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*Research Paper*

# ANALYSIS OF FRP COMPOSITE CYLINDERS

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The present work deals with the analysis of FRP composite cylinders. Two types of laminates, (1) cross-ply, and (2) angle-ply laminates are considered for the present analysis. Radial deflection and stresses are obtained by varying the diameter to thickness ratio (S), fiber orientation ($\theta$) in both the laminates. The problem is modeled with layered element of ANSYS software which is designed based on 3D-elasticity theory which can be successfully applicable for the analysis of thick FRP composite cylinders. Major findings: The composite cylinder with cross-ply obeying plane strain condition, so limited length model is sufficient for infinitely long cylinder analysis. The composite cylinder with angle-ply obeying plane strain condition with d/t ratio 100 and length is 15 mm, so the limited length model is sufficient to analyze the cylinder. For all other cases we need to analyze full length model.

***Keywords:*** Composites, Laminates, Fiber angle

## INTRODUCTION

Composite cylinders are being widely used in commercial, civil, aeronautics and astronautics industries, for example in rocket motor cases, fuel tanks, and portable oxygen storage bottles, and so on. With the development of material manufacturing technology, they offer a high stiffness and strength combined with a low weight and an excellent corrosion resistance. Composite cylinders are commonly constructed with a filament overwrap of fiberglass, carbon fiber, or Kevlar in customized resin systems. Various properties can be achieved through an appropriate selection of fiber type, fiber orientation, inner pot, and resin matrix of the composite structure required for the applications in question. The strong and stiff fibers carry the load imposed on the composite, while the resin matrix distributes the load across the fibers, the inner pot keep the cylinder airtight and partake some loads. Typical CFRP composite cylinders are generally designed with a central cylindrical section and two spherical end caps with optional polar openings. Here CFRP composite cylinders with cylindrical shape were analyzed.

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### Composite Cylinder Benefits

- Lower weight, even lower than aluminum and comparable to magnesium.
- Better corrosion resistance allowing use in caustic environments.
- Improved impact resistance.
- Enhanced impingement resistance-resists denting.
- Non-conductive.

### Applications of Composite Cylinders

- Industrial
  - Self-Contained Breathing Apparatus (SCBA)
  - Nitrogen
  - Oxygen
- Aerospace
  - Nitrogen
  - Oxygen
  - Composite air
- Automotive
  - Nitrogen oxide
  - Natural gas
  - Hydrogen fuel storage
  - Composite air

### Fiber Reinforced Polymers

Fiber-reinforced polymers or FRPs include wood (comprising cellulose fibers in a lignin and hemicelluloses matrix), Carbon-Fiber Reinforced Plastic (CFRP), and glass-reinforced plastic or GRP. If classified by matrix then there are thermoplastic composites, short fiber thermoplastics, long fiber thermoplastics or long fiber-reinforced thermoplastics. There are numerous thermo set composites, but advanced systems usually incorporate agamid fiber and carbon fiber in an epoxy resin matrix.

### Lamina

The basic building block of a Composite structure is the lamina, which usually consists of one of the fiber/matrix configurations.

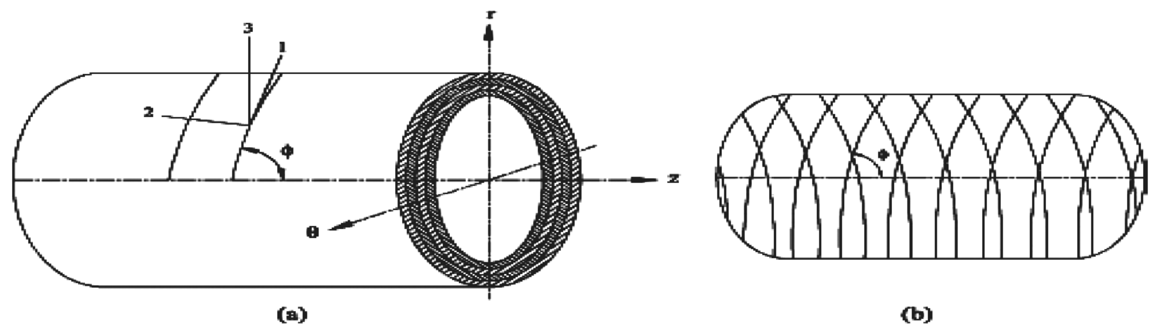
### Laminate

Laminated composites are made by bonding several layers or lamina having properties in such a way that they together give a set of desired properties. Such laminated composites are used in the form of plates, shells, pipes, thin walled beams and columns in a variety of applications.

## PROBLEM STATEMENT

The present work deals with the analysis of the thick FRP composite cylinders. The main

**Figure 1: Multilayered E-Glass/Epoxy Cylinder and Pressure Vessel**



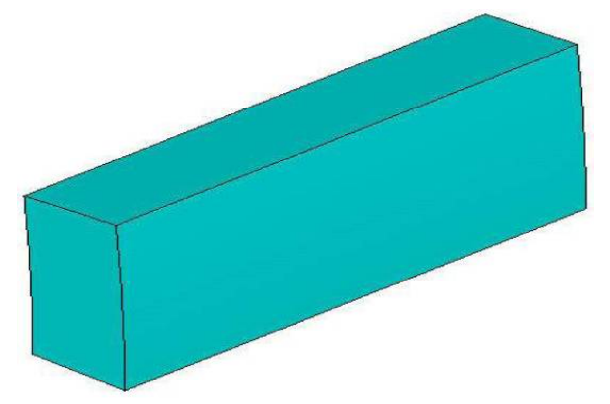
aim is to evaluate the stresses and deflections in the composite cylinder, which is subjected to transverse pressure load with the following three cases.

1. Four layered cross-ply laminate at various diameters to thickness ratio (S) for various stacking sequence.
2. Four layered angle-ply laminate at various diameters to thickness ratio (S) and fiber orientation ($\theta$).
3. Eight-layered angle-ply laminate.

## Geometric Modeling

The geometry of the FE model for cross-ply laminate is a Sector with following dimensions (Figure 2):

**Figure 2: Solid Geometry of a Sector**



Diameter of the cylinder = 100 mm,

Geometry angle = 50,

Thickness of the cylinder = Dia. of cylinder (100 mm)/S

Where 'S' is the diameter to thickness ratio. 'S' values varied from 20 to 100.

### Length of the Cylinder in Cross-Ply

At sector angle 50 it satisfies the plane strain condition, so it was assumed as cylinder is infinitely long, hence length of the cylinder was taken as 10 mm.

The geometry of the FE model for angle-ply laminate is full circle model with following dimensions:

Diameter of the cylinder = 100 mm,

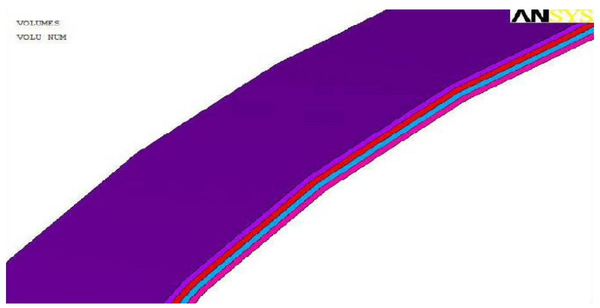
Geometry angle = 3600,

Thickness of the cylinder = Dia. of cylinder (100 mm)/S

Where 'S' is the diameter to thickness ratio. 'S' values varied from 20 to 100.

The full circle model of composite cylinder having the four layers was shown in Figure 3.

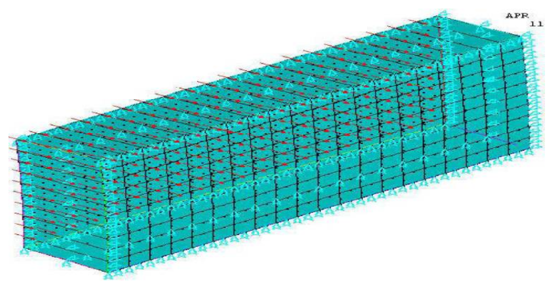
**Figure 3: A Composite Cylinder with Four Layers**




## Finite Element Modeling

A finite element mesh was generated for cross-ply laminate using solid191 element and was shown in Figure 4.

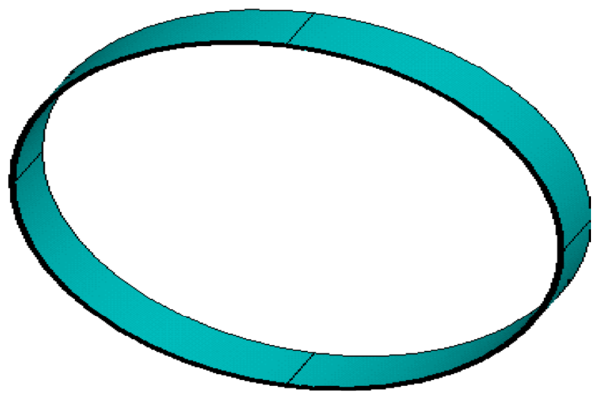
**Figure 4: FE Solid Geometry of Sector**



A finite element mesh was generated for angle-ply laminate using solid191 element and was shown in Figure 5.

A finite element mesh was generated for angle-ply laminate using solid191 eight layered element and is shown in Figure 6.

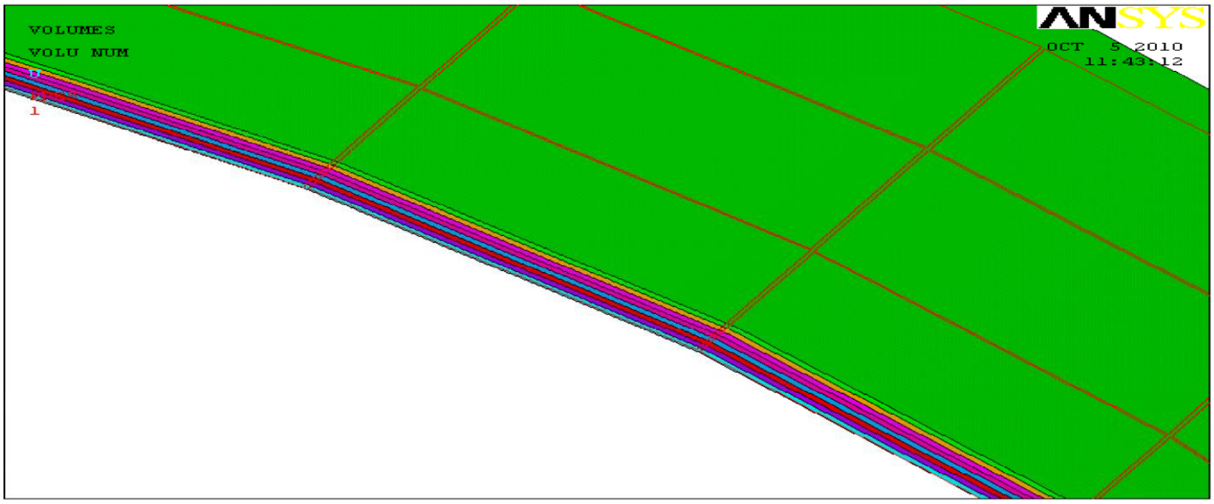
**Figure 5: FE Solid Full Circle Composite**



## RESULTS

The finite element model was generated in ANSYS software and the stresses and deflections were obtained. The results were taken from Cross-ply and Angle-ply laminate.

**Figure 6: FE Solid Composite Cylinder with Eight Layers**




The effect of fiber orientation ($\theta$) and the effect of diameter to thickness ratio (S) are considered in the above cases. The results were taken for various cases they are:

- Four-layered cross-ply laminate at various stacking sequence are:
  - Cross-ply (0/90/90/0)
  - Cross-ply (90/0/0/90)
  - Cross-ply (90/0/90/0)
  - Cross-ply (0/90/0/90)
- Four-layered angle-ply laminate.
- Eight-layer angle-ply laminate.

The material for all layers is carbon-epoxy for both cross-ply and angle-ply laminate.

### Stresses Evaluation

#### *Analysis of Cross-Ply Laminate at Various Stacking Sequence*

The analysis on cross-ply laminate done in the following cases Infinite long cylinder boundary conditions were taken on the end faces of the sector, i.e., degrees of freedom in Z-direction were constrained.

- Symmetric boundary conditions were taken along the edges of sector, i.e., degrees of freedom in Y-direction were constrained.
- An Internal pressure of 1 MPa was applied on the inner surface of the cylinder.

  Cross-Ply (0-90-90-0)

## Effect of (D/T) Ratio-'S'

The variation of the ór with respect to the diameter to thickness ratio(S) plotted in the Figure 7, and it was observed that $\sigma_r$ increases with increase in diameter to thickness ratio.

The variation of the óc with respect to the diameter to thickness ratio(S) plotted in the Figure 8, and it was observed that $\sigma_c$ increases with increase in diameter to thickness ratio.

**Figure 7: Variation of the $\sigma_r$ with Respect to S**

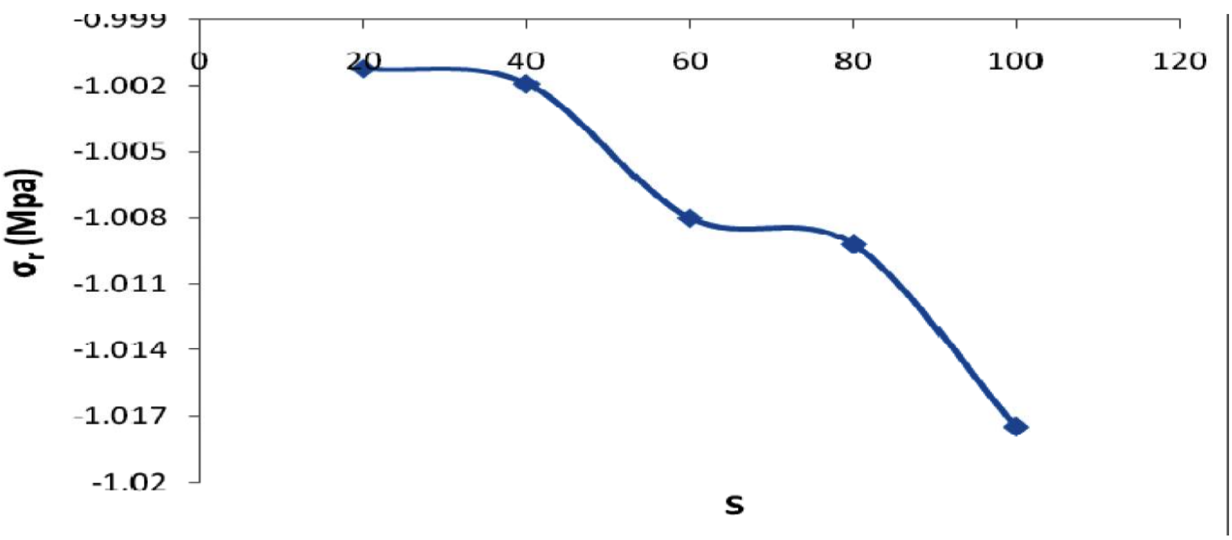
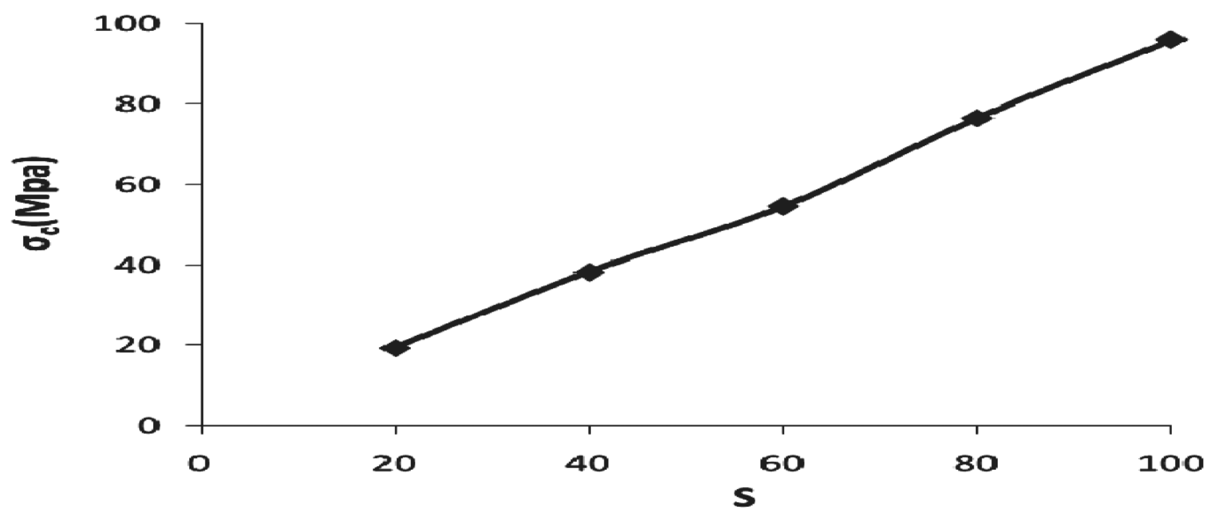



**Figure 8: Variation of the $\sigma_c$ with Respect to S**



The variation of the óa with respect to the diameter to thickness ratio(S) plotted in the Figure 9, and it was observed that $\sigma_a$ increases with increase in diameter to thickness ratio.

The variation of the $\sigma_{rc}$ with respect to the diameter to thickness ratio(S) plotted in the Figure 10, and it was observed that $\sigma_{rc}$ increases with increase in diameter to thickness ratio.

**Figure 9: Variation of the $\sigma_a$ with Respect to S**

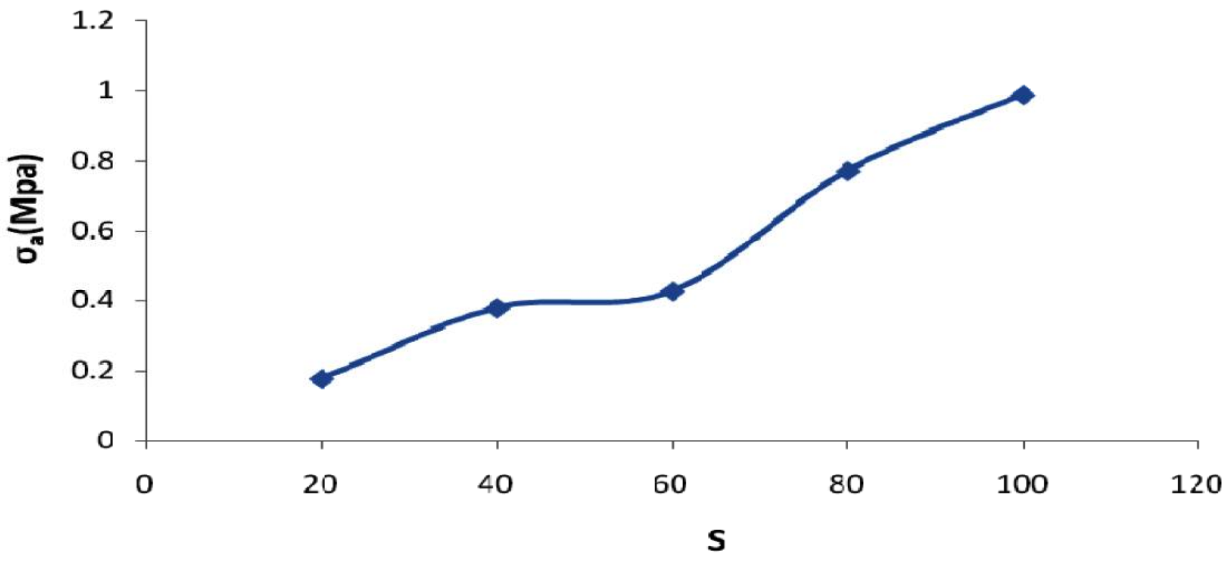
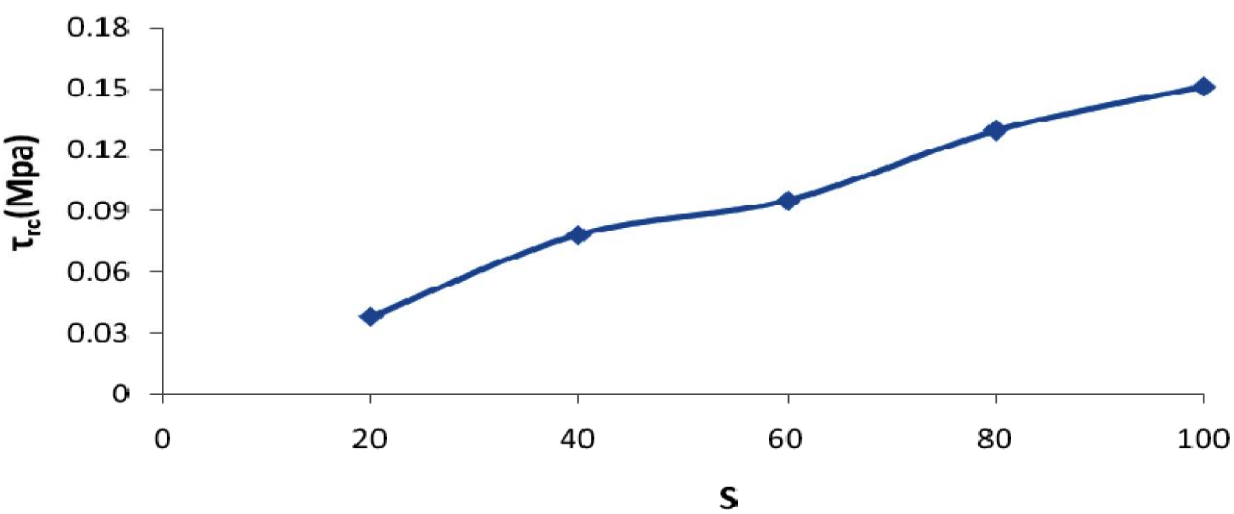



**Figure 10: Variation of the $\sigma_{rc}$ with Respect to S**




## Analysis of Angle-Ply Laminate

The analysis of angle-ply laminate done in the following two cases

**Case 1:** Applying the boundary conditions, Degrees of freedom in Z-direction was constrained on one end of the cylinder.

**Case 2:** Applying the boundary condition Degrees of freedom in Z-direction was constrained on two ends of the cylinder.

Stresses and deflections are obtained for different d/t ratios and different fiber angle in two cases and % error was calculated.

## Effect of (D/T) Ratio-'S'

The variation of $\sigma_r$ with respect to the diameter to thickness ratio(S) plotted in the Figure 11. From the figure, it was observed that $\sigma_r$ increases with increase in diameter to thickness ratio. The % error decreases with increase in diameter to thickness ratio.

The variation of $\sigma_c$ with respect to the diameter to thickness ratio(S) plotted in the Figure 12. From the figure it was observed that the $\sigma_c$ increases with increase in diameter to thickness ratio. The % error decreases with increase in diameter to thickness ratio.

**Figure 11: Variation of the $\sigma_r$ with Respect to S**

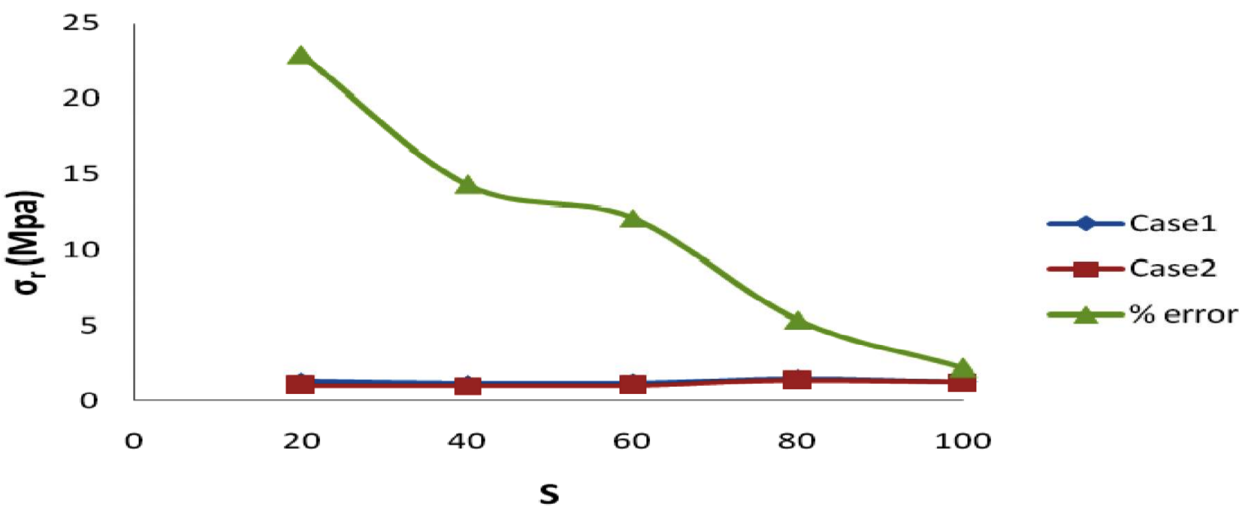
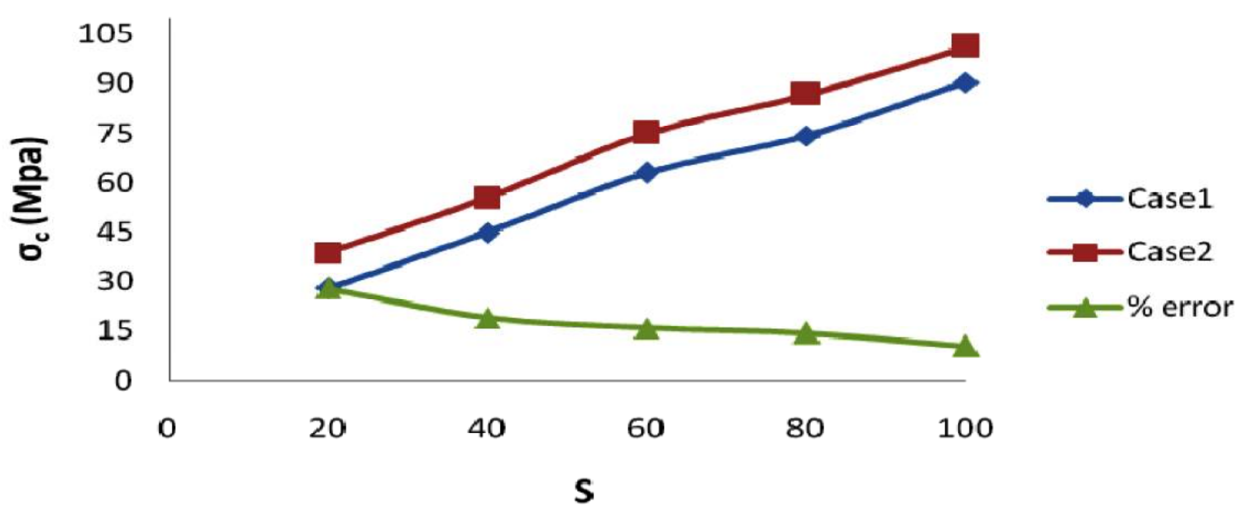



**Figure 12: Variation of the $\sigma_c$ with Respect to S**



The variation of óa with respect to the diameter to thickness ratio(S) plotted in the Figure 13. From the figure it was observed that the $\sigma_a$ increases with increase in diameter to thickness ratio. The % error decreases with increase in diameter to thickness ratio.

The variation of $\sigma_{rc}$ with respect to the diameter to thickness ratio(S) plotted in the Figure 14. From the figure it was observed that the ôrc decreased upto d/t ratio 40 and its value increased between diameter to thickness ratio 40 to 100. The % error increased with increases of diameter to thickness ratio increases.

The variation of $\sigma_{ca}$ with respect to the diameter to thickness ratio(S) plotted in the Figure 15. From the figure it was observed that the ôca decreased upto d/t ratio 40 and its value increased between diameter to thickness ratio 40 to 100. The % error

**Figure 13: Variation of the $\sigma_a$ with Respect to S**

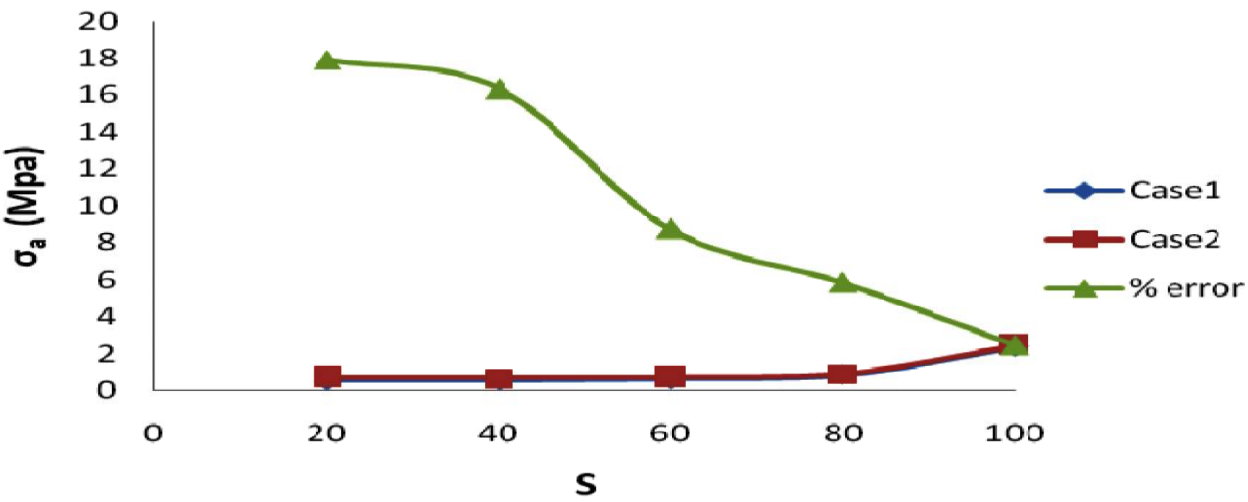



**Figure 14: Variation of the $\sigma_{rc}$ with Respect to S**

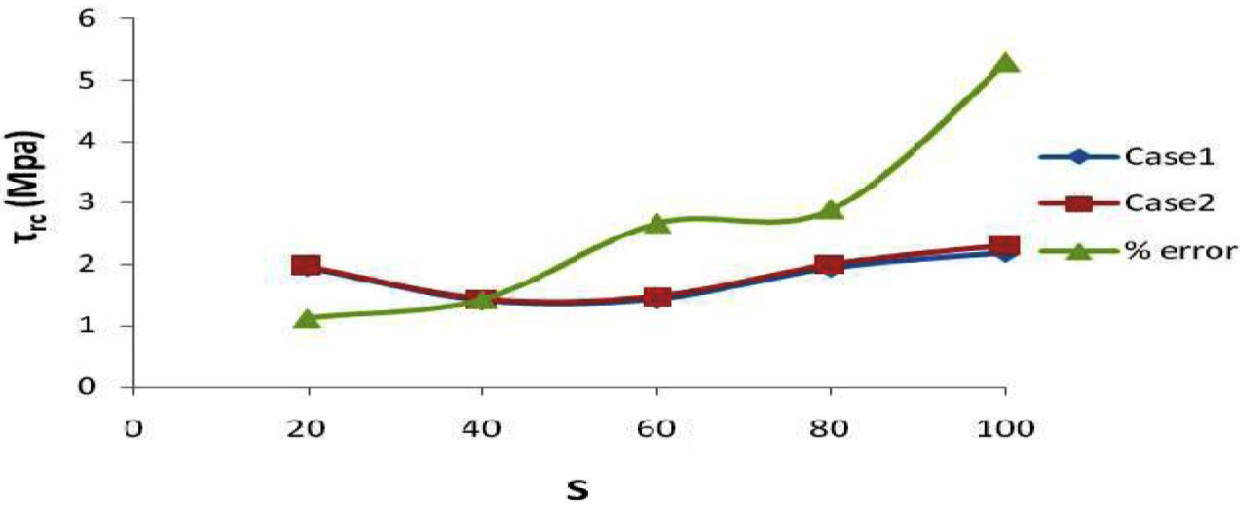
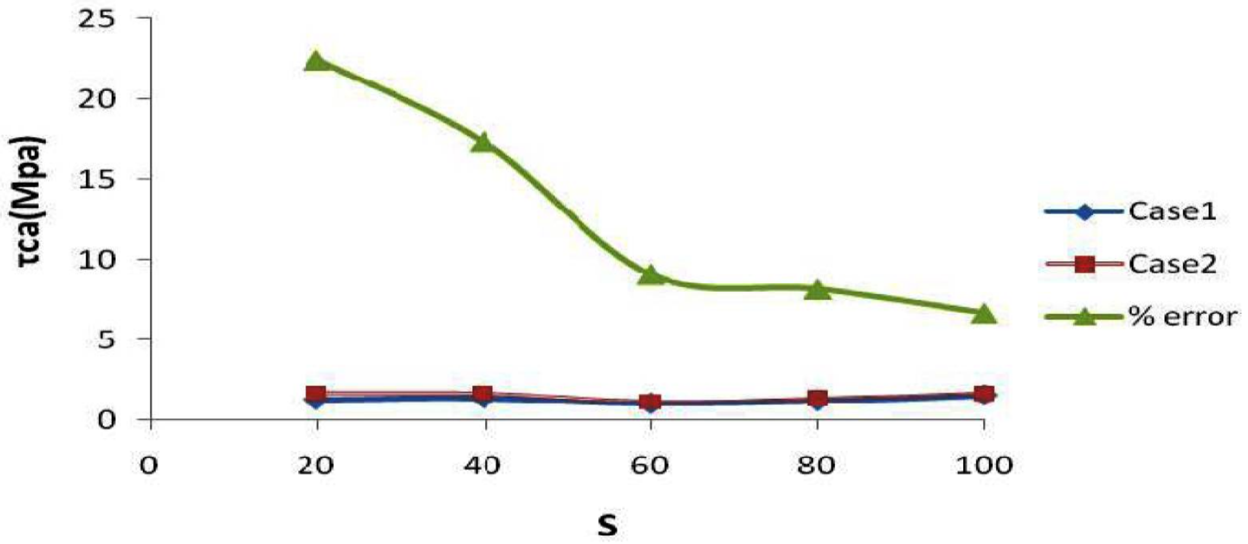


**Figure 15: Variation of the $\sigma_{ca}$ with Respect to S**




increased with increases of diameter to thickness ratio increases.

Cross-Ply (90-0-0-90)

## Effect of (D/T) Ratio-'S'

The variation of transverse deflection with respect to diameter to thickness ratio(S) plotted in Figure 16. From the figure it was observed that the deflection increases with increase in diameter to thickness ratio.

Cross-Ply (0-90-0-90)

## Effect of (D/T) Ratio-'S'

The variation of transverse deflection with respect to diameter to thickness ratio(S) plotted in Figure 17. From the figure it was

**Figure 16: Variation of the Deflection with Respect to S**

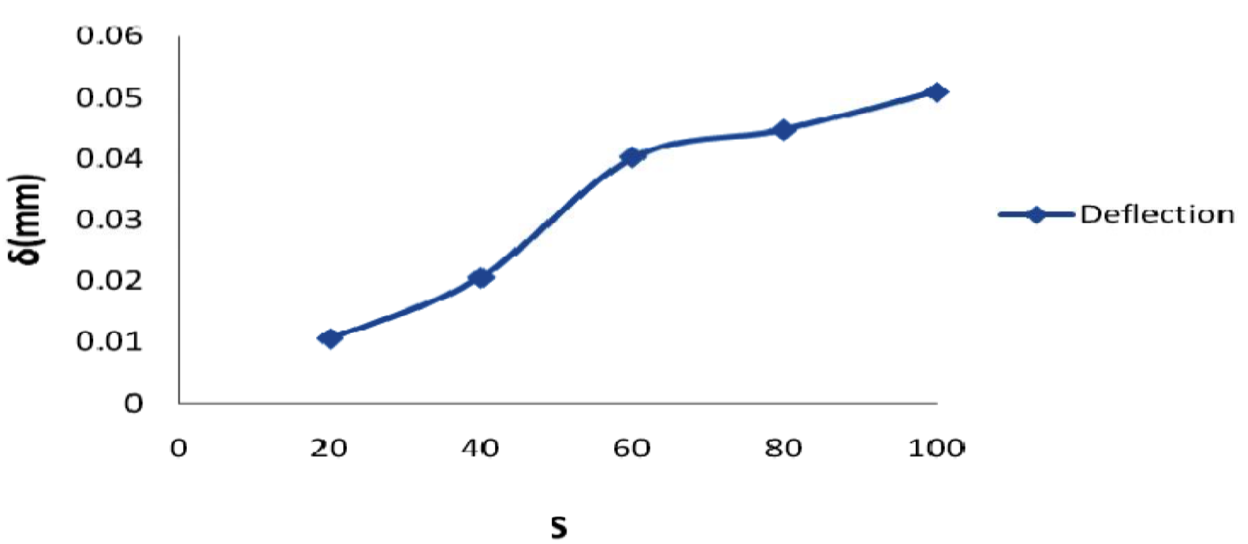
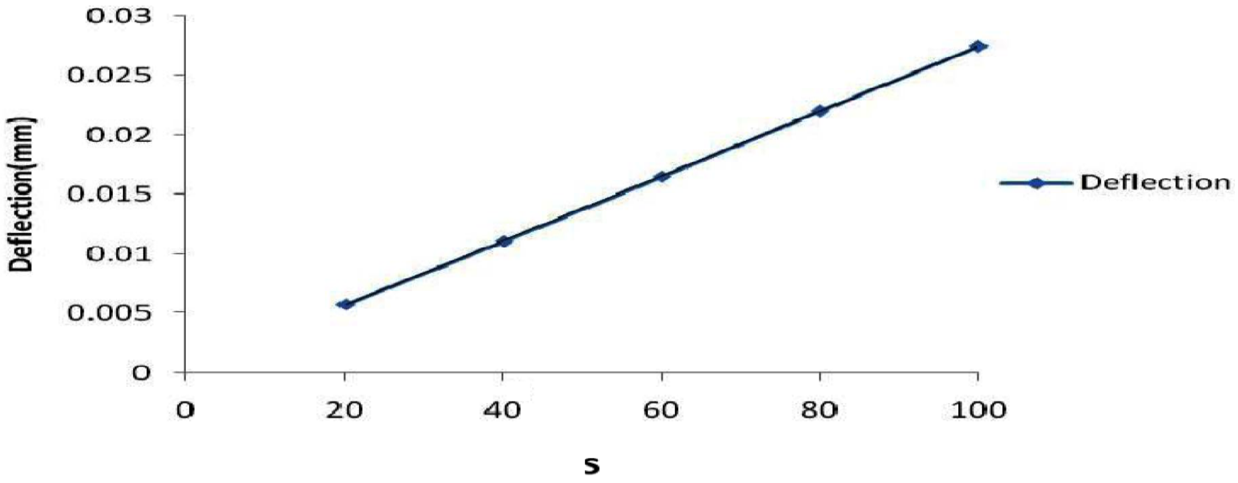


**Figure 17: Variation of the Deflection with Respect to S**




observed that the deflection increases with increase in diameter to thickness ratio.

Cross-Ply (90-0-90-0)

### Effect of (D/T) Ratio-'S'

The variation of transverse deflection with respect to diameter to thickness ratio(S) plotted in Figure 18. From the figure it was observed that the deflection increases with increase in diameter to thickness ratio.

## ANALYSIS OF ANGLE-PLY LAMINATES

### Effect of (D/T) Ratio-'S'

The variation of deflection with respect to the diameter to thickness ratio(S) plotted in the Figure 19. From the figure, it was observed that deflection increases with increase in diameter to thickness ratio. The % error decreases with increase in diameter to thickness ratio.

**Figure 18: Variation of the Deflection with Respect to S**

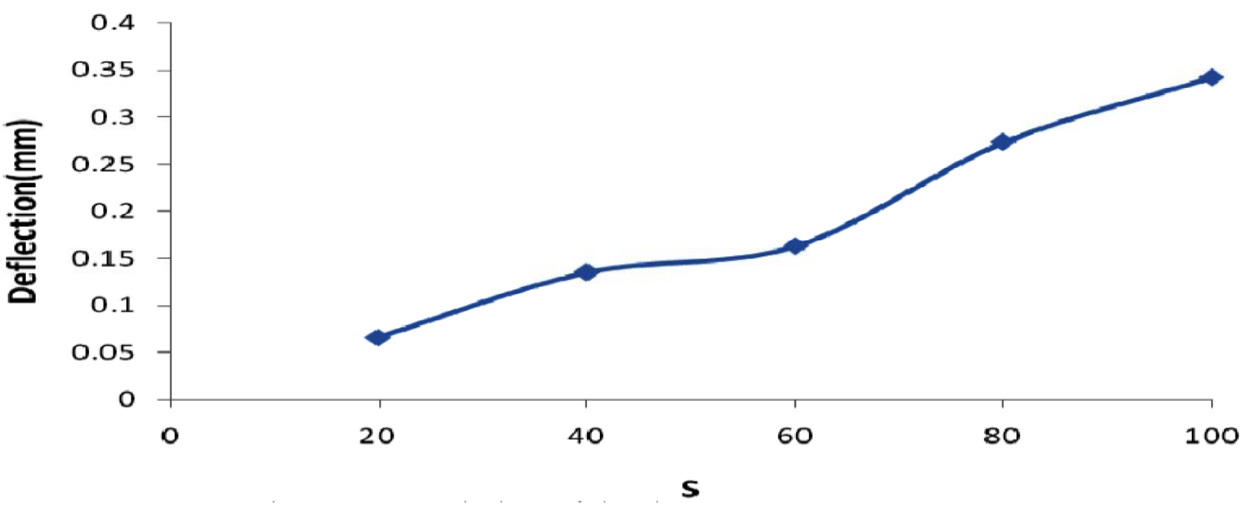
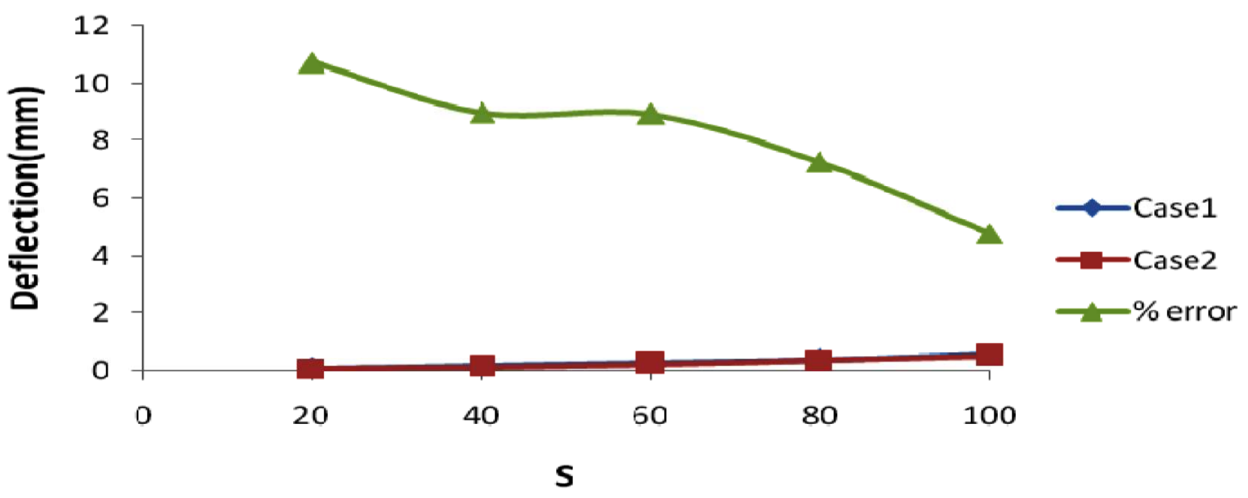


**Figure 19: Variation of the Deflection with Respect to S**




### Effect of Fiber Angle ($\theta$)

The variation of deflection with respect to fiber angle ($\theta$) plotted in the Figure 20. From the figure, it was observed that deflection decreases with increase in fiber angle. The % error increases with increase in fiber angle.

## ANALYSIS OF EIGHT LAYERED COMPOSITE CYLINDER

Following dimensions were taken for angle-ply laminate of eight layered composite cylinder with stacking sequence (90/0/ 5/-5/-5/5/0/90) and results obtained were tabulated as shown below:

Diameter of the cylinder = 100 mm,

Geometry angle = 3600,

Thickness of the cylinder = Dia. of cylinder (100 mm)/S

Where 'S' is the diameter to thickness ratio. 'S'= 100

**Figure 20: Variation of the Deflection with Respect to $\theta$**

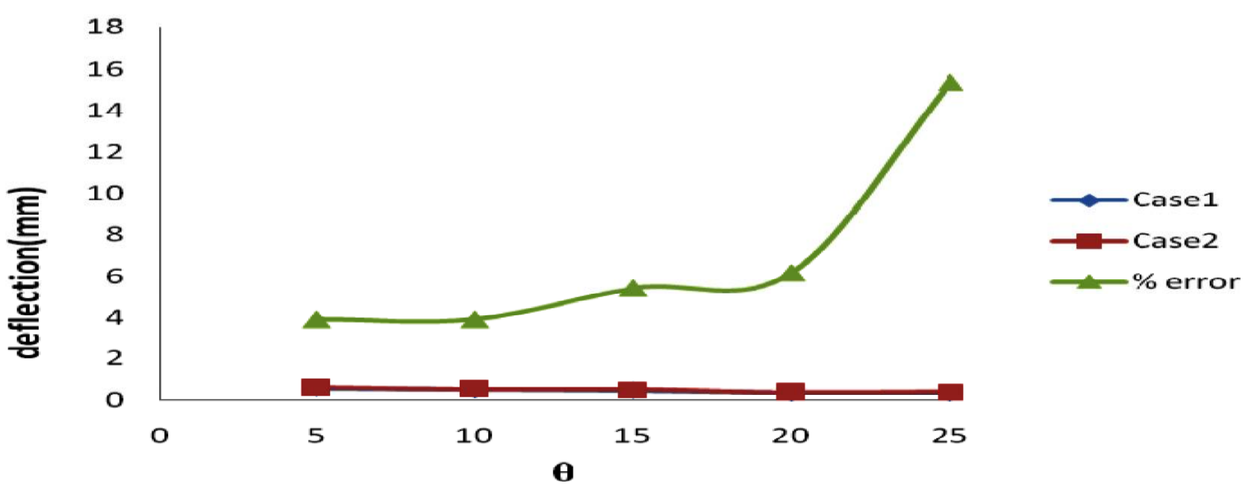


**Table 1: Angle-Ply Laminate of Eight Layered Composite Cylinder with Stacking Sequence (90/0/5/-5/-5/5/0/90)**

| | Deflection (mm) | $\sigma_r$ (MPa) | $\sigma_c$ (MPa) | $\sigma_a$ (MPa) | $\tau_{rc}$ (MPa) | $\tau_{ca}$ (MPa) | $\tau_{ra}$ (MPa) |
|---|---|---|---|---|---|---|---|
| Real Constant 1 | 0.26674 | –3.3053 | 215.330 | 1.6298 | 3.34498 | 0.45949 | 0.061991 |
| Real Constant 2 | 0.26674 | –2.4218 | 100.080 | 1.3263 | 2.00860 | 0.45000 | 0.091792 |
| Real Constant 3 | 0.24735 | –2.1033 | 91.856 | 1.3013 | 23.2150 | 0.34676 | 0.406170 |
| Real Constant 4 | 0.24956 | –1.8884 | 90.391 | 1.4274 | 32.4630 | 0.37816 | 0.450130 |

## CONCLUSION

Analysis of thick Fiber Reinforced Plastic (FRP) composite cylinder has been studied in the present work. The laminate considered for the present analysis was four layered cross-ply laminate and angle-ply laminate. The effect of parameters: 1) Fiber angle ($\theta$), (2) Diameter to thickness ratio(S) were studied and the effect of each parameter on the deflection and stresses was presented.

- Effect of d/t ratio in cross-ply laminate:
  - In cross-ply laminates radial deflection increases proportionately with increase in d/t ratio.
  - No effect of d/t ratio on $\sigma_r$ for all stacking sequence except 90/0/90/0.
  - $\sigma_c$ increases with increase in d/t ratio.
  - No significant change in $\sigma_a$ with d/t ratio for all stacking sequence except 90/0/90/0.
  - The shear stresses are increasing with increase in d/t ratio.
- Length effect on angle-ply laminate:
  - The % error is minimum at d/t ratio 100 for all parameters except $\sigma_{rc}$
  - The % error for radial deflection, $\sigma_r$ slightly increasing with increase in fiber orientation
  - There was no effect of fiber orientation on $\sigma_c$, $\sigma_a$ with respect to % error.
  - The % error maximum at 200 fiber orientation for $\sigma_{rc}$ and $\sigma_{ra}$.
- Effect of d/t ratio in angle-ply laminate:
  - There is no effect on radial deflection with d/t ratio.
  - No variation in $\sigma_r$ with respect to d/t ratio.
  - Proportionate change in the $\sigma_c$ with d/t ratio.
  - Upto d/t ratio 80 there was no effect on $\sigma_a$.
  - There was no effect of d/t ratio on all shear stresses except $\sigma_{rc}$ which varies with respect to d/t ratio and minimum at d/t ratio 40.
- Effect of fiber orientation in angle-ply laminate
  - There was no effect on radial deflection with fiber orientation.
  - There was no effect on $\sigma_r$ with fiber orientation.
  - $\sigma_c$ slightly increasing with respect to the fiber angle.
  - There was no effect on $\sigma_a$ with fiber orientation.

– No variation in the all shear stress with respect to fiber orientation except $\sigma_{rc}$ which is decreasing with increase in fiber angle.

## SCOPE OF FURTHER WORK

- Validity of continuity condition along length direction by varying fiber orientation and d/t ratio.
- Analysis with other stacking sequence.
- Analysis with variable fiber orientation with respect to length.
- Effect of unequal ends of cylinder.
- Analysis of cylinder with closed ends.

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