ANALYSIS OF MULTI-LAYERED THICK-WALLED FILAMENT-WOUND PRESSURE VESSELS

Lei Zu, Sotiris Koussios, Adriaan Beukers

Design and Production of Composite Structures, Faculty of Aerospace Engineering, Delft University of Technology, Kluyverweg 1, 2629 HS Delft, The Netherlands

e-mail: L.Zu@tudelft.nl, web page: http://www.tudelft.nl

Key words: Filament winding, Thick-walled pressure vessel, Three-dimensional analysis, Elasticity solution, Twisting.

Summary. A three-dimensional elasticity analysis on multi-layered thick-walled filament-wound pressure vessels under uniformly distributed internal pressure is outlined. An exact solution to stresses of the isotropic liner and each anisotropic layer is presented based on the Lekhnitskii’s theory and the generalized plane strain assumption. The governing equation for determining the radial displacement of the pressure vessel is derived and the matrix equation that solves the integration coefficients of the governing equation is formulated by considering the boundary and interface conditions. The normal and in-plane shear stress components and the twisting rate of the cylinder are calculated for various liner thicknesses. In addition, various combinations of anisotropic composite and isotropic liner materials are here examined to pinpoint preferable material combinations.

1 INTRODUCTION

The cylindrical section of a pressure vessel consists of an inner metal liner for preventing gas diffusion and a four-layered composite overwrap for reinforcing the structure (Fig. 1). The four layers are oriented symmetrically as [55°/-55°/55°/-55°] and the vessel is subjected to an internal pressure of 10 MPa. The stresses in the metal liner are considered within the elastic limit up to the design pressure. The analysis of cylinders by elasticity solutions can be divided into "thin wall" and "thick wall" structures. The division point is often chosen as a radius-to-thickness ratio of 10. The thin-shell theory could lead to errors for prediction of the structural behavior of thick-walled pressure vessels. Therefore, a 3D thick-walled multilayered analysis is here proposed for calculating the stress and deformation fields. One of the key issues for the thick-walled analysis is that the through-thickness stress gradients are no longer considered negligible; the radial stress distribution must be incorporated in the shell analysis. Twisting, caused by lack of exact symmetry in ply stacking, is also taken into account in this paper.
2 RESULTS AND DISCUSSION

Various combinations among three composite materials (T300/934, B(4)/5505, E-glass/epoxy) and three liner materials (A6063-T6, B-120VCA, Steel 301) are evaluated by calculating the equivalent Von Mises stress through the wall of the metal liner (Fig. 2(a)) and the Tsai-Wu strength ratio $R$ through the wall of anisotropic composite laminate (Fig. 2(b)).

![Figure 2: (a) Von Mises stress through the liner wall; (b) Tsai-Wu strength ratios through the composite wall](image)

3 CONCLUSIONS

The addition of the liner and the increase of the liner thickness results in smoother stress gradients and more homogenous stress distributions through the wall of the pressure vessel and can thus improve the structural performance of pressure vessels. The twisting effect is also reduced by increasing the liner thickness. The hoop-to-axial stress ratio is no longer a constant through the vessel wall and varies along the wall thickness. The use of a high-anisotropy composite material or a low-modulus metal liner leads to a lower equivalent stress of the liner and should be chosen when the yield of the metal liner becomes a critical issue; in addition, a high-anisotropy composite material combined with a high-modulus liner reserves more additional strength to which the composite overwrap may be subjected prior to failure.