Structural Analysis of Multi-Layered Pressure Vessel with Fem Approach by Using S2 Glass Material

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Abstract:
The pressure vessels are used to store fluids under pressure. The fluid being stored may undergo a change of state inside the pressure vessels as in case of steam boilers or it may combine with other reagents as in chemical plants. This thesis work aims to develop a methodology where tedious and repetitive design processes are automated. The design of Pressure vessel will be used as a proof of concept. The modeling is done in Solid Works and is evaluated structurally in ANSYS. The FE process in ANSYS is automated by the use of the programming languages Python and JavaScript. Furthermore a user interface is created using Microsoft Excel with Visual Basic. To allow automatic FEM, a parametric CAD model of Pressure Vessel is constructed. It is shown that the parametric CAD model can be obtained with high accuracy.

Key Words: Modeling, Analysis, S2 Glass.

Introduction:
Pressure vessels find wide applications in thermal and nuclear power plants. The material of a pressure vessel may be brittle such as cast iron, or ductile such as mild steel. A pressure vessel is a container designed to hold gases or liquids at a pressure substantially different from the ambient pressure and pressure tests, usually involving water, also known as hydrates, but could be pneumatically tested involving air or another gas. The preferred test is hydrostatic testing because it's a much safer method of testing as it releases much less energy if fracture were to occur (water does not rapidly increase its volume while rapid depressurization occurs, unlike gases like air, i.e. gasses fail explosively).

Design Parameters:
The design of multilayered pressure vessel includes,
- Design of Shell thickness
- Design of Dished end thickness

Design of Shell Thickness (t):
The Shell holds the fluid under pressure and the tangential stress is taken as design stress. A joint in the longitudinal direction, which is considered in terms of joint efficiency, forms the shell.

Input Data:
Design pressure, $P$ : 21 N/mm$^2$
Inside radius of shell, $R_i$ : 1143 mm
Inside Diameter of the shell, $D_i$ : 2286 mm
Corrosion allowance, C.A : 3.0mm
Joint efficiency, $J$ : 1.0

Thickness of shell, $t$ : 161.64mm

Permissible Stress for shell material ($S$)

$$ S = 164 \text{ N/mm}^2 $$

Design of Hemispherical Dished End:
To close either end of the cylindrical shell a cover or a closure is essential. This can be attached to the shell by welded, riveted or bolted construction. For a large number of cylindrical shells, dished heads with torispherical or elliptical or hemispherical shapes are commonly used. Hemispherical dished head is the strongest of all the formed heads and expensive also. The thickness of these heads is calculated on the basis of circumferential stresses, created by the internal pressure acting on the concave side of the dished end.

Input Data:
Design pressure, $P$ : 21 N/mm$^2$
Inside radius of shell, $R_i$ : 1143 mm
Strength of the material, $S$ : 123 N/mm$^2$
Corrosion allowance, C.A : 3.0mm
Joint efficiency, $J$ : 1.0

Thickness of the dished end is given by:

$$ t_d = \frac{P R_i}{2 S J - 0.2 P} + C.A $$

$$ t_d = \frac{21 \times 1143}{2 \times 123 \times 1.0 - 0.2 \times 21} + 3.0 $$

The adopted thickness of the dished end = 162 mm.
Introduction to S2 Glass:

High-strength glass, carbon or other advanced fibers are used in applications requiring greater strength and lower weight. High-strength glass is generally known as S-type glass in the United States, R-glass in Europe and T-glass in Japan. S-glass was originally developed for military applications in the 1960s, and a lower cost version, S-2 glass, was later developed for commercial applications. High-strength glass has appreciably higher amounts of silica oxide, aluminum oxide and magnesium oxide than E-glass. S-2 glass is approximately 40-70% stronger than E-glass.

Properties:

<table>
<thead>
<tr>
<th>Physical Properties</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Density</td>
<td>2.46 g/cc</td>
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</table>

<table>
<thead>
<tr>
<th>Mechanical Properties</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile Strength</td>
<td>4890 MPa</td>
</tr>
<tr>
<td>Elongation at Break</td>
<td>5.70 %</td>
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<tr>
<td>Modulus of Elasticity</td>
<td>86.9 GPa</td>
</tr>
<tr>
<td>Poisson’s Ratio</td>
<td>0.23</td>
</tr>
<tr>
<td>Shear Modulus</td>
<td>35.0 GPa</td>
</tr>
</tbody>
</table>

Analysis of Solid Wall Pressure Vessel:

For Steel:

3D model of the pressure vessel shown in figure.1 was developed in Solid Works and then imported for simulation.

![Fig.1: Solid Wall Pressure Vessel in ANSYS](image)

Material Properties:

Young’s Modulus – 209000Mpa
Poisson’s ratio – 0.3
Density – 0.00000785Kg/mm³

The figure.2 shows the meshed model of the solid domain.

The figure.3 shows the application of pressure i.e. 21 N/mm² on the meshed model.

![Fig.2: Meshed Model of Pressure Vessel](image)

![Fig.3: Application of Pressure](image)

Figure.4. shows total displacement is 0.73mm

![Fig.4: Displacement](image)

Analysis of Multi Layer Pressure Vessel:

For Steel:

Liner Material – SA515 GR70:
Young’s Modulus – 205000Mpa
Poisson’s ratio – 0.29
Density – 0.00000785Kg/mm³

![Fig.5: Von-Mises Stress plot of the model](image)
For S2 Glass Epoxy:

Material Properties:
- Young’s Modulus – 86900Mpa
- Poisson’s ratio – 0.23
- Density – 0.00000246Kg/mm³

Result Table:

<table>
<thead>
<tr>
<th></th>
<th>SINGLE LAYER</th>
<th>MULTI LAYER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement (mm)</td>
<td>0.738</td>
<td>2.78</td>
</tr>
<tr>
<td>Stress (N/mm²)</td>
<td>144.38</td>
<td>169.062</td>
</tr>
</tbody>
</table>

Weight Comparison (Kg):

<table>
<thead>
<tr>
<th></th>
<th>SINGLE LAYER</th>
<th>MULTI LAYER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>79439.265</td>
<td>60943.7427</td>
</tr>
<tr>
<td>S2 Glass</td>
<td>4999.9044</td>
<td>4999.9044</td>
</tr>
</tbody>
</table>

Conclusion:

At present, solid wall pressure vessels are used extensively. But by using multilayered vessels, there is a huge difference in weight. The weight is almost decreased by 18495Kg when multilayered vessels are used in place of solid vessels.

This decreases not only the overall weight of the component but also the cost of the material required to manufacture the pressure vessel. This is one of the main aspects of designer to keep the weight and cost as low as possible.

The stresses developed in the multilayered vessels are more when compared with solid vessels. Minimization of stress concentration is another most important aspect of the designer. It also shows that the material is utilized most effectively in the fabrication of shell.

Owing to the advantages of the multi layered pressure vessels over the conventional single walls pressure vessels, it is concluded that multi layered pressure vessels are superior for high pressures and high temperature operating conditions.

By using composite material S2 Glass epoxy in place of steel, decreases the overall weight of multilayered vessels almost by 50000kg and also by analysis it is proved that using S2 glass epoxy is also safe since the analyzed stress value is less than yield stress value.

References:


8. Henry H. Bednar “Pressure Vessel Code Book”