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Optimization of Composite Pressure Vessel

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Abstract: ***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 study deals with the winding angle on filament wound composite pressure vessels. Finite element method was employed to verify the optimum winding angles. The solution was presented and discussed for various orientation angles. Glass reinforced plastic (GRP) was manufactured by E-glass-epoxy fiber. 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: Glass reinforced plastic (GRP), Epoxy, Angle ply orientation**.**

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.

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).

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.

Composite laminates have been used increasingly in a variety of industrial areas due to their high stiffness and strength-to-weight ratios, long fatigue life, resistance to electrochemical corrosion, and other superior material properties of composites. A true understanding of their structural behavior is required, such as the deflections, buckling loads and modal characteristics, the through-thickness distributions of stresses and strains, the large deflection behavior and, of extreme importance for obtaining strong, reliable multi-layered structures, the failure characteristics. Finite element method is especially versatile and efficient for the analysis of complex structural **behavior** of the composite laminated structures. Using finite element method, a significant amount of research has been devoted to the analysis of vibration and dynamics, buckling and post buckling, failure and damage analysis.

2. Literature Review

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 hygro thermal 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. Xiaetal .(2001) studied multi-layered filament-wound composite pipes under internal pressure. Xiaetal (2001) presented an exact solution for multi-layered filament-wound composite pipes with resin core under pure bending. Rao and Sinha (2004) studied the effects of temperature and moisture on the free vibration and transient response of multi directional composites. A three-dimensional finite element analysis is developed for the solution. Parnas and Katırcı (2002) discussed the design of fibre-reinforced composite pressure vessels under various loading conditions based on a linear elasticity solution of the thick-walled multi layered filament wound cylindrical shell. A cylindrical shell having number of sub layers, each of which is cylindrically orthotropic, is treated as in the state of plane strain.

Royetal.(1992)studiedthe design of thick multi-layered composite spherical pressure vessels based on a 3-D linear elastic solution. They found that the Tsai-Wu failure criterion is suitable for strength analysis. One of the important discoveries of Roy's research is that hybrid spheres made from two materials presented an opportunity to increase the burst pressure.

Adalietal.(1995)gave another method on the optimization of multi-layered composite pressure vessels using an exact elasticity solution. A three dimensional theory for an isotropic thick composite cylinders subjected to axis symmetrical loading conditions was derived. The three dimensional interactive Tsai-Wu failure criterion was employed to predict the maximum burst pressure. The optimization of pressure vessels show that the stacking sequence can be employed effectively to maximum burst pressure. However Adali's results were not compared with experimental testing and the stiffness degradation was not considered during analysis. The effect of surface cracks on strength has been investigated theoretically and experimentally for glass/epoxy filament wound pipes, by Tarakçioğluetal.(2000). They were investigated theoretically and experimentally the effect of surface cracks on strength in glass/epoxy filament wound pipes which were exposed to open ended internal pressure.

Mirza etal.(2001) investigated the composite vessels under concentrated moments applied at discrete compositions by finite element method. Jacquemin and Vautrin(2002) examined and the moisture content and stress fields for evaluating the durability of thick composite pipes submitted to cyclic environmental condition. Sunetal.(1999) calculated the stresses and bursting pressure of filament wound solid-rocket motor cases which are a kind of composite pressure vessel; maximum stress failure criteria and stiffness-degradation model were introduced to the failure analysis. Hwangetal.(2003) manufactured composite pressure vessels made by continuous winding of fibrous tapes reinforced in longitudinal and transverse directions and proposed for commercial applications instead of traditional vessels. Sonnenetal.(2004) studied computerized calculation of composite laminates and structures.

From the literature reveals that, Most of the finite element analyses of composite pressure vessels are based on elastic constitutive relations and traditional thin-walled laminated shell theory. Optimization of composite pressure vessels is done by changing the parameters of the composite materials including filament winding angle, lamination sequence, and material. A Tsai-Wu failure criterion is regarded as one of the best theories at predicting failure in composite material.

3. Problem Definition

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.

4. Modeling of the Pressure Vessel

In order to model the problem, a small element was taken from on the pressure vessel. Solid 46 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. The element may also be stacked as an alternative approach. The element has three degrees of freedom at each node: translations in the nodal x, y, and z directions.

Real constant sets were defined for 4layers, various orientation angles and each layer thickness was entered 0.4mm. After material properties was defined, linear orthotropic material was chosen and the mechanical properties of E-glass/epoxy composite material was added.

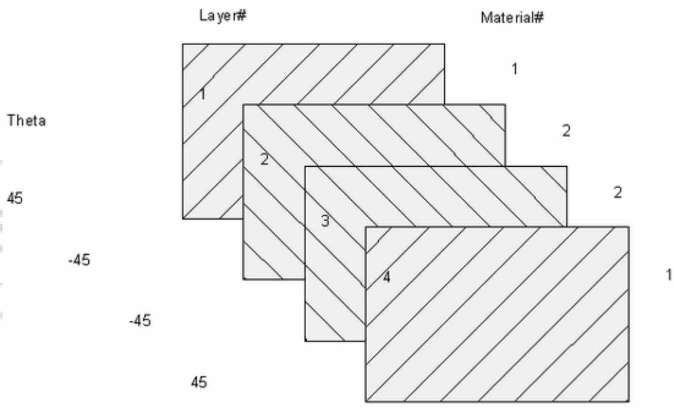

Figure 1: Sample lay plot display for [45/-45/-45/45] sequence

In order to calculate failure criteria, ultimate tensile strength, compressive strength and shear strength were entered both in fiber direction and in matrix direction.

4.1 Design Specifications

Pressure vessel outside diameter =112.9 mm
Pressure vessel inside diameter =102.9 mm
Pressure vessel thickness =10 mm

5. FEA Result Tabulation for Steel

Table 1: FEA results for steel

Applied pressure in MPa	*Hoop Stress[maximum]*	*Hoop stress[minimum]*
10	106.39	41.782
20	212.795	83.56
30	319.19	125.34
50	531.98	208.30

6. FEA Result Tabulation for Glass Epoxy

Table 2: FEA results for Glass epoxy

Applied pressure in MPa	*Hoop Stress[maximum]*	*Hoop stress[minimum]*
10	86.435	24.25
20	184.456	63.521
30	276.262	112.13
50	422.346	164.23

7. Conclusion

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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Author Profile

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