Delamination Analysis and Experimental validation of Compression loaded Composite cylinder for composite pressure vessel

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Abstract: The design and development of composite pressure vessels are driven by the need for minimum weight. Design, analysis, and optimization complexities are compromised due to constraints of computational resources and shorter cycle time. Advanced lightweight laminated composites are increasingly being used in modern Aerospace structures, for enhancing their structural efficiency and performance. One of the most common failure modes for composite structures is delamination. The remote loading applied to the composite components are typically resolved into interlaminar tension and shear stresses at discontinuities that create a mixed mode I, mode II and mode III delaminations.

In this study, we focused on the former option by keeping the ply sequence constant and varying the associated ply angle. For the case of un-cracked shell, the cylindrical shell with the composite ply angle of 30 leads to maximum load capacity against buckling load. In addition, the effect of crack length and orientation on the buckling behavior of composite cylindrical shells comprising a through crack is studied, using a special meshing scheme and providing the inter205 element. Based on the fracture analysis and calculated the crack growth (7.5 TON) and failure load (10.5 TON) based on power law

Cylinder were tested up to 7.5 TON and LVDTs removed. The cylinder failure load is 11.2 TON against a failure strain in carbon fabric/ epoxy composite is 3200-3500 micro-strains. They show good agreement at all the regions. However, the result finite element analysis shows close agreement with the experimental results. Also, the design stresses were within safe limits. Radial displacement as per FEA is 0.8mm and experimental value is 0.6mm at 7.5 Ton load. For the case of un-cracked cylindrical shell with the composite ply angle of 30 leads to maximum buckling capability. Investigation was carried out on the composite cylinder with delamination, when cylinder was subjected to compressive load. The strain energy release rate is increase in mode-2 leads to reducing the buckling factor was observed.

Keywords- Fracture analysis, inter205 and composite cylinder, etc

1. Introduction

Composites are ideal candidates for making composite rocket motor casing (CRMC) which are essentially cylindrical pressure vessels comprising two tapered-end domes, and end-fittings terms as polar bosses and skirts. Polar bosses have features for connecting the igniter and the nozzle of the missile to the casting and the skirts for transfer of loads to interfacing systems. The RMC generally has different sizes for the two end openings due to varied interfacing parts. This presents a challenge for filament winding technology. That has to be non geodesic in nature, which successfully nets the fibre in tension. The optimum composites RMC need to have high specific strength and light weight and needs to with stand high internal pressure. The composite generally includes carbon and aramid fibers. Advanced carbon fibre composite rocket motor casings for propulsion stages and such CRMCs have been fabricated indigenously.

Filament winders can expect greater fiber placement control due to increased tack of the towpreg, leading to increased design freedom and more accurate burst pressure predictions. The delamination’s mostly occur in CRMC between fabric to fabric layers on dome portion as well as skirt locations. To study the behaviour and also determining the fracture toughness of a material between the fabric and fabric layer. The model is considered as a composite plate, by creating the delamination in between the fabric and fabric layer, is used to carried out the fracture toughness, buckling analysis and testing of composite plate by varying delamination sizes using carbon fabric prepreg by hand lay-up process.

Fracture behaviour of Epoxy composites is investigated in dry condition at room temperature. Materials used in this study are epoxy nanocomposites with different loadings of nano-clay particles. Tests were conducted to study the effects of different loadings of nano-clay particles on fracture toughness. A comparison is carried out based on the effect of the nanoclay particles on fracture toughness of epoxy. When we compare the several experimental results from the literature [3-6] it can be found that the fracture toughness has increased with increase in the percentage of the additive materials like glass beads [3], particulate [4], poly ether imide [5], and tyre rubber [6].

In the current study a modified Arcan specimen is designed to determine the fracture toughness of Mode-I, Mode-II and Mode-III for carbon fabric towpreg composite[7]. Also carried out the delamination analysis of composite cylinder to find out the load bearing capability with different size of patches. And composite cylinder were fabricated with patch and load tested to find out the failure behaviour.

2. Background

Interlaminar fracture mechanics has proven useful for characterizing the onset of delaminations in composites and has been used with limited success primarily to investigate onset in fracture toughness specimens and laboratory size coupon type specimens. Future acceptance of the methodology by industry and certification authorities however, requires the successful demonstration of the methodology on the structural level. In this paper, the state-of-the-art in fracture toughness characterization, and interlaminar fracture mechanics analysis tools are described. To demonstrate the application on the structural level, a panel was selected which is reinforced with stringers. Full implementation of interlaminar fracture mechanics in design however remains a challenge and requires a continuing development effort of codes to calculate energy release rates and advancements in delamination onset and growth criteria under mixed mode conditions

3. Fracture toughness of CFRP

The fracture toughness of CFRP is determined by modifying the Arcan specimen. Arcan specimen gives the opportunity of utilizing just one kind of specimen for extracting fracture properties for mode I, mode II and Mode III of materials. The specimen is modified since the procedure of joining the specimen to main apparatus is complex. Adhesive joints are more used in many experiments but steps of preparing two parts and adherent need so much time and cost and also employing advanced equipments is needed. These kinds of joints have very low resistance against shear forces and using them in mode II fracture test may lead to unreliable results.

For this an I-section specimen is developed. In the I-section the three different fixtures are designed and used for testing of specimens for the three modes of strain energy release rate. Summary of test results for two different material are given in Table.1.

Table-1: Strain energy release rate

S.No	**Material**	**Strain energy release rate GI, GII & GIII (N/mm)**		
		Mode-I	**Mode-II**	**Mode-III**
1.	Carbon towpreg-T700 composite	1.19	1.929	0.287
2.	BD Carbon fabric prepreg composite	1.08	1.823	0.296

4. Delamination analysis of composite cylinder

The composite cylinder having a size of length 600 mm and 300 mm diameter is considered for a design load of 66.5KN. The composite shell is given in Figure.1.The CFRP materials exploited and property details are tabulated below in Table.2. Delamination analysis, the inter element is considered and nodes are separating at patch location. INTER205 is a 3-D 8-node linear interface element. When used in conjunction with 3-D linear structural elements (SOLID45, SOLID185, and SOLSH190), INTER205 simulates an interface between two surfaces and the subsequent delamination process, where the separation is represented by an increasing displacement between nodes, within the interface element itself. The nodes are initially coincident. Size of the delamination is 200mmX100mm. Delamination analysis is carried out by considering VCCT technique and results are given in Figure.2 to 6.

Table.2: Material Properties

Property	**Carbon fiber /epoxy**	**Carbon fabric/epoxy**
Young's modulus,(E_x) (GPa)	140	66
Young's modulus,(E_y) (GPa)	8	67
Young's modulus,(E_z) (GPa)	8	4.5
Poison's ratio,ν_{12}	0.25	0.23
Poison's ratio,ν_{23}	0.32	0.35
Poison's ratio,ν_{13}	0.25	0.23
Shear modulus,(G_{12}) (Gpa)	3.58	3.5
Shear modulus,(G_{23}) (Gpa)	4.50	4.5
Shear modulus,(G_{13}) (Gpa)	3.58	3.5

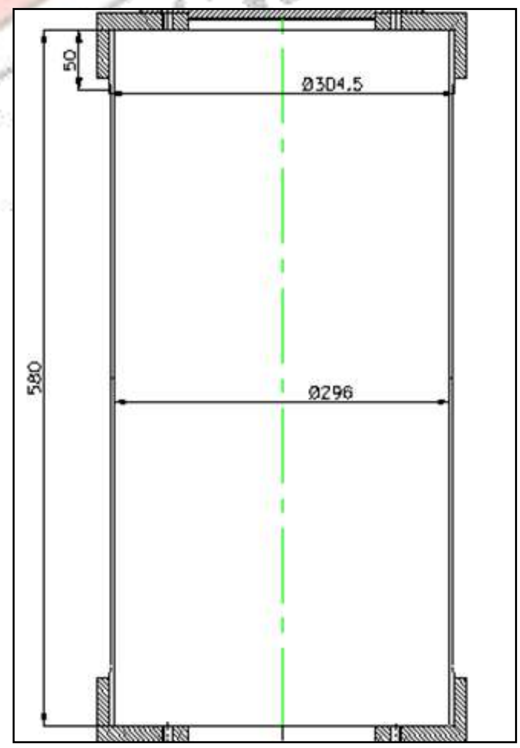

Figure.1: Composite shell

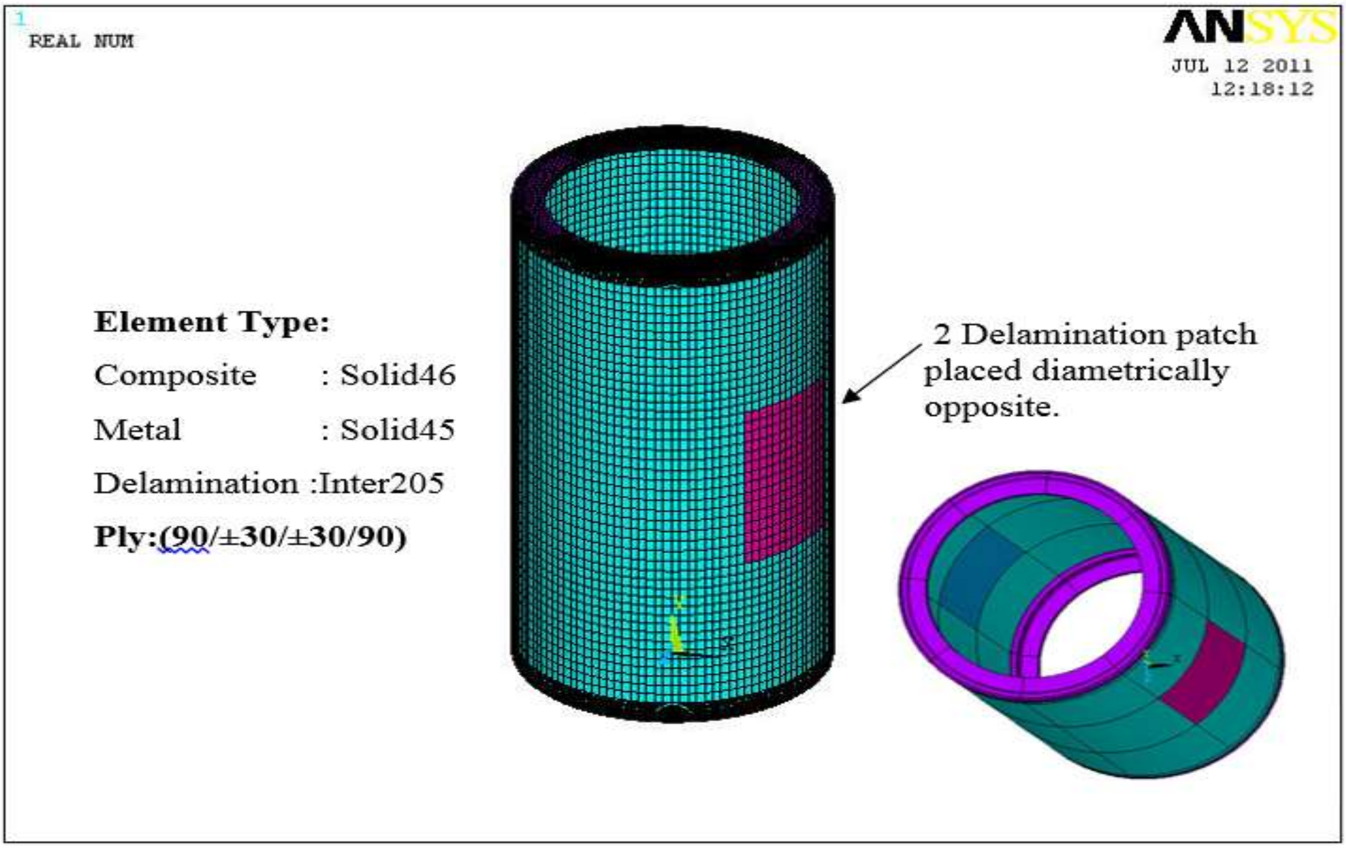

Figure.2: FE model with delamination patch

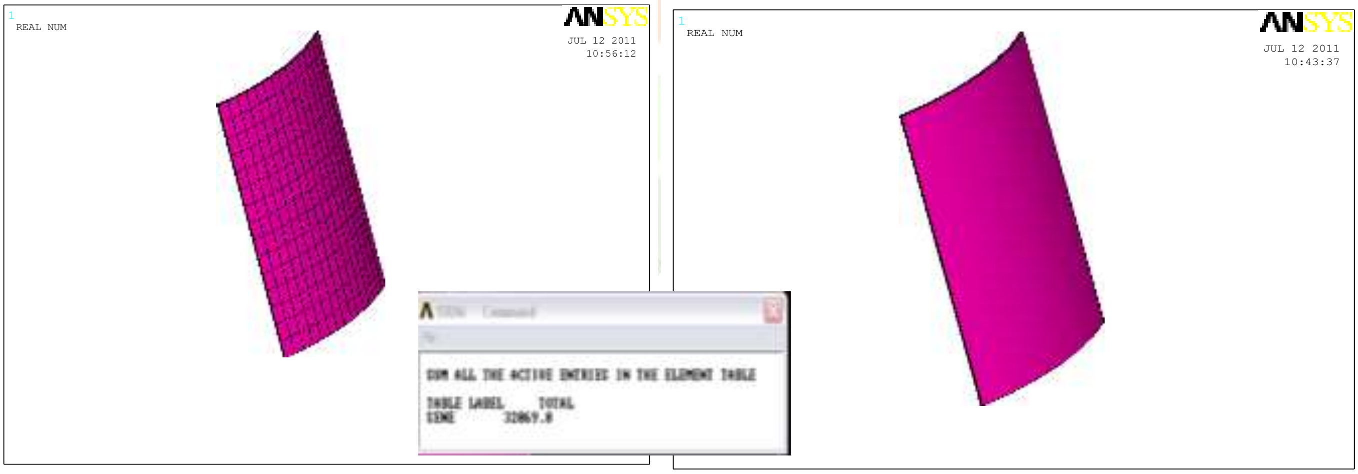

Figure.3: Strain energy at inter element

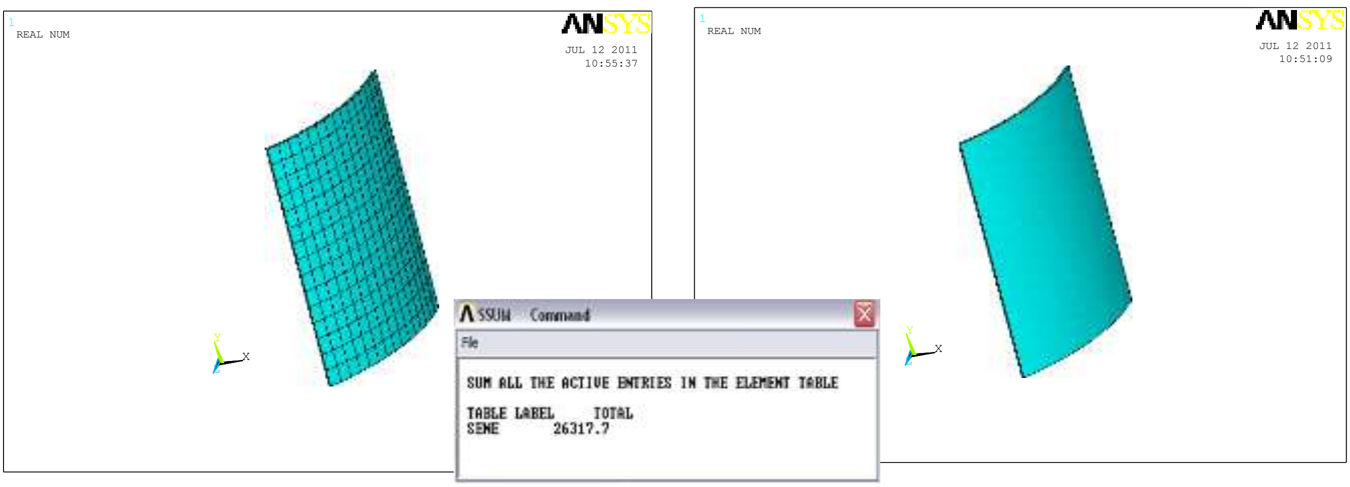

Figure.4: Strain energy at bottom layer of patch

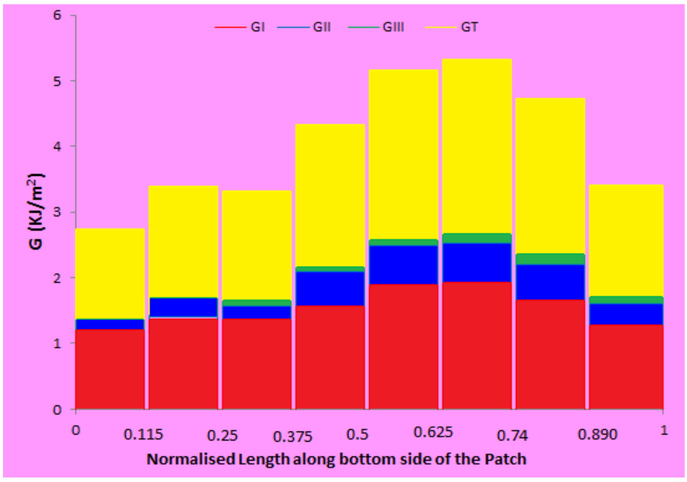

Figure.5: Variation of GI, GII, GIII, GT along bottom edge of the patch

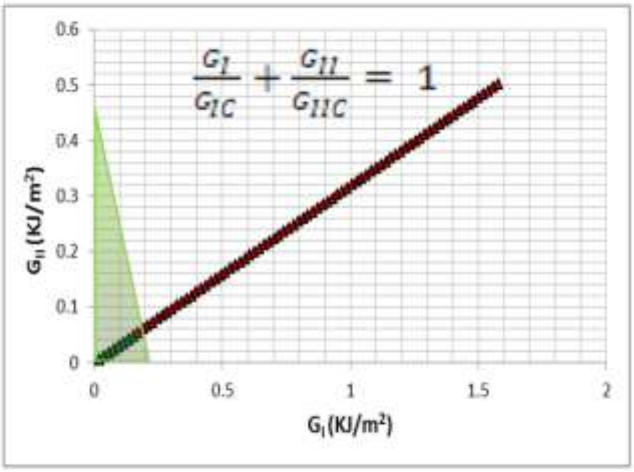

Figure.6: Fracture Critical Load of Cylinder

5. Experimental Investigation

To validate the results obtained from finite element analysis, the composite shell was carried out with the three different delamination sizes being studied. Composite shell were manufactured and confirmed to be devoid of any defects by ultrasonic inspection. The process details are given in Figure.7. A test fixture was designed to simulate the axial compressive loading .Load was gradually applied in increments and strain data was recorded using strain data acquisition system. The shell were tested until failure. The test set up is shown below in Figure.8, and failure mode of shell is shown in Figure.9 to 10.


Figure.7: Filament winding of CFRP shell


Figure.8: Test setup


Figure.9: strain gauge at patch

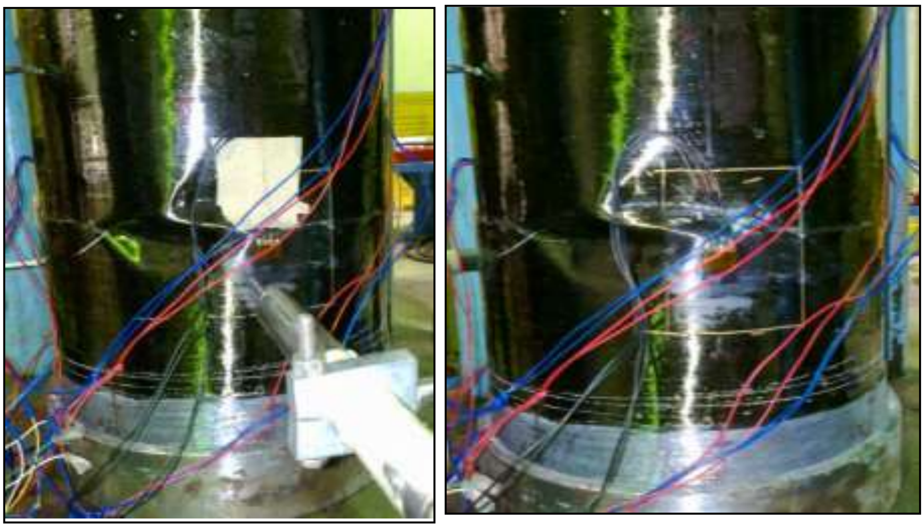
Figure.10: Failure modes of shell

7. Test Results

The buckling load results for Layered-46 element type and from practical test data are showing different. To cater to the manufacturing defects knock down factor of 0.8 is considered and critical buckling load estimated. It is observed that increase in material stiffness is directly proportional to buckling load. The results are given based on load test performed on the actual composite cylinder. The three locations considered for testing and the strain comparison are given in Figure.11 to 14.

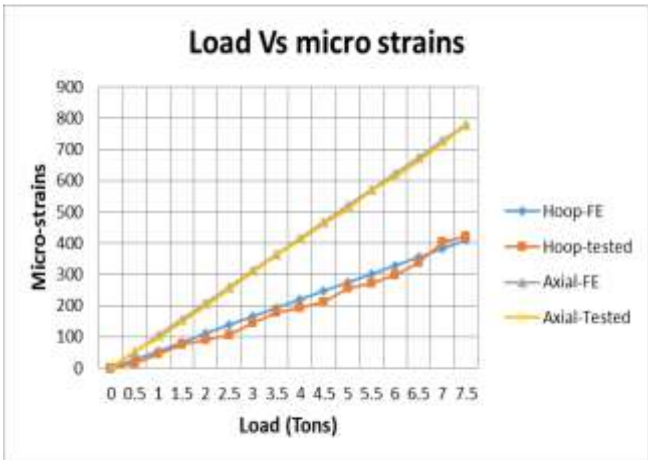

Figure.11: Measured strains at top of cylinder

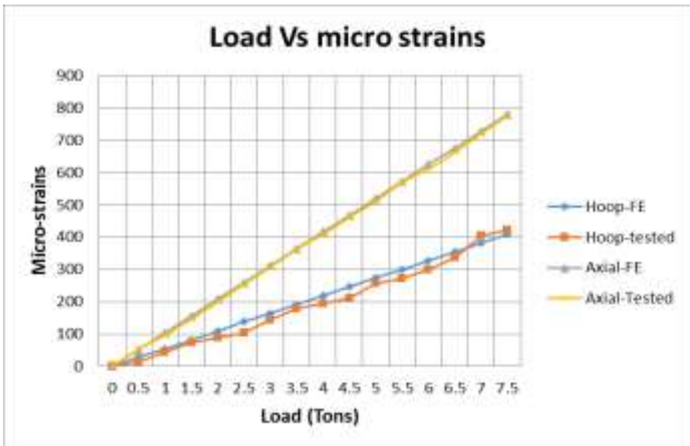

Figure.12: Measure strains at delamination zone

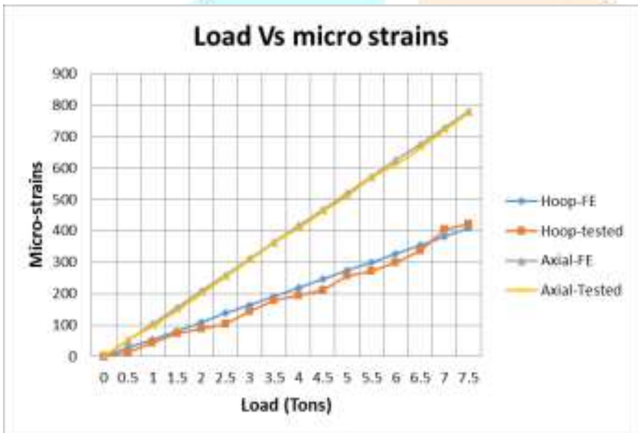

Figure.13: Measure strains at bottom of cylinder

Figure.14: Measure radial & axial displacements

8. Discussions

In this study, eigenvalue analysis is carried out to explore the linear buckling behavior of un-cracked and cracked composite cylindrical shells subject to axial compression. Linear buckling analysis, apart from its theoretical importance, is the basis for most of the available design guides and provides design engineers with an initial estimate of the buckling load for various configurations in early stages of design. In this study, we focused on the former option by keeping the ply sequence constant and varying the associated ply angle. For the case of un-cracked shell, the cylindrical shell with the composite ply angle of 30 leads to maximum load capacity against buckling.

In addition, the effect of crack length and orientation on the buckling behavior of composite cylindrical shells comprising a through crack is studied, using a special meshing scheme and providing the Inter205 element. Based on the fracture analysis and calculated the crack growth (7.5Ton) and failure load (10.5 Ton) based on power law. Cylinder were tested up to 7.5 TON and LVDTs removed. The cylinder failure load is 11.2 TON against a failure strain in carbon fabric/ epoxy composite is 3200-3500 micro-strains. They show good agreement at all the regions. However, the result finite element analysis shows close agreement with the experimental results. Also, the design stresses were within safe limits. Radial displacement as per FEA is 0.8mm and experimental value is 0.6mm at 7.5 Ton load.

9. Conclusion

The composite cylinder is successfully designed to meet the stipulated loading condition. The geometry of the cylinder has been obtained after giving it through analytical treatment. In this study, we focused on the former option by keeping the ply sequence constant and varying the associated ply angle. For the case of un-cracked shell, the cylindrical shell with the composite ply angle of 30 leads to maximum load capacity against buckling .In this study, Delamination is assumed to exist prior to loading. Buckling behavior of laminated CFRP cylinder with delamination is investigated using finite element code (ANSYS) and using numerical models validated by experimental static buckling test.**The fracture analysis approach with VCCT technique can be applied in delamination analysis of CPVs for defence applications.**

8. References:

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