 4.5 Mpa. While design pressure deformation starts from 3.2 Mpa.
4) When compared with conventional materials like mild steel, the weight of composite materials will be 20-30% lesser.
5) The pressure vessel with aluminum liners and filament wound procedures can withstand pressure about 70 Mpa and can be used for hydrogen storage.

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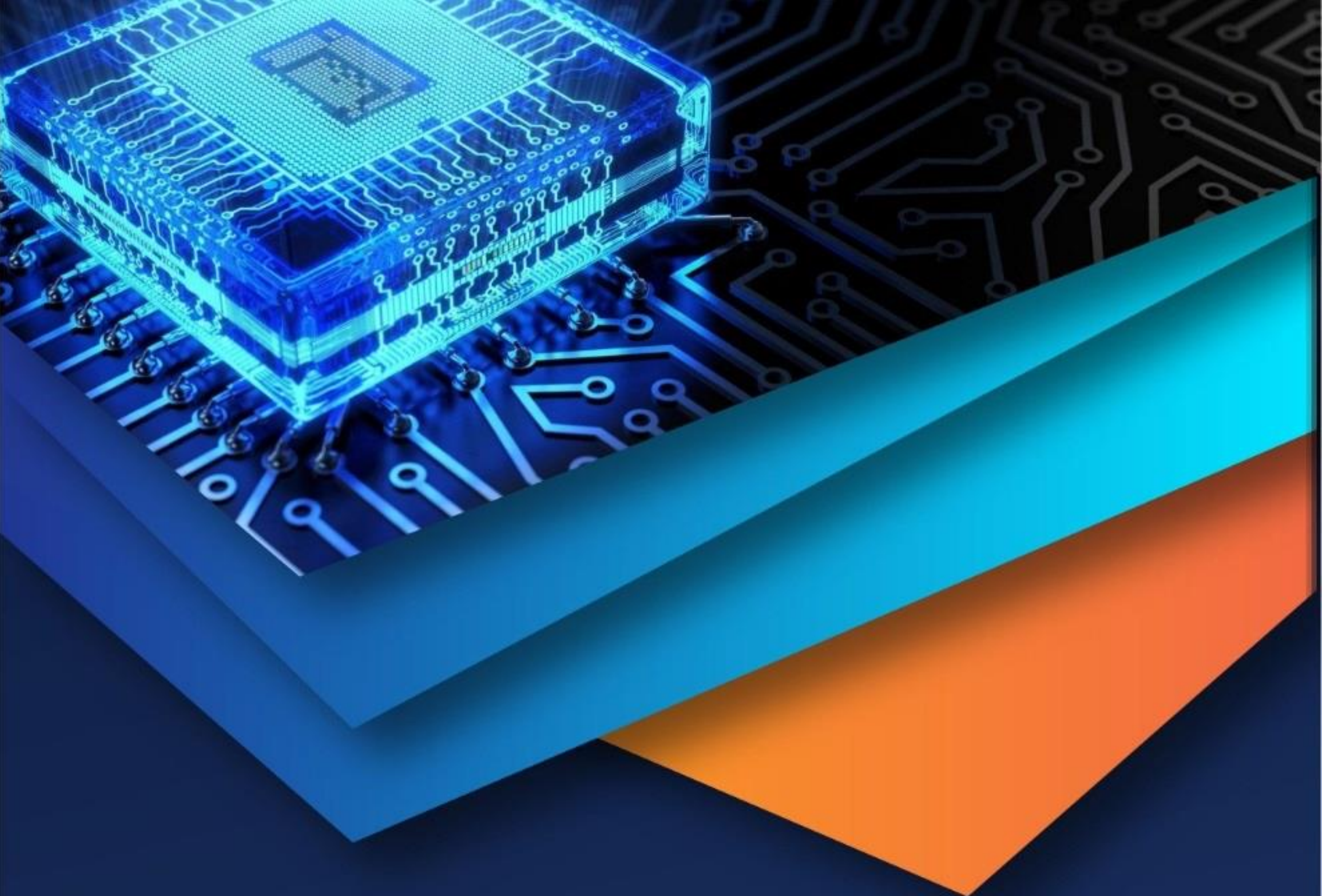

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