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Stress analysis in filament wounded composite pressure vessels

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Main goal of presented work is comparison of the results for cylindrical and spherical pressure vessel (manufactured by filament winding technology) obtained by analytical solution with results from finite element method (FEM). Classic lamination theory for shells is used in combination with netting theory (see [1] for an example) for determination of stresses in axial and circumferential direction. The assumptions for the solution comprise:

- an elastic material model of the composite,
- a wall thickness h that is significantly lower than the smallest radius of the shell,
- an inner pressure that leads to membrane loading in the walls of the shell,
- a composite wall that is a balanced laminate consisting of two layers with fiber orientations of $\pm\omega$ of the same thickness and volumetric fiber contents.

Cylindrical pressure vessel is manufactured with integrated domes (dome analysis is not presented in this study) with ($90/\pm\omega_0/90$) lay-up. Balanced laminated $\pm\omega_0$ creates dome, hoop winding reinforces cylindrical part of the vessel (See Fig. 1).

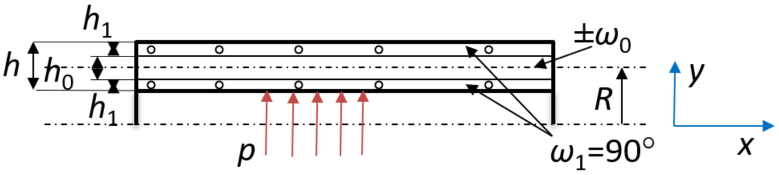

Fig. 1. Cylindrical part of pressure vessel

Thickness of layers is given by the isotensoidal condition of the construction (same stress/strain in all layers), $\pm\omega_0$ is given by the geodesic condition of the winding (ratio of polar opening r_0 and radius R of the cylindrical part of the shell – see Fig. 2).

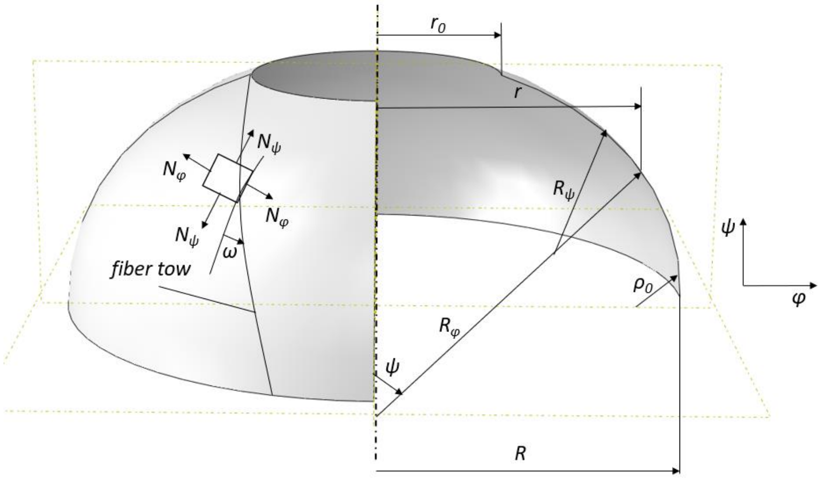

Fig. 2. The geometry and forces on the shell of the revolution of double curvature manufactured by means of helical winding

Spherical pressure vessel is manufactured with ±ω lay-up and it has maximum volume with minimum surface area [2]. Spherical shell is not isotensoid construction and compared to isotropic sphere, which is symmetrical to the centre, filament wounded sphere is symmetrical just to the axis of the rotating mandrel. For each filament wounded shell of the revolution of double curvature is typical change of thickness and winding angle along the meridian curve. Minimum thickness is on the equator, maximum thickness is near polar opening. Winding angle has its minimum on the biggest radius (equator) and its maximum (90°) near polar opening – stiffness/compliance/strength vary along meridian curve.

For computational example a cylinder/sphere manufactured from glass/epoxy system with volumetric fiber content 60 %, loaded with inner pressure 1 MPa was chosen. Polar opening radius is $r_0 = 20$ mm and radius $R = 50$ mm of the cylindrical part of the shell (or radius on sphere equator respectively). Last input parameters were thickness of hoop layers $h_1 = 1$ mm for case of cylindrical vessel and thickness on equator $h_0 = 1$ mm in case of spherical vessel. FE model was prepared in Abaqus software with the use of shell elements in spherical case and shell and continuum shell elements in cylindrical case. Comparison of calculated stress can be seen in Fig. 3 – 5 for cylindrical case and in Fig. 6 for spherical case.

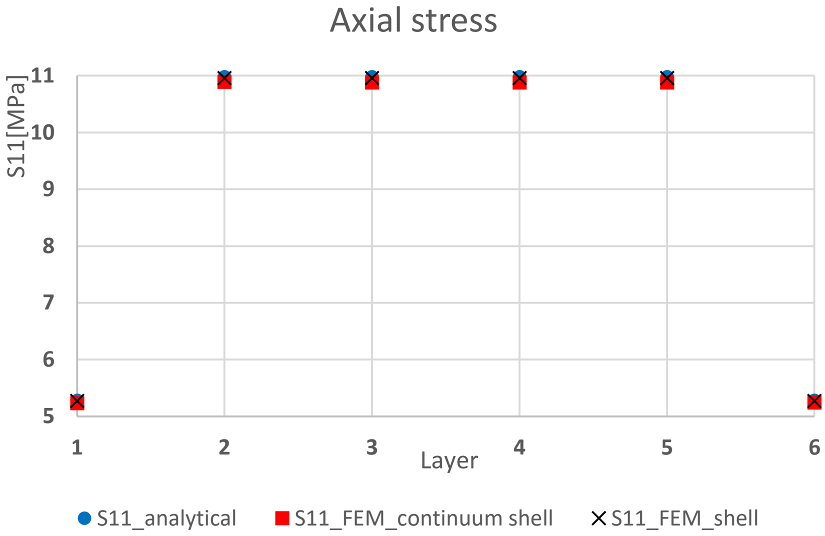

Fig. 3. Comparison of axial stress values for cylindrical case

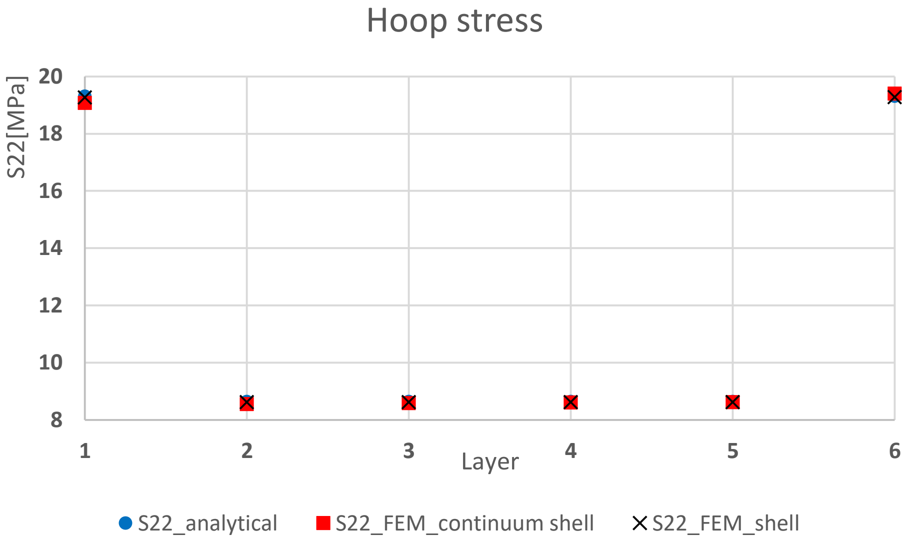

Fig. 4. Comparison of hoop stress values for cylindrical case

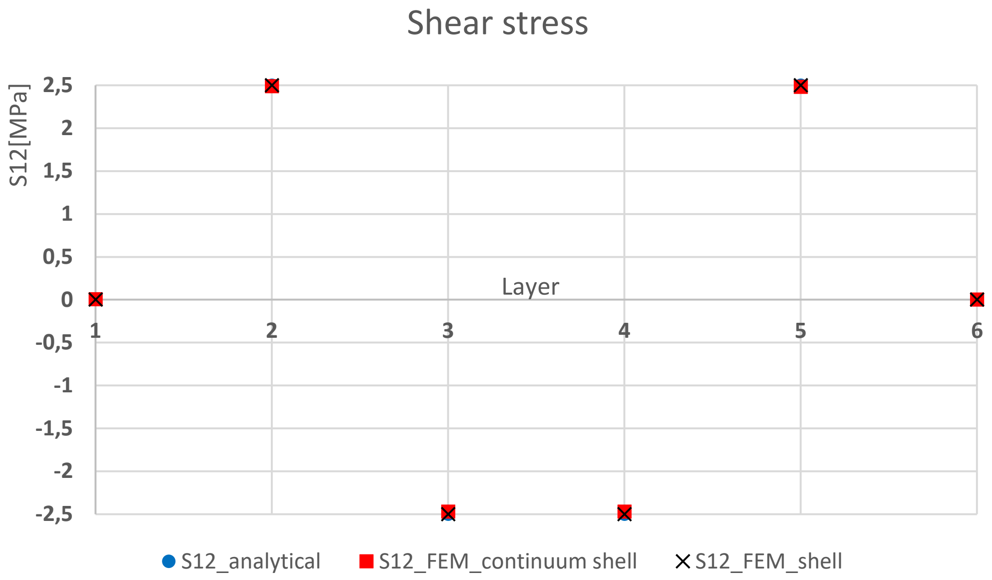

Fig. 5. Comparison of shear stress values for cylindrical case

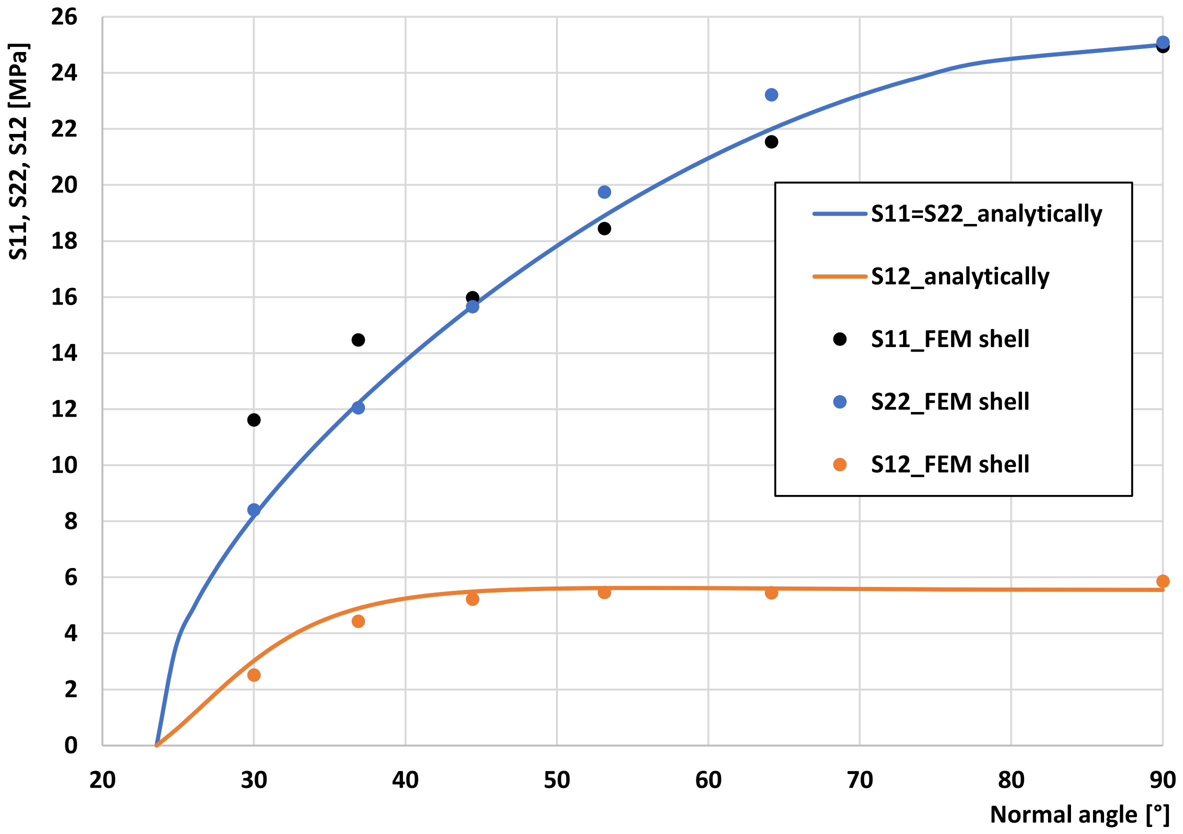

Fig. 6. Comparison of computed stress values for spherical case

The analytical computations were prepared in the MATLAB code, which allows both for the rapid determination of the results and the simple changing of the input parameters (the material, the polar hole and the equator radius, the thickness, and the inner pressure). The FEA provided comparable results to those of the analytical solution for cylindrical case, for spherical case particularly for a normal angle of ψ of 90° to 40° (the difference amounted to 10%). The areas defined with a lower normal angle of ψ were affected by the closure of the polar hole and by the discretization of areas with the same thickness.

Acknowledgements

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References

[1] Young, R., E., History and potential of filament winding, Proceedings of 13th Annual Technical Conference SPI – RP, Chicago, sect. 15 – C 1958.

[2] Vasiliev, V., V., Composite pressure vessels: Design, analysis and manufacturing, Bull Ridge Publishing, Blacksburg, 2009.