DESIGN AND ANALYSIS OF COMPOSITE CYLINDER

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Abstract - *Filament-wound composite pressure vessels are an important type of high-pressure container that is widely used in the commercial and aerospace industries. The metallic pressure vessels are having more strength but due to their high weight to strength ratio and corrosive properties they are least preferred in aerospace as well as oil and gas industries. These industries are in need of pressure vessels which will have low weight to strength ratio without affecting the strength. On the other hand FRP composite materials with their higher specific strength and moduli and tailoribility characteristics will result in reduction of weight of the structure.*

In this dissertation work ANSYS software is used to carry out the structural analysis of steel and FRP composite pressure vessels. For studying the effect of winding angle, pressure and thickness of the FRP composite pressure vessel analytical calculation will be more time consuming and less accurate. So the analytical results are calculated for steel pressure vessel and compared wit Ansys results.

For the same geometrical parameters of the steel pressure vessel the stress state of FRP composite pressure vessel is calculated under different internal pressures by Ansys and experimentally. So for different pressure values ansys results of steel and composite pressure vessel are compared. To have optimized FRP composite pressure vessel some of the composite parameters like no. of ply and angle of ply is taken as per available reference. The solution is presented and discussed for various orientation angles. Test specimens have four layers, which have various orientation angles. The layers are oriented symmetrically for $[45^o/ 45^o]_s$ $[55^o/-55^o]_s$ $[65^o/-65^o]_s$ $[75^o/-75^o]_s$ *and* $[88^o/-88^o]_s$ *orientations. From the FE results it is observed that the optimum winding angle for the composite pressure vessel analysis with the internal pressure loading case is obtained as* 65^0*. A finite element method and experimental approaches are studied to verify optimum winding angles and internal pressures. Finally weight and structural efficiency of composite pressure vessel is compared with steel pressure vessel.*

Key Words: *Introduction, Analysis,Results, and Conclusion*

1. Introduction

A pressure vessel is a closed container designed to hold gases or liquids at a pressure substantially different from the ambient pressure. In industry pressure vessels used as leak-tight pressure containers, usually they are in cylindrical or spherical shape, with different head configurations. Usually these are made from carbon or stainless steel and assembled in welding. In practice, vessels are usually composed of a complete pressure-containing shell together with flange rings and fastening devices for connecting and securing mating parts. As the name implies, their main purpose is to contain a media under pressure and temperature; however, in doing so they are subjected to the action of steady and dynamic support loadings, piping reactions, and thermal shocks which require an overall knowledge of the stresses imposed by these conditions on various vessel shapes and appropriate design means to ensure safe and long life.

The design of pressure vessel includes the calculation of the detail dimensioning of a member, and also all inclusion terms incorporating: (1) the method of stress analysis employed and significance of results, and (2) the selection of material type and its environmental behavior. (3) The reasoning that established the most likely mode of damage or failure.

1.1 Development of Composite Pressure Vessels

The metallic pressure vessels are having more strength but due to their high weight to strength ratio and corrosive properties they are least preferred in aerospace as well as oil and gas industries

Composites consist of two or more materials and, macroscopically, according to the combination and array of materials these materials have an anisotropic mechanical characteristic. In particular, a composite material is composed of the fiber that receives the primary load and the matrix that plays a role of the load's transmission and maintains the shape. Composite material has higher stiffness and specific strength than conventional materials such as plastic and metal. Because of this reason , it has got high structural efficiency. Therefore they are applied in several design structures.

In the filament winding process, which is a popular technique for producing generally axisymmetric composite structures, a fiber bundle is placed on a rotating and removable mandrel. Examples of axisymmetric filament wound structures under internal pressure include fuel tanks, oxidizer tanks, motor cases and pipes [10].

Filament-wound composite pressure vessels utilizing high strength and high modulus to density ratio materials offer significant weight savings over conventional all-metal pressure vessels for the containment of high pressure gases and fluids. The structural efficiency of pressure vessels is defined as:

e=PV/W

Where: P = pressure

V = Contained volume

W = Vessel weight

The structural efficiencies of all-metal pressure vessels range from 7.6×10^6 to 15.2×10^6 mm, while filament wound composite vessels have efficiencies in the range from 20.3×10^6 to 30.5×10^6 mm for the structural efficiencies of composite pressure vessels of similar volume and pressure.

1.2 Structure of Composite Pressure Vessel

Cylindrical composite pressure vessels constitute a metallic internal liner and a filament wound and a composite outer shell as shown in Fig.1. The metal liner is necessary to prevent leaking, while some of the metal liners also provide strength to share internal pressure load. For composite pressure vessels, most of the applied load is carried by the strong outer layers made from filament wound composite material.

Fig.1 Example of filament wound composite pressure vessels

1. Ultra thin-walled aluminium liner
2. Protexal smooth, inert, corrosion resistant internal finish
3. Insulating layer
4. High - performance carbon - fiber overwrap in epoxy resin matrix
5. High - strength fibreglass-reinforced plastic (FRP) protective layer with smooth gel coat
6. Precision – machined thread.

1.3 Composite Materials

A composite material is made by combining two or more materials to give a unique combination of properties. The above definition is more general and can include metals alloys, plastic co-polymers, minerals, and wood. Fiber-reinforced composite materials differ from the above materials in that the constituent materials are different at the molecular level and are mechanically separable. In bulk form, the constituent materials work together but remain in their original forms. The final properties of composite materials are better than constituent material properties.

The main concept of a composite is that it contains matrix materials. Typically, composite material is formed by reinforcing fibers in a matrix resin as shown in Fig below. The reinforcements can be fibers, particulates, or whiskers, and the matrix materials can be metals, plastics, or ceramics.

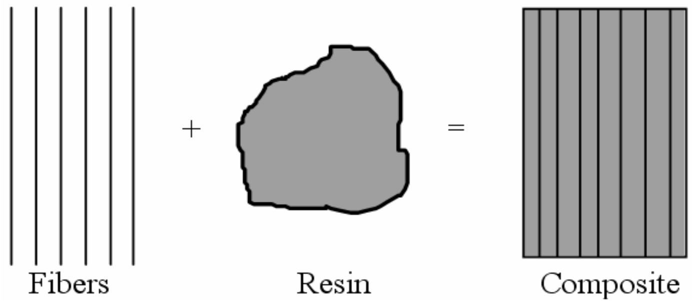

Fig.2 Formation of a composite material using fibers and resin

The reinforcements can be made from polymers, ceramics, and metals. The fibers can be continuous, long, or short. Composites made with a polymer matrix have become more common and are widely used in various industries.

2.Modeling and Analysis

2.1 Modeling

The cylindrical pressure vessel model is modeled using solidworks modeling software. Here we are using the basic drawing commands like point, line, rectangle, circle, extrude, cylinder etc to build the model in solidworks software as shown in figure

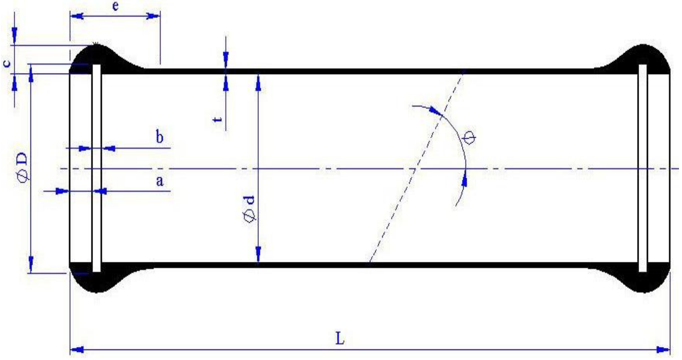

Fig.4 2-D model of the cylinder

The dimensions of the 2-D model are as follows.

L = 400 mm D = 110 mm

a = 20 mm b = 6 mm

c = 15 mm d = 100 mm

e = 60 mm t = 1.6 mm

φ= winding angle

By using the dimensions of the 2-D model we created 3-D model of the cylinder. At first we created full 3-D model of the cylinder then modified that into one fourth model as shown in fig.3

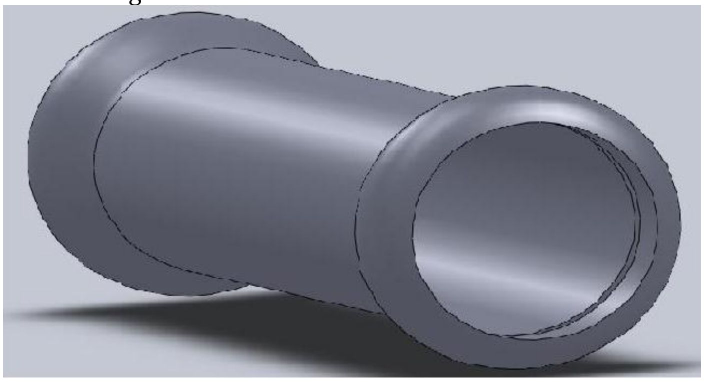

Fig.3 Full 3-D model of the cylinder

2.2 Analysis

Finite element study was conducted by simulating the conditions of the tests. The established finite element software ANSYS 11.0 was used in the simulations. A 3-D CAD model was imported and suitable material properties were assigned to the model.

We carried out the static–linear analysis for pressure vessel with steel material. We used only one fourth models to reduce the time for analysis. Fig.5 shows preprocessor modeling geometry of the steel cylinder.

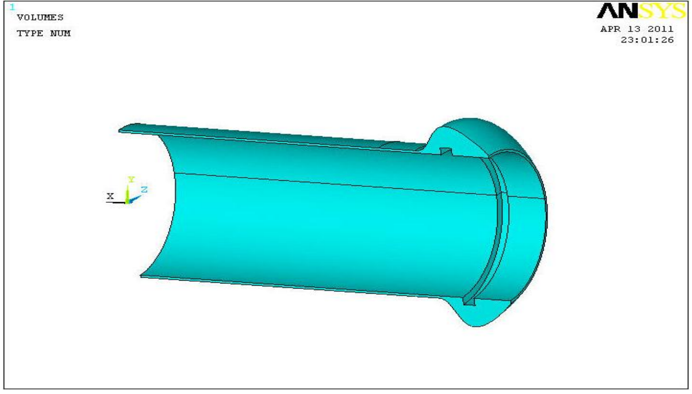

Fig.5 Modeling geometry of the steel cylinder

Then a volume block was modeled and material properties, real constant sets and element type were appointed to the volume. After that the model was meshed by using hexahedral sweeped elements Fig.6

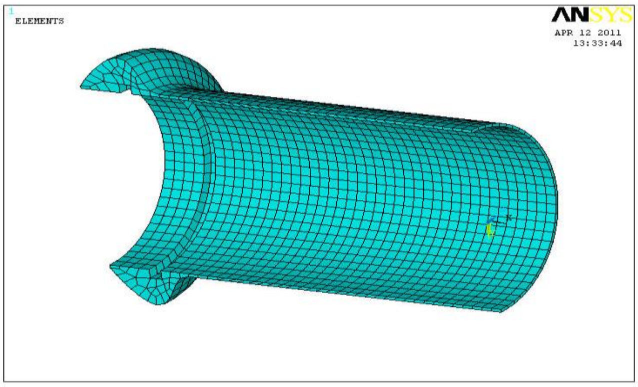

Fig.6 Meshed model of composite cylinder

The similar boundary conditions were applied to composite material as to compare with steel material. So boundary conditions were defined to corresponding to each side surfaces by using Loads- pressure on areas functions.

Constraints:

1. Both ends are fixed in all degrees of freedom.
2. Symmetric Boundary conditions as one fourth model symmetry is considered for analysis to reduce model size.

Then analysis was run and the solutions were observed with plot results, nodal solutions. After the solution has been obtained, there are many ways to present ANSYS' results, choose from many options such as tables, graphs, and contour plots.

2.3 Results

In post processing section of the ANSYS the results of stress analysis are reviewed. The different results obtained by using ANSYS are as follows.

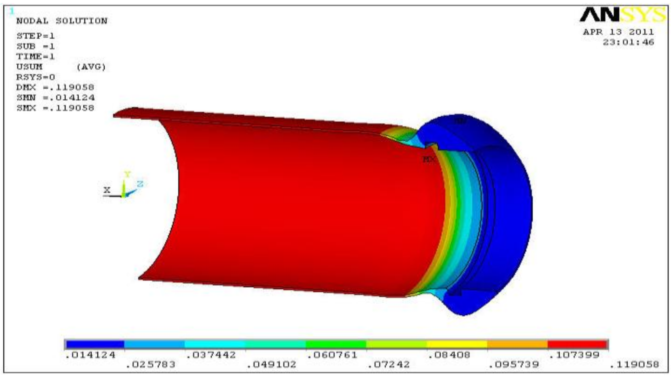

Fig.7 Von-Mises Stress Plot for steel pressure vessel

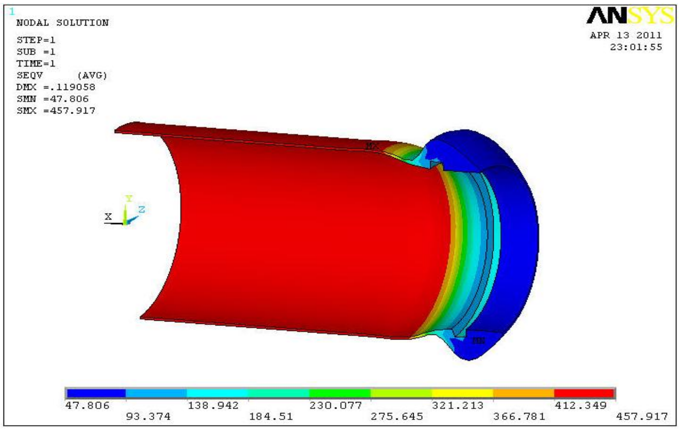

Fig.8 Deformation plot for steel pressure vessel

The above fig .8 shows the maximum stress result for steel pressure vessel with internal pressure 15 Mpa and same analysis was carried out for 25 Mpa. Table shows the comparision between analytical and Ansys results for steel presssure vessel.

Pressure(Mpa)	Analytical(Max stress in Mpa)	Ansys(Max stress in Mpa)	Remarks
15	468.75	457.91	2.31%
25	78525	769.40	2.15%

3. CONCLUSIONS

In this study the theoretical results and FE model of a steel pressure vessel are established. FE model of a steel and filament wound FRP pressure vessel is established using ANSYS 11 software. Experimental investigations of composite pressure vessels are presented in chapter 7. It is significant to integrate the composite material and composite failure into a FE analysis geared towards the design of composite pressure vessels. In this study analytical results are compared with Ansys results of steel material. FEA analysis on one E-glass-epoxy composite pressure vessel is carried out. Discussed results in terms of stresses and displacement through the thickness, fibre angle, and internal pressure are discussed. Ansys results of steel and composite pressure vessel are compared for different internal pressures. This result shows composites having more strength than steel depending upon design criteria. The analysis shows that the behavior of this solution strongly depends on the stacking sequences of the composite. The optimum winding angle for the composite pressure vessel analysis with the internal pressure loading case is obtained 65° for laminates. Finally, the different results optimized with the 65° winding angle, thickness of 1.6mm and internal pressure is 25Mpa for maximum hoop stress. The experimental results are observed for composite pressure vessel. In which tests are conducted for different internal pressure and fibre winding angles to find hoop stress in pressure vessel. By comparing analysis and experimental results, there is small percentage of difference in results and it is acceptable. Comparison of the weights shows that composite pressure vessel have 75% less weight than steel pressure vessel. The structural efficiency of the composite pressure vessel is 76 % more than steel pressure vessel.

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BIOGRAPHIES

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