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Design and Analysis of Composite High Pressure Vessel with Different Layers using FEA

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***Abstract*—the composite Material like aluminium and fiber matrix to sustain different criteria. In the present work, structure of the composite pressure vessel and different orientations of symmetric shells designed. For pressure were investigated and 3-D finite element analyses using APDL Programming. FEA software is used for failure analysis on the composite shell of continuous angle ply laminas. The Tsai-Wu failure criterion is applied for the checking the first-ply failure of layers in a simple form. Some analytical and experimental solutions are compared with the finite element solutions, in which commercial software ANSYS 15.0 was utilized and close results are obtained between them.**

Key words: Non Linear FEA, Partial differential equation, Stress Concentration Criteria, Failure Criterion T-Sai Wu

I. INTRODUCTION:

In many applications in mechanical engineering [1-6] a composite component must sustain for many years, stress levels that are a significant fraction of its ultimate tensile strength, and often in deleterious environments. Various applications in pressure vessels in aerospace, automotive and nuclear power. A generally recognized problem is creep fracture, a catastrophic failure event that typically occurs with little or no warning [6]. However, due to the lack of through-the-thickness reinforcement, structures made from these materials are highly liable to failures caused by delamination. Therefore within a design process a structures resistance to delamination should be addressed to maximize its durability and damage tolerance. The phenomenon of progressive failure in laminated composite structures is yet to be understood, and as a result, reliable strategies for designing optimal composite structures for desired life and strength are in demand [33].Various methods, utilizing analytical and experimental approaches, have been presented for designing the composite pressure vessels shapes of pressure vessels [27]. During the past two decades, several authors have performed detailed analyses of composite pressure vessels by using the theory of orthotropic plates. Composite pressure vessels tend to fail in their composite pressure vessels parts; the design of these parts is the most important issue for such vessels [32]. A number of factors must be taken into account in designing composite pressure vessels, including the strength of the materials selected, the effect of winding stability, geometric variables, and so on. The winding stability and composite pressure vessels shapes must be chosen carefully to obtain an optimal design [15]. Several previous studies have examined the optimal design of composite pressure vessels, but the effects caused by the width of the winding Layers on the stability of winding pattern in the composite pressure vessels have not been studied. Therefore, the aim of this study is to optimize the design of composite vessels operating under an internal pressure [16].

The design variables used in the optimization problem include the winding angle. The effects of winding process parameters on the slippage tendency at the edges of the band are also considered. The results presented may prove to be helpful for designers of composite pressure vessels. In addition, the procedure employed in this study can also be utilized during the primary design stage. All Composite overwrapped pressure vessels (COPV's) are made of a thin metallic liner wrapped with a high-strength low-density composite.[8] The metallic liner provides shape, toughness, tightness and interface with the gas feeding systems while the overwrapped composite ensures mechanical strength to withstand high pressures and protects the vessel against scratches, indents and other forms of impact damage. Other examples of pressure vessels are fuel tanks, rocket motor cases, diving cylinders, recompression chambers, distillation towers, pressure reactors, autoclaves, vessels in mining operations, oil refineries and petrochemical plants, nuclear reactor vessels, submarine and space ship habitats, Pneumatic reservoir, hydraulic reservoir under pressure, rail vehicle airbrake, reservoirs, road vehicle airbrake, reservoirs and storage vessels for liquefied gases such as ammonia, chlorine, propane, butane, and LPG. [31]

II. OBJECTIVE OF PROJECT:

The objective of the project is to:

a. Design of pressure vessel for operating 0.34 MPa as per ASME Code section VIII.
b. Analysis of composite pressure vessel using FEA.

c. To check at how many layers composite pressure vessel fails using T-Sai Wu failure criteria.

A finite-element simulation of a composite pressure vessel is performed first to gain insight into its mechanical behaviors, and then simulation results are processed using failure analysis to determine at which layer composite pressure vessel fails when winding layers decreases from 20-Layers to 5-Layers.

Unidirectional lamina a single lamina (also called layer or ply) or several lamina (plural) with same material and orientation in all laminate and bonded together, where at least some lamina have different orientation or material.[37] Bulk composite for which lamina cannot be identified including bulk molding compound composite particle- reinforced composite and so on.

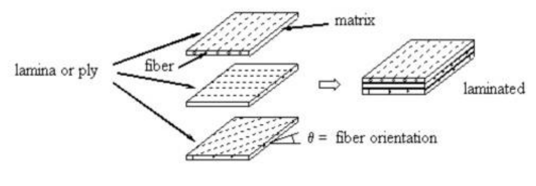


Fig. 2.1 Laminated Composite Material

III. DESIGN AND ANALYSIS OF COMPOSITE PRESSURE VESSEL USING ANSYS:

A. *Composite Pressure vessels Equipment Design Data:*

The mechanical properties of the liner are aluminium and fiber matrix in composite filament winding using ASME Code-III and Stiffness, toughness as follows:

Table I

Properties of carbon Fibers

Sr. No	Mechanical	Nominal Value (SI)
1	E_{11} - Longitudinal	161.3 GPa
2	E_{22} – Transverse	8.82 GPa
3	Shear Modulus (G_{12} - In-Plane)	5.14 GPa
4	Poisson's Ratio (v_{12} - In-Plane)	0.300

B. *Composite Pressure vessels material of construction:*

The composite material depends upon following parameters of material like strength, hardness, ductility, Creep resistance, corrosion factors. The fiber matrix always use in one dimensional.

Table II

Configuration of matrix and Aluminium liner

Section	Layer Thickness	Material ID	Material Orientation Angle	Integration Points
Main tank wall	1.9e-3	1	0	3
	0.1e-3	2	0	3
	0.1e-3	2	0	3
	0.1e-3	2	0	3
	0.1e-3	2	0	3
Inlet/outlet wall	1.9e-3	1	0	3

The fibers have a one-dimensional constitutive relation and are significantly stiffer than the bonding material. For simplicity, it is assumed that all materials in this problem are linear-elastic and temperature independent.

C. *Composite Pressure vessels design:*

Design according to T-Sai Wu failure criteria as given below.

$\varepsilon 3 = A + B$

And if the criteria used is the inverse of strength index

$$\varepsilon_3 = \frac{1.0}{\left(-\frac{B}{2A}\right)+\sqrt{\left(\frac{B}{2A}\right)^2+\frac{1.0}{A}}}$$

Where ε_3 is the value of T Sai Wu failure criteria.

$$A = -\frac{(\sigma_1)^2}{(\sigma_{1t}*\sigma_{1c})} - \frac{(\sigma_2)^2}{(\sigma_{2t}*\sigma_{2c})} - \frac{(\sigma_3)^2}{(\sigma_{3t}*\sigma_{3c})} + \frac{(\sigma_4)^2}{(F_4)^2} + \frac{(\sigma_5)^2}{(F_5)^2} + \frac{(\sigma_6)^2}{(F_6)^2} + \frac{C_{12}*\sigma_1*\sigma_2}{\sqrt{F_{1t}*F_{1c}*F_{2t}*F_{2c}}} + \frac{C_{23}*\sigma_2*\sigma_3}{\sqrt{F_{2t}*F_{2c}*F_{3t}*F_{3c}}} + \frac{C_{31}*\sigma_3*\sigma_1}{\sqrt{F_{3t}*F_{3c}*F_{1t}*F_{1c}}}$$

$$B = \left(\frac{1}{F_{1t}}+\frac{1}{F_{1c}}\right)\sigma_1 + \left(\frac{1}{F_{2t}}+\frac{1}{F_{2c}}\right)\sigma_{2} + \left(\frac{1}{F_{3t}}+\frac{1}{F_{3c}}\right)\sigma_3$$

Where C_{12}, C_{23}, C_{31} are coupling coefficients of T Sai Wu theory.

3.4 APDL Programming of Composite Pressure vessels Using ANSYS 15.0:

```
/prep7
/title
!--- define parameters ---
ce1 = 161.3e9   ! E11
ce2 = 8.82e9    ! E22
theta = 45      ! Layer orientation angle
srenf = .5e-4   ! Cross-section area of a single reinforcing fiber.
s = 1.0         ! Distance between two adjacent reinforcing fibers
p = 50.e5       ! Internal pressure
pi = 3.14159265358979323846264338327950
/prep7
!--- element type ---
et,1,SHELL281              ! 8-Node Structural Shell
keyopt,1,2,1     ! Use the improved shell option
keyopt,1,8,1     ! Store all layer results
!--- materials---
! aluminum
mp,ex,1,72.0e9
mp,prxy,1,0.29
mp,alpx,1,5e-6
! Matrix
mp,ex,2,ce2
mp,prxy,2,0.33
mp,alpx,2,5e-6
! Fibers
mp,ex,3,2.0*(ce1-ce2)
mp,alpx,3,1e-6
csys,1
!---composite lay-up of the main wall---
sectype,1,shell
secdata,1.9e-3,1,,5          !Aluminum liner
secdata,0.1e-3,2,,5                   !1st matrix section_Epoxy
```

```
secdata,0.1e-3,2,,5                    !2nd matrix section_Epoxy
secdata,0.1e-3,2,,5                    !3rd matrix section_Epoxy
secdata,0.1e-3,2,,5                    !4ht matrix section_Epoxy
secdata,0.1e-3,2,,5                    !5ht matrix section_Epoxy
secdata,0.1e-3,2,,5                    !6ht matrix section_Epoxy
secdata,0.1e-3,2,,5                    !7ht matrix section_Epoxy
secdata,0.1e-3,2,,5                    !8ht matrix section_Epoxy
secoffset,bot
!---reinforcing fibers---
sectype,2,reinf,smear
secdata,3,srenf,s,, theta,layn,2   !reinforce section for layer #1
secdata,3,srenf,s,,-theta,layn,3   !reinforce section for layer #2
secdata,3,srenf,s,, theta,layn,4   !reinforce section for layer #3
secdata,3,srenf,s,,-theta,layn,5   !reinforce section for layer #4
secdata,3,srenf,s,, theta,layn,6   !reinforce section for layer #5
secdata,3,srenf,s,,-theta,layn,7   !reinforce section for layer #6
secdata,3,srenf,s,, theta,layn,8   !reinforce section for layer #7
secdata,3,srenf,s,,-theta,layn,9   !reinforce section for layer #8
!---outlet---
sectype,3,shell
secdata,1.9e-3,1,,5
secoffset,bot
csys,0
```

IV. ANALYSIS OF ONE/EIGHT PART OF COMPOSITE PRESSURE VESSELS FOR PRESSURE 0.34 MPa:

The failure analysis is applied to calculation which addresses the T-Sai Wu Criteria, static analysis and displacement analysis. during the analysis, ANSYS 15.0 is used and analysis is carried out in the different steps. The purpose of analysis is to insure safety of the composite pressure vessels and supporting structure. Sustained loads are by using operating pressure conditions.

For Layer 6- deformation=0.054661

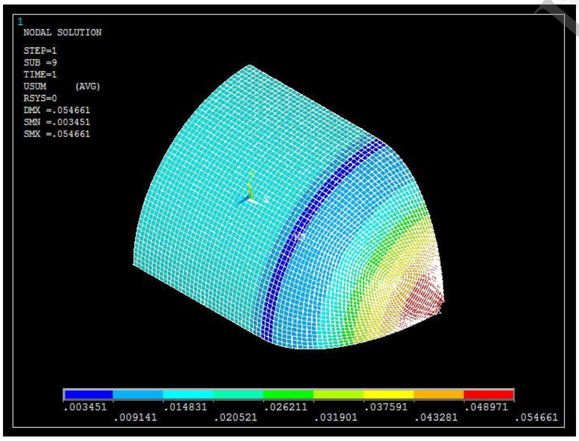


Fig. 4.1 Deformations at 6-Layers.

For Layer 6- von misses stress=0.198E10 N/m^2

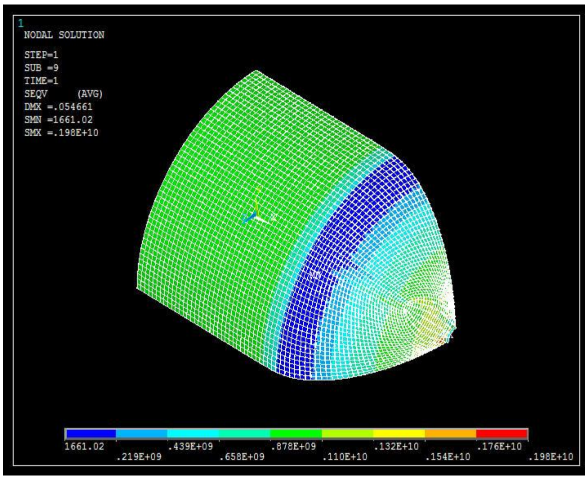


Fig. 4.2 Von-misses stress at 6-Layers.

For Layer-6 inverse of T Sai Wu strength
Ratio index =1.02064.

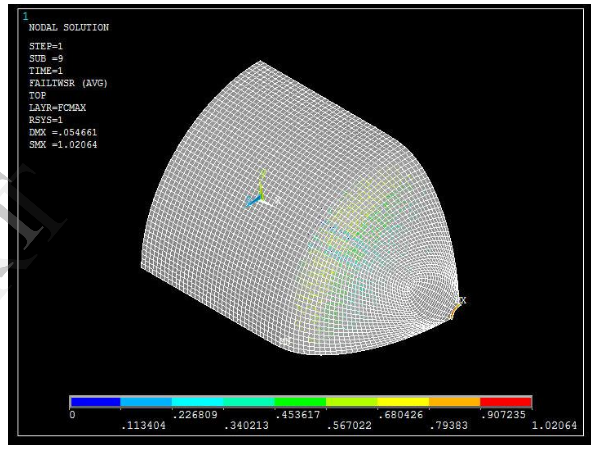


Fig. 4.3 Inverse of T Sai Wu strength ratio
Index at 6-Layers.

For Layer -8 Deformation=0.052663

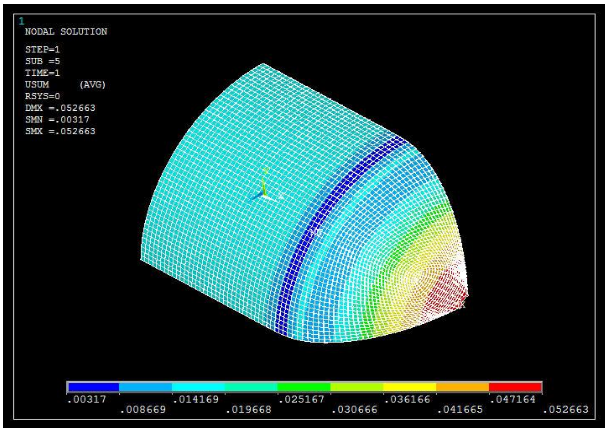


Fig. 4.4 Deformation at 8-Layers.

For Layer-8 von misses=0.186E10 N/m^2

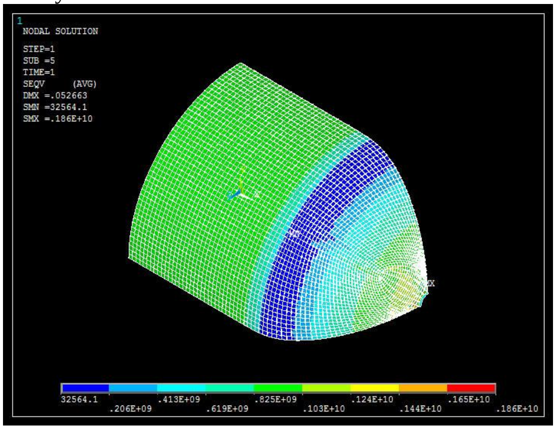


Fig. 4.5 Von-misses stress at 8-Layers.

For Layer-8 inverse of T Sai Wu strength Ratio index = 0.988183.

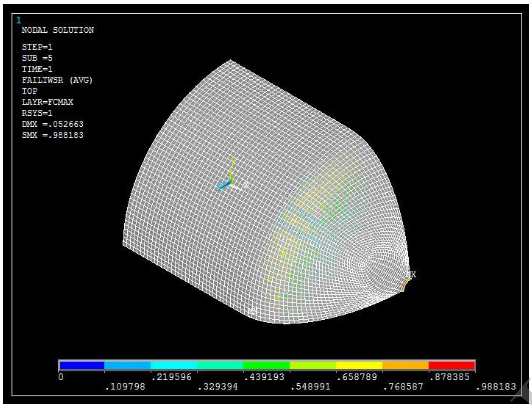


Fig. 4.6 Inverse of T Sai Wu strength ratio Index at 8-Layers.

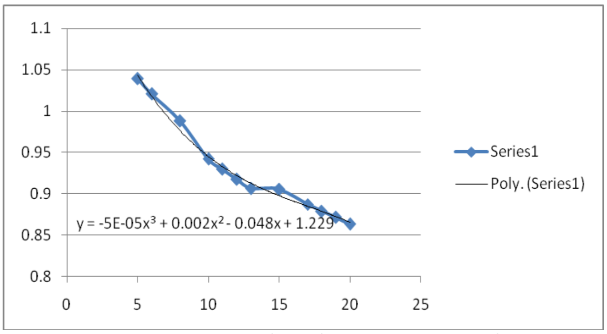
V. RESULTS AND DISCUSSION

Analysis is carried out from Number of Layer-5 to 20-Layer. But here Results are noted down between Layer 8 to Layer 5 in below Table-III The total analysis and modeling APDL, design procedure, learning and training time is including approximately seventy-four hours taken by the software, Project work.

Table III
Deformation and Inverse Tsai strength index

No. of Layer	Deform-ation (meter)	Stress (N/m^2)	Inverse T-Sai Wu strength index	
			DMX	SMX
5	0.055789	0.214 E 10	0.055789	1.039200
6	0.054661	0.198 E 10	0.054661	1.020640
7	0.053621	0.193 E 10	0.053841	1.008156
8	0.052663	0.186 E 10	0.052663	0.988180

It is observed that during analysis, Failure occurs in composite pressure vessels by using T-Sai Wu Criteria. When value of inverse of T-Sai Wu strength ratio index is greater is than one than composite pressure vessel fails.



Graph 5.1 Graph of no of layers Vs Inverse of T-Sai strength index

In analysis we increase layers from 5 to 20. From graph structure fails at 6-Layer and 7-Layer (inverse of T Sai strength index is 1.02064 & 1.008156) but as we add 8-Layer on pressure vessel its strength increased (inverse of T Sai strength index is 0.988183).

VI. CONCLUSION

Analyses are carried out for number of layer from 5-Layer to 20 Layer. But here Results are noted between Layer 8 to Layer 5 in Table 5.1, we can reduce number of layers to obtain optimized design. At 8-Layers value is 0.988180 structure is safe and is at optimum level. At 7-Layer its value is 1.00815 i.e. fails, which is matches with the value of test results. Therefore we can conclude that T-Sai Wu failure criteria can yield fairly good results with consistent accuracy for the composite pressure vessels.

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Nomenclature

Abbreviation	Particulars
A	Length of delamination.
a= a/L	Normalized delamination length.
E_{11}, E_{22}, G_{12}, m_{12}	Material constants.
G	Strain energy release rate.
t_1, t_2	Thicknesses of upper and lower sublaminates, respectively.
$h = t_1/t$	Normalized delamination thickness.
L, r, t	Length, Radius And Thickness Of The Overall cylindrical shell, respectively.
X, Y, Z	Nodal Force Components In The X, Y And Z.
P	Pressure.
Pc	Critical Buckling Pressure Of An Intact Cylinder Under External Pressure Alone.
Pcr	Critical Buckling Pressure Of A Delaminate Cylinder.
R	Compressive axial load.
Rc	Critical axial compression of an intact cylinder under axial compressive alone.
Rcr	Critical axial compression of a delaminated cylinder.
u(or ux), v(or uy), w(or uz)	Axial, circumferential and radial displacements, respectively.
x, y, z	Axial, circumferential and radial coordinates, respectively.
∝	Angle of the delamination region.