International Research Journal of Emerging Trends in Multidisciplinary
ISSN 2395-4434
Volume 1, Issue 3 May 2015
www.irjetm.com

DESIGN AND ANALYSIS OF COMPOSITE PRESSURE VESSEL BY USING FINITE ELEMENT ANALYSIS

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ABSTRACT

Presently due to the growth of technology its benefits are at optimum level. This situation favors for attempting new ideas in engineering. Our project aims at developing a pressure vessel which is used for aerospace applications. Nowadays the aerospace pressure vessels are made by steel. Generally in the aerospace components must be lighter weight without giving up the safety criteria. For overcoming this barrier finding the alternative material that must be lighter weight and higher strength is essential.In this study, optimal angle-ply orientations of symmetric and antisymmetric shells designed for maximum burst pressure were examined. Burst pressure of filament wound composite pressure vessels under alternating pure internal pressure was investigated. The solution was presented and discussed for various orientation angles. The specimen had ten layers which had various orientation angles. The layers were oriented symmetrically and antisymmetrically for, [45°/-45°/90°/45°] orientations. The finite element solution was obtained using commercial software ANSYS 11.0.

Keywords: composite pressure vessel; burst pressure;finite element method

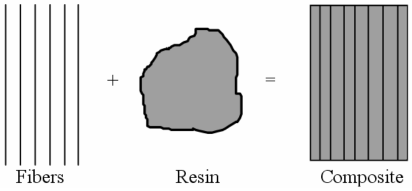
1.INTRODUCTION

Composite materials (or composites for short) are engineered materials made from two or more constituent materials with significantly different physical or chemical properties and which remain separate and distinct on a macroscopic level within the finished structure. Fiber reinforced composite materials can be divided into two main categories normally referred to as short fiber reinforced materials and continuous fiber reinforced materials. Continuous reinforced materials will often constitute a layered or laminated structure. The short and long fibers are typically employed in compression molding and sheet molding operations. These come in the form of flakes, chips, and random mate (which can also be made from a continuous fiber laid in random fashion until the desired thickness of the ply / laminate is achieved). Composites can fail on the microscopic or macroscopic scale. Compression failures can occur at both the macro scale or at each individual reinforcing fiber in compression buckling. Tension failures can be net section failures of the part or degradation of the composite at a microscopic scale where one or more of the layers in the composite fail in tension of the matrix or failure the bond between the matrix and fibers . Some composites are brittle and have little reserve strength beyond the initial onset of failure while others may have large deformations and have reserve energy absorbing capacity past the onset of damage. The best known failure occurred when the carbon-fiber wing of the Space Shuttle Columbia fractured when impacted during take-off. It led to catastrophic break-up of the vehicle when it re-entered the earth's atmosphere on February 1, 2003.The structural efficiency of pressure vessels is defined as:

$$e = \frac{P_b V}{W}$$

Where:

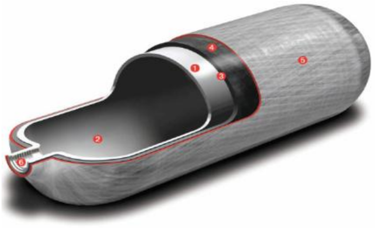
P_b = Burst pressure
V = Contained volume
W = Vessel weight



Formation of a composite material using fibers and resin.

Pressure vessels: Pressure vessels have long been manufactured by filament winding. Although they appear to be simple structures, pressure vessels are among the most difficult to design. Filament wound composite pressure vessels have found widespread use not only for military use but also for civilian applications.

Structure of Composite Pressure Vessels: Cylindrical composite pressure vessels constitute a metallic internal liner and a filament wound and a composite outer shell as shown in Fig.. The metal liner is necessary to prevent leaking, while some of the metal liners also provide strength to share internal pressure load.



Example of filament wound composite pressure vessels

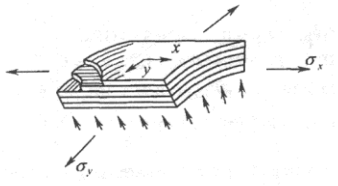
2. LITERATURE REVIEW

It was found that most of design and analysis of composite pressure vessels are based on thin-walled vessels. the vessel should be considered thick-walled. Only a few researchers have considered the effect of wall thickness.

The solution of composite cylinders is based on the *Lekhnitskii's theory* (1981). He investigated the plane strain case or the generalized plane strain cases. *Roy and Tsai* (1988) proposed a simple and efficient design method for thick composite cylinders; the stress analysis is based on 3-dimensional elasticity by considering the cylinder in the state of generalized plane strain for both open-end (pipes) and closed- end (pressure vessel). *Sayman* (2005) studied analysis of multi-layered composite cylinders under hygrothermal loading. *Mackerle* (2002) gives a bibliographical review of finite element methods applied for the analysis of pressure vessel structures and piping from the theoretical as well as practical points of view. *Rao and Sinha* (2004) studied the effects of temperature and moisture on the free vibration and transient response of multidirectional composites. A three-dimensional finite element analysis is developed for the solution. *Parnas and Katırcı* (2002) discussed the design of fiber-reinforced composite pressure vessels under various loading conditions based on a linear elasticity solution of the thick-walled multilayered filament wound cylindrical shell. *Roy et al.* (1992) studied the design of thick multi-layered composite spherical pressure vessels based on a 3-D linear elastic solution.

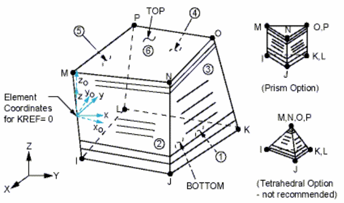
3.MODELLING OF THE PRESSURE VESSEL

In this study, maximum failure pressure value was found by finite element analysis using ANSYS. In order to model the problem, a small element was taken from on the pressure vessel which is shown in Figure:



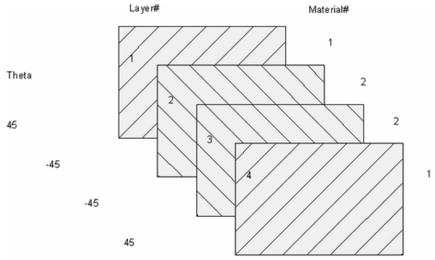
An element of composite pressure vessel

First element type was defined with solid layered 46 in Figure 3.2. Solid46 is a layered version of the 8-node structural solid element designed to model layered thick shells or solids. The element allows up to 250 different material layers.



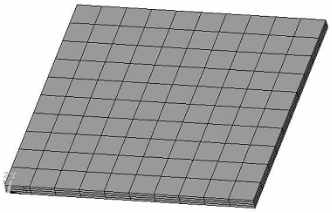
SOLID46 geometry

Real constant sets were defined for 4 layers, various orientation angles and each layer thickness was entered 0.4 mm



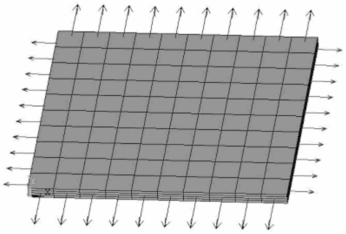
Sample lay plot display for [45/-45/-45/45] sequence.

Then a volume block was modeled and material properties, real constant sets and element type were appointed to the volume.



Finite element mesh.

Boundary conditions were defined to corresponding to each side surfaces by using loads pressure on areas functions as shown in Figure:



Finite element boundary conditions

Then analysis was run and the solutions were observed with plot results- nodal solutions- failure criteria- Tsai-Wu strength index.Then this pressure values was substituted as a stresses to calculate burst pressure of the composite pressure vessel.

4. FINITE ELEMENT ANALYSIS

The basic idea in the finite element method is to find the solution of a complicated problem by replacing it by a simpler one. Since the actual problem is replaced by a simpler one in finding the solution. From this, we can able to find only an approximate solution rather than the exact solution. The existing mathematical tools will not be sufficient to find the exact solution (and sometimes, even an approximate solution) of most of the practical problems. Thus in the absence of any other convenient method to find even the approximate solution of a given problem, we have to prefer the finite element method.

The following steps show in general how the finite element method works.

Discrete The Given Continuum: The importance of the finite element method is to divide a continuum that is problem domain, into quasi-disjoint, non-overlapping elements. This is achieved by replacing the continuum by the set of key points; called nodes when connected properly, produce the elements. The collection of nodes and elements form the finite element mesh.

Select The Solution Approximation: The variation of the unknown (called field variable) in the problem is approximated within each element by a polynomial. The field variable may be a scalar (e.g. temperature) or a vector (e.g., horizontal and vertical displacements). Polynomials are usually used to approximate the solution over an element domain because they are easy to integrate and differentiate.

Develop Element Matrices And Equations: The finite element formulation involves transformation of the governing equilibrium equations form the continuum domain to the element domain. Once the nodes and material properties of a given element it's be derived. Four methods are used to derive element matrices and equations; the direct method, the variation method, the weighted residual method, and the energy method.

Assembling The Element Equations: The individual element matrices are added together by summing equilibrium the equations of the elements to obtain the global matrices and systems to algebraic equations. Before solving this system, it must be modified by applying the boundary conditions. It boundary conditions are nor applied, wrong results are obtained or a singular system of equations may result.

Solve For The Unknown At The Nodes: The global system of algebraic equations is solved via Gauss elimination methods to prove the values of the field variables at the nodes of the finite element mesh. Values of field variables at their derivatives at the nodes from the complete finite element solution of the original continuum other than nodes are possible to obtain although it is not usually done.

Interpret The Result: The final step is to analyze the solution and the results obtained from the previous stop to make design decisions. The correct interpretation of these results requires a sound background in both engineering and FEA.

5. DESIGN OF PRESSURE VESSEL

The pressure vessel has to be designed as per the design requirements; since it obeys axis symmetric conditions it can be designed by assuming 2-d axisymmetric continuum method using Ansys software

Steel pressure vessel				
1	Pressure vessel outside diameter.	d_{out}	mm	112.9
2	Pressure vessel inside diameter.	d_{int}	mm	102.9
3	Pressure vessel thickness	THK	mm	10

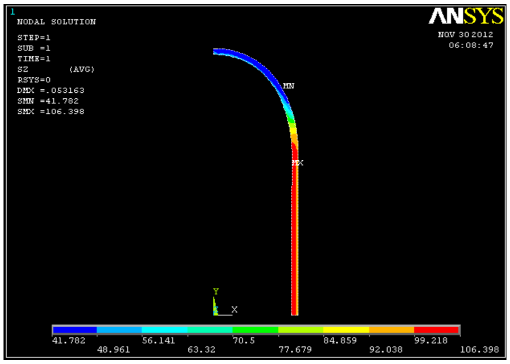
Design specifications of steel pressure vessels

6. ANALYSIS OF PRESSURE VESSEL USING M.S STEEL

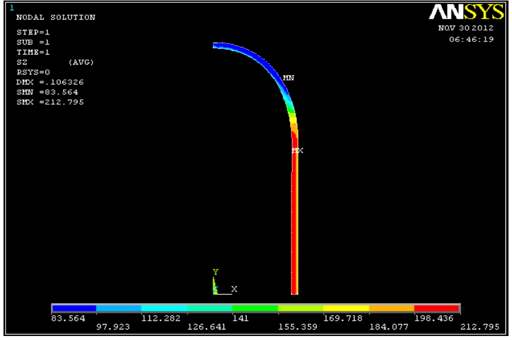
This project is mainly carried out with the intention of selecting the best material for the pressure vessel used in rocket engines and space applications with the available standard dimensions. It is modeled using Ansys software package. The analysis is also carried out by Ansys software using the structural analysis method. The hoop stresses [Z component stress] are found for various loads on the pressure vessel. The pressure vessel material taken for analysis is M.S steel and composite material such as glass epoxy fiber reinforced plastic.

Ansys plots for structural comparison of stress:

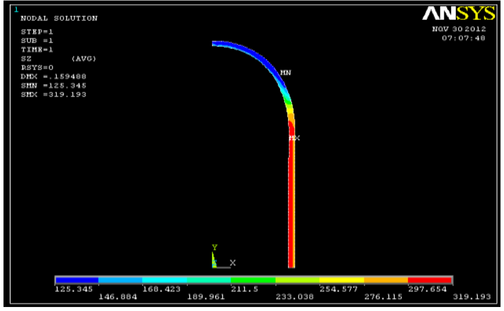
FOR STEEL at 10Mpa



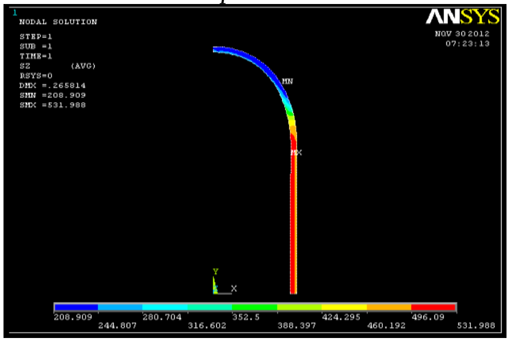
FOR STEEL at 20Mpa



FOR STEEL at 30Mpa



FOR STEEL at 50Mpa



Tabulation of FEA results for steel:

SL.NO	Applied pressure in Mpa	Hoop stress[maximum]	Hoop stress[minimum]
1	10	106.39	41.782
2	20	212.795	83.56
3	30	319.19	125.34
4	50	531.98	208.30

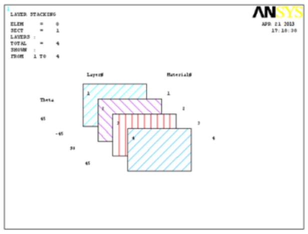
7. ANALYSIS OF PRESSURE VESSEL USING COMPOSITE MATERIALS

Glass epoxy FRP material is selected as pressure vessel material for analysis. Fiber glass is a material made from extremely fine fibers of glass. The material behavior is observed using conventional testing machine.

Design secifications:

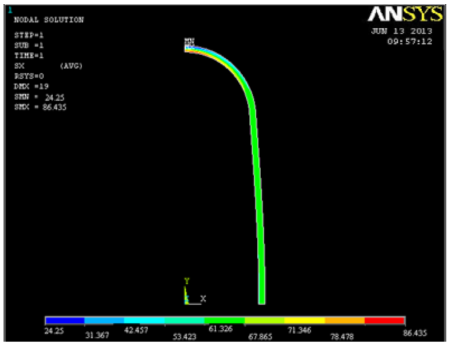
Glass epoxy composite pressure vessel				
1	Pressure vessel outside diameter.	d_{out}	mm	112.9
2	Pressure vessel inside diameter.	d_{int}	mm	102.9
3	Pressure vessel thickness	THK	mm	10

Lay plot arrangement : The layers formed using those orientation angles are shown as following

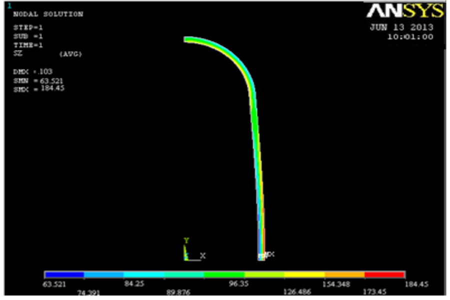


Ansys plots for structural comparison of stress:

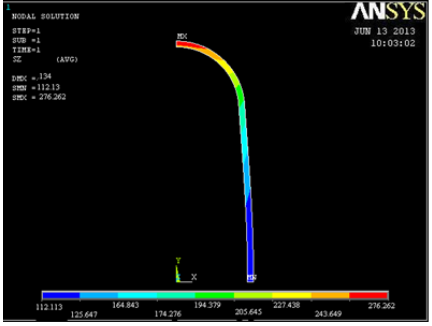
FOR GLASS EPOXY at 10Mpa



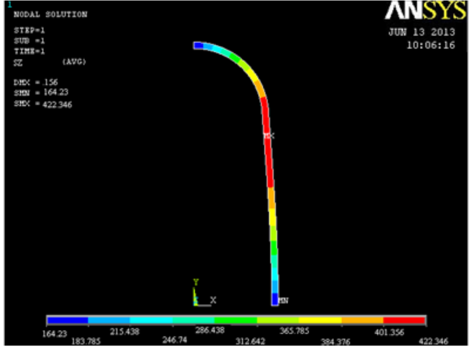
FOR GLASS EPOXY at 20Mpa



FOR GLASS EPOXY at 30Mpa



FOR GLASS EPOXY at 50Mpa



Tabulation of FEA results for glass epoxy

SL.NO	Applied pressure in Mpa	Hoop stress[maximum]	Hoop stress[minimum]
1	10	86.435	24.25
2	20	184.456	63.521
3	30	276.262	112.13
4	50	422.346	164.23

8. CONCLUSION

An existing design of steel was modeled and analyzed for available boundary conditions The pressure vessel was analyzed for newly proposed composite materials such as glass epoxy fiber reinforced plastics.The maximum hoop stress developed in the model for the conventional materials, namely for steel is 212.95 N/mm^2 for an applied pressure of 20 Mpa , Whereas in the proposed new model designed by using Glass epoxy fiber reinforced plastic material, The maximum hoop stress developed is 184.456 N/mm^2 , for the same value of applied pressure . This was much lower when compared to steel.

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