Modelling of FRP Cylinder for Stress Analysis

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Abstract

Proper modelling of a FRP cylinder is most vital thing in piping applications. A FRP Composite cylinder with multiple number of layers in accordance with reality should be considered in such a way that, each layer corresponds to a different volume. But, when the number of layers increases to a large number or in case of composite cylinder with variable thicknesses with several zones, it will be a tedious task to perform FE Modelling. The present research work aims at performing the stress analysis separately on 3 different models of infinitely long FRP composite cylinder:

Model-1: Cylindrical model having different volumes [Each volume corresponds to a layer].

Model-2: Cylindrical model with single volume [Layered model].

Model-3: Cylindrical Shell model.

The aim of the present work is to study the variation in percentage error for different stress values between Model-1 and Model-2, thereafter between Model-1 and Model-3 for different values of thickness ratios(S) varying from 5 to 100 on a four layered angle-ply ($30^0/-30^0/-30^0/30^0$). This analysis is performed using FEM in ANSYS Software. The study is intended for appropriate selection of cylinder model for thick and thin FRP cylinders.

1. Introduction

Roy and Tsai [1] 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 [2] studied analysis of multi-layered composite cylinders under hygrothermal loading. Mackerle [3] 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. Xia et. al. [4-6] studied multi-layered filament-wound composite pipes under internal pressure. Xia et. al. [4-6] presented an exact solution for multi-layered filament-wound composite pipes with resin core under pure bending.

Parnas and Katırcı [7] discussed the design of fibre-reinforced composite pressure vessels under various loading conditions based on a linear elasticity solution of the thick-walled multilayered 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.

Adali et. al. [8] gave another method on the optimization of multi-layered composite pressure vessels using an exact elasticity solution. A three dimensional theory for anisotropic thick composite cylinders subjected to Axi-symmetrical loading conditions was derived.

Starbuck [9] have done stress analysis of laminated composite cylinders under non-Axi symmetric loading. A closed-form solution is presented for determining the layer-by-layer stresses, strains. The formulation is based on the theory of anisotropic elasticity and a state of generalized plane deformation along the axis of the composite cylinder.. Kranthi et al. [10] found that a minimum length of 100mm is required to study the behaviour an infinitely long FRP Composite cylinder.

The present investigation intends to apply three-dimensional finite element techniques to analyze three different four layered angle ply ($30^0/-30^0/-30^0/30^0$) FRP composite cylinder models (Model-1, Model-2, Model-3) by varying thickness ratio ‘S’ [S= 5, 10, 20, 40, 60, 80,100].

2. Problem Modelling

2.1 Geometric Modelling

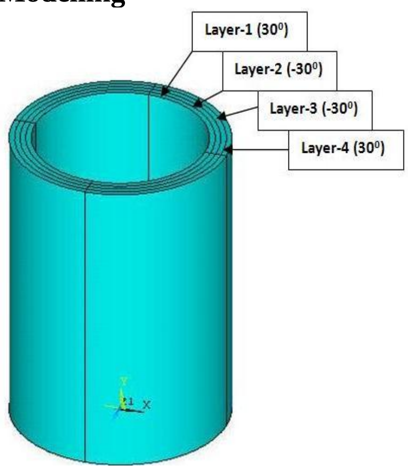

Figure 1. Model-1

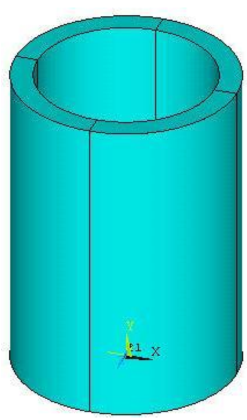

Figure 2. Model-2

Figure 3. Model-3

Geometry of the present problem is:

Diameter of the cylinder = 100 mm.
Length of the cylinder = 150 mm [10]
Thickness of the cylinder = Diameter / 'S'
Where, 'S' is the Diameter to thickness ratio.
Value of 'S' is varied as, S= 5, 10, 20, 40, 60, 80,100.

2.2 Finite element Modelling

The problem is modelled in ANSYS software and the finite element mesh is generated using SOLID 191 element [11] for four volumes corresponding to four layers of laminate structure (Model-1). Solid 191 is a 20node second order brick element having three degrees of freedom at each node and is suitable to incorporate orthotropic material properties. Solid Layered 191 element type is used to model the cylinder of single volume (Model-2). For model-3, shell Layered 99 element is used and meshing is performed.

The mesh refinement is carried out until the radial stresses at inner and outer surfaces of the cylinder closely matches with applied pressure and zero respectively.

2.3 Loads and Boundary conditions

At the bottom face of the cylinder, degrees of freedom in Z-direction (axial) and in Y-direction (Hoop) are constrained. An internal pressure of 1MPa is applied on the inner surface of the cylinder (Figures 4, 5, 6).

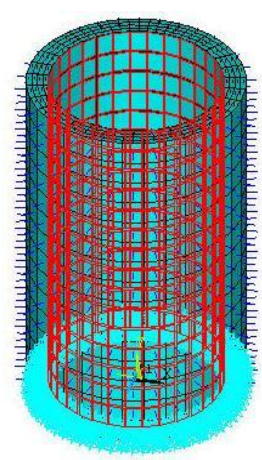

Figure 4. Model-1 with Loads and boundary conditions

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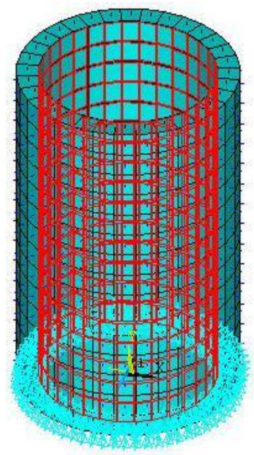

Figure 5. Model-2 with Loads and boundary conditions

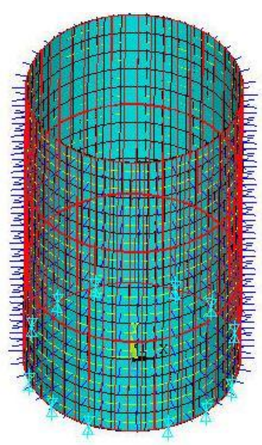

Figure 6. Model-3 with Loads and boundary conditions

2.4 Material properties

Material used is Orthotropic (Carbon-Epoxy) [12].

E_1 = 147000 MPa	ν_{12} = 0.27	G_{12} = 7000 MPa
E_2 = 10300 MPa	ν_{23} = 0.54	G_{23} = 3700 MPa
E_3 = 10300 MPa	ν_{13} = 0.27	G_{13} = 7000 MPa

3. Analysis of Results

Different components of Stress are calculated for the 3 models considered. % Error in Radial stress is compared in Figure 7. Percentage error between shell (Model-3) and model with 4 different volumes (Model-1) is enormous in case of thick cylinders (S=5, 10, 20). But when the value of 'S' is increasing, i.e. when the cylinder is becoming thin, percentage error has been reducing gradually and when the value of 'S' reaches to 80, 100; the percentage error is nearly negligible. Same observation is made even in case of comparison between the model with single volume (Model-2) and the model with four different volumes (Model-1). As the value of 'S' is being increased, percentage error of the Radial stress values has been reduced. Same trend is even observed in case of Hoop stress (Figure 8); Axial stress (Figure 9); Shear stress, τ_{rc}(Figure 10); Shear stress, τ_{ca}(Figure 11), Shear stress; τ_{ar}(Figure 12)

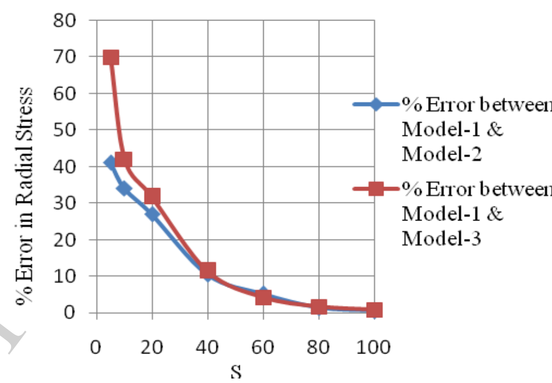

Figure 7. Variation of % Error in Radial stress by varying 'S'

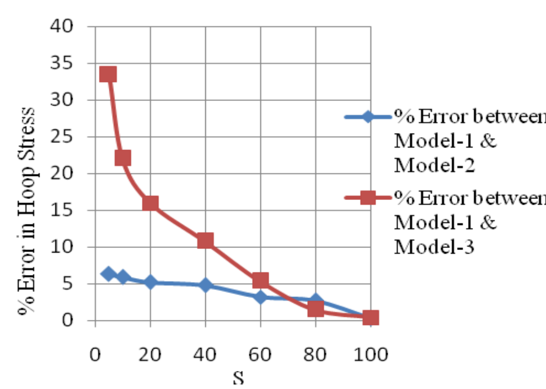

Figure 8. Variation of % Error in Hoop stress by varying 'S'

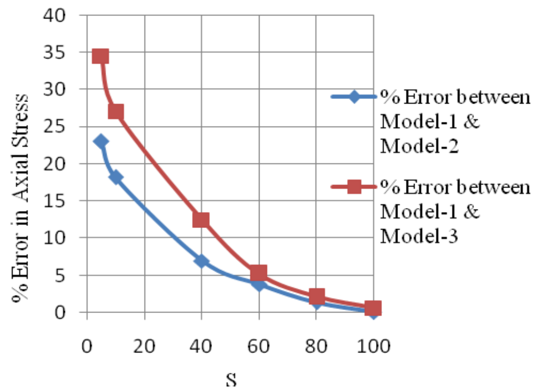

Figure 9. Variation of % Error in Axial stress by varying 'S'

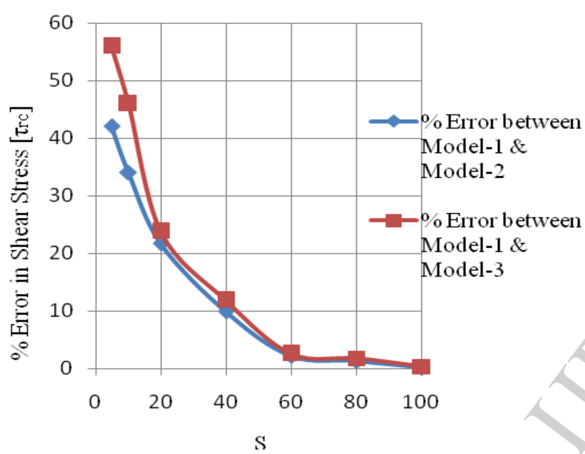

Figure 10. Variation of % Error in Shear stress [τ_{rc}] by varying 'S'

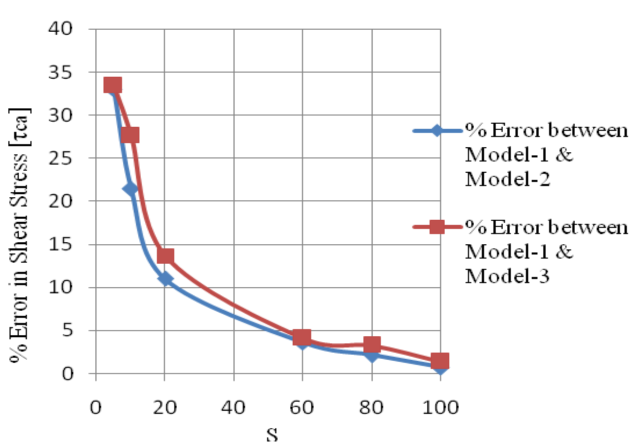

Figure 11. Variation of % Error in Shear stress [τ_{ca}] by varying 'S'

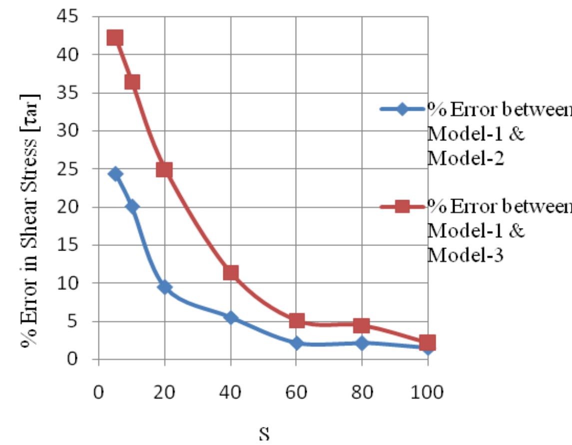

Figure 12. Variation of % Error in Shear stress [τ_{ar}] by varying 'S'

4. Conclusions

Stress analysis of the three different composite cylinder models is performed for different values of the thickness ratio 'S' (d/t). Error is calculated by taking Model-1(Cylindrical model with four different volumes) as reference. Percentage Error for all the various components of stresses (Normal and shear stresses) between Model-1 & Model-2; and also between Model-1 & Model-3 for different values of 'S' are calculated. It is observed clearly that, as the thickness of the cylinder decreases (i.e. when the value of 'S' increases beyond 80); all the composite cylinder models give same result with a negligible percentage of error.

Hence, it is apparent from the above results that for the analysis of multilayered thick cylinders, a model with different volumes where each volume corresponds to a layer should be used. For the analysis of multi layered thin cylinders, instead of modelling it by creating separate volume for each layer, a layered model or Shell model can be used which is much easier to be performed. As it is also evident that layered model is having less percentage error than that of the shell model, a layered model (Model-2) is best suited for the situations where adoption of shell model is not suitable.

5. References

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