NUMERICAL STUDY ON CORE CONFIGURATIONS IN SANDWICH METAL COMPOSITE CYLINDER UNDER COMBINED LOADING CONDITION

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ABSTRACT

Thin structures are integral to various industries, including construction, electronics, aerospace, and automotive engineering, due to their lightweight and efficient design. These structures are made as sheets, plates, shells, and membranes, and their mechanical performance is shaped by material properties, geometric constraints, environmental effects, and loading conditions .However, the design and analysis of thin structures have several challenges, primarily due to their vulnerability to buckling, deformation, and failure under applied loads. Optimising their geometry and incorporating structural reinforcements like ribs, stiffeners, and corrugations can enhance their load-bearing capacity, stiffness, and stability, mitigating these risks . Features like rectangular cutouts can further increase the risk of concentrating stress and diminishing structural integrity. In aerospace vehicles, apart from the compressive load due to thrust force, pressure loading from aerodynamic forces, internal pressurisation, and environmental variations induce stresses that can cause buckling, deformation, and stress concentrations. Features like cutouts and stiffeners again heighten these risks, especially under combined thermal and pressure effects in spacecraft. To mitigate these challenges, there is a need to develop properly optimised designs with suitable stiffener configurations and proper material utilisation such as advanced materials like alloys and composites, to ensure stability and reliability. In this thesis work, a numerical investigation is conducted to understand the impact of core configurations of a sandwich metal composite cylinder under internal pressure, compressive and torsional load.

Keywords: *Sandwich metal composite cylinder, Structural analysis, Axial compressive load, Torsional load, Core configuration, Pressure gradient .*

1. INTRODUCTION

1.1 General Background

Thin structures are widely utilized across various industries, including construction, engineering, electronics, and aerospace. These structures, which can be in the form of sheets, plates, shells, or membranes, are designed to be lightweight, efficient, and often flexible. However, their design and analysis cause challenges due to their susceptibility to buckling, deformation, and failure under applied loads. The mechanical behaviour of thin structures is influenced by factors such as material properties, geometric constraints, loading conditions, and environmental factors. By optimising geometry and incorporating structural reinforcements like ribs, stiffeners, and corrugations, the load-bearing capacity, stiffness, and stability of these structures can be improved. For past few decades, Sandwich metal composite structures have been increasingly used in the aerospace industry due to their unique combination of strength, stiffness, and lightweight properties. The primary advantage of sandwich metal composite structures lies in their ability to achieve a high stiffness-to-weight ratio, which is critical in aerospace applications where weight reduction is prime objective. This allows for the design of structures that are both lightweight and capable of bearing substantial loads without compromising on performance or safety. These structures are commonly used in the fabrication of fuselages, wings, empennages, and interior components of aerospace vehicles, where both strength and weight savings are essential for fuel efficiency, payload capacity, and overall performance. However, the design and performance of these structures depend heavily on factors such as the choice of face sheet material, core configuration, and load distribution. For aerospace applications, factors such as fatigue resistance, resistance to high-temperature environments, and the ability to endure external and internal pressure loads are critical.

1.2 Sandwhich metal composite structures

A sandwich metal composite structure is a lightweight and high-strength material design that consists of two thin, strong outer metal layers (face sheets) and a low-density core material placed between them. The face sheets are typically made from metals like aluminum alloys, titanium, or high-strength steel, which provide the necessary mechanical strength and resistance to external loads. The core material, often made of honeycomb, foam, or other composite materials, serves to provide low weight, shear resistance, and additional stiffness to the structure. These structures offer a highly efficient way to achieve a strong, yet lightweight design, which is particularly important in aerospace, automotive, and marine applications, where minimizing weight while maximizing strength is essential. Sandwich metal composites can be optimized to specific performance requirements, such as thermal and acoustic insulation, resistance to fatigue, and high-temperature stability.

1.3 Core Configuration

In sandwich metal composite structures, the core material plays a crucial role in providing strength, stiffness, and lightweight characteristics. The core configuration determines the overall mechanical performance, including resistance to shear, compression, and bending. Several types of core configurations are commonly used in sandwich metal composite structures, each with specific advantages depending on the application. Some of the core configurations are discussed below

1.4 Buckling

Buckling is a critical failure mode that occur when a slender or thin-walled structure experiences sudden and catastrophic deformation under compressive loads. This deformation typically manifests as lateral or sideways bending, indicating a loss of stability in the structure. Understanding the mechanics of buckling is essential in engineering design, as it can lead to structural collapse or failure. The primary cause of buckling is the instability generated by compressive loads acting on a slender element, such as a column, beam, or thin-walled component. When a compressive load is applied, it induces bending stresses within the material. As the load increases, these stresses build up, and the structure may reach a critical point where small imperfections or disturbances trigger significant deviations from the expected behaviour, resulting in buckling. Several factors influence buckling, including the slenderness ratio, material properties (such as modulus of elasticity and yield strength), boundary or end conditions, and the method of load application .

1.5 Modal Analysis

Modal analysis is a fundamental technique in structural engineering used to thesis and understand the dynamic behaviour of structures. It involves determining the natural frequencies, mode shapes, and damping characteristics of a structure, which are essential in predicting how the structure will respond to dynamic loads such as vibrations, earthquakes, or wind forces. This analysis is critical for ensuring the safety, performance, and reliability of structures, as resonance—when a structure vibrates at its natural frequency—can lead to catastrophic failures. Modal analysis aids in identifying critical regions of a structure prone to excessive vibration, enabling engineers to make informed design modifications or implement vibration control measures. It is extensively applied in various industries, including aerospace, automotive, and civil engineering, to optimise designs and prevent structural damage. The insights from modal analysis are also used to validate finite element models and ensure compliance with safety standards.

1.6 ANSYS SOFTWARE

ANSYS is a versatile and powerful engineering simulation software widely employed for finite element analysis (FEA), computational fluid dynamics (CFD), and other advanced simulations across multiple industries. It enables engineers to model and analyze the performance of components and systems under various loading conditions, considering thermal, mechanical, and fluidic interactions. ANSYS supports a broad range of analyses, including structural, thermal, fluid dynamics, electromagnetics, and optimization, making it suitable for applications in automotive, aerospace, electronics, biomedical engineering, and more. One of its most notable features is its user-friendly interface, which simplifies the creation of complex geometries and simulations, allowing engineers to quickly model real-world scenarios.

2. LITERATURE REVIEW

Frostig (1998) analyzed the buckling of sandwich panels with a flexible "soft" core using high-order theory [1]. The study developed governing equations for panels with metallic or composite skins and isotropic or orthotropic cores, such as foam or honeycomb. Results highlighted bifurcation loads, local and global buckling modes, deformations, and stresses at the skin-core interface. Numerical analysis of simply supported panels showed that local buckling often dominated, influenced by core flexibility and imperfections. Closed-form solutions were provided for identical and non-identical skin panels under compressive.

Papadopoulos et al. (2013) investigate the impact of random geometric imperfections on the I-profile steel beam–column members and portal frame structures under compressive load [2]. The geometric imperfections are assumed to be non-homogeneous Gaussian random fields. The results provide valuable insights into the imperfection-induced buckling behaviour and the variability of buckling loads for these structures, highlighting how imperfections and core flexibility influence the overall buckling response.

Wang and Abdalla (2015) studied global and local buckling in orthogrid- and isogrid-stiffened composite panels[3]. They used homogenized properties from classical lamination theory and applied Bloch wave theory for local buckling analysis. By integrating skin and stiffeners at the cell level, the approach captures critical instabilities and predicts material failure. Numerical simulation results show the method’s accuracy in predicting local buckling loads, aligning with finite element calculations for various stiffener configurations, confirming its validity for composite flat panels and cylindrical structures.

Kwon et al. (2016) developed a new mechanical device by to apply internal pressure loading to cylindrical structures, enabling the determination of their failure strength and failure mode under pressure[4] . This device can be used with a uniaxial testing machine, does not require fluid to generate internal pressure. It consists of two truncated conical rams and eight identical wedges. The device’s effectiveness was evaluated through finite element analyses of metallic cylinders and analytical methods. Experimental tests were performed on aluminum alloy cylinders to compare failure strengths with numerical and analytical results. Additionally, composite cylinders made of glass-fiber and carbon-fiber woven fabrics were tested, with the experimental results aligning well with predictions from a multiscale analysis model.

Vuong and Nguyen (2020) conduct an analytical investigation into the buckling and post-buckling behavior of shear deformable sandwich toroidal shell segments with a functionally graded core and homogeneous face sheets [5]. The core's material properties vary in the thickness direction using a power-law distribution based on volume fraction index. The shells, supported by an elastic foundation, are subjected to axial compressive or thermal loads. Using Reddy's third-order shear deformation theory (TSDT), the Galerkin method solves the governing equations to derive closed-form expressions for buckling stresses and post-buckling behavior. The work explores the impact of material, geometric parameters, and elastic foundations on stability, and compares the results from TSDT with classical shell theory (CST).

Arefi and Najafitabar (2021) investigates the buckling and free vibration analyses of a sandwich beam comprising a soft core with integrated functionally graded graphene nanoplatelets (GPLs) reinforced composite face sheets [6]. Kinematic relations are developed based on the Extended Higher-Order Sandwich Beam Theory (EHSPT), and governing equations are derived using Ritz-Lagrange formulation. The effective mechanical properties of the epoxy/GPLs composites are determined through the Halpin-Tsai micro-mechanical model and the rule of mixture. Numerical results are obtained using the Ritz Method, presenting natural frequencies and buckling loads in relation to various parameters such as weight fraction and distribution of graphene nanoplatelets, length-to-thickness ratio, core-to-surface ratio, and different boundary conditions. To ensure the accuracy of the results, a comparative study is conducted before presenting the complete numerical results. The findings indicate that the sandwich nanobeam exhibits maximum and minimum natural frequencies, as well as critical buckling loads, for FG-X and FG-O distributions, respectively.

3.METHODOLOGY

In this thesis work, a numerical model (Structural analysis) is developed to understand the influence of core configuration over the metal sandwich cylinder under internal pressure, axial loading and torsional load using ANSYS software. Initially, Proposed FE model is validated using numerical and experiment data available in **B. Wang et al. (2018)** [16]. Three different design cases are addressed in the work, namely solid cylinder, metal composite structure with rectangular grid core and metal composite structure with isogrid core. Structural analysis, Buckling analysis and Modal analysis of the proposed three designs is conducted to understand its structural stability under internal pressure.

4.MATERIAL PROPERTIES

For this thesis work, Aluminium 6061 are chosen for conducting the initial numerical simulation and its material properties are given in Table

Table 1 Material Properties

Material Properties	Value
Youngs Modulus	70.29 GPa
Poisson Ratio	0.33
Bulk Modulus	68.91 GPa
Shear Modulus	26.43 GPa
Density	2713 Kg/m^3
Yield strength	260 MPa
Ultimate Strength	313 MPa

5.NUMERICAL SIMULATION

5.1 Model Analysis

In the current study, modal analysis of all three design configurations are conducted to evaluate its natural frequency. The boundary conditions applied to the model for conducting modal analysis are all DOF of bottom end ring of the cylinder are constrained. The boundary condition is depicted in fig 1

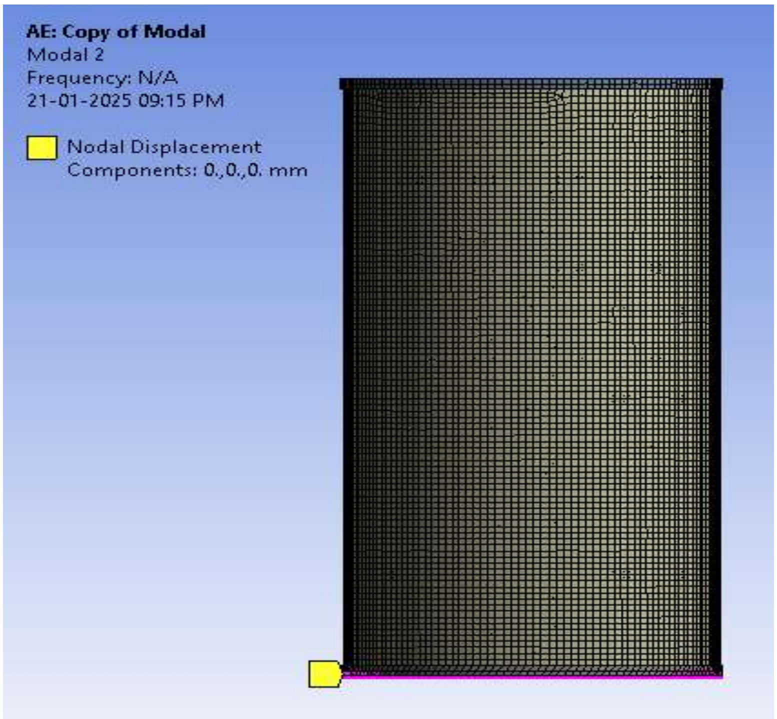

Fig 1 Boundary condition for model Analysis

5.2 Structural Analysis

In this study, the structural integrity of the structures mentioned in 3.6 is found by conducting structural analysis with suitable boundary conditions. Typical FE meshed model developed for the solid cylinder is shown in fig2and with a mesh size of 2 mm.

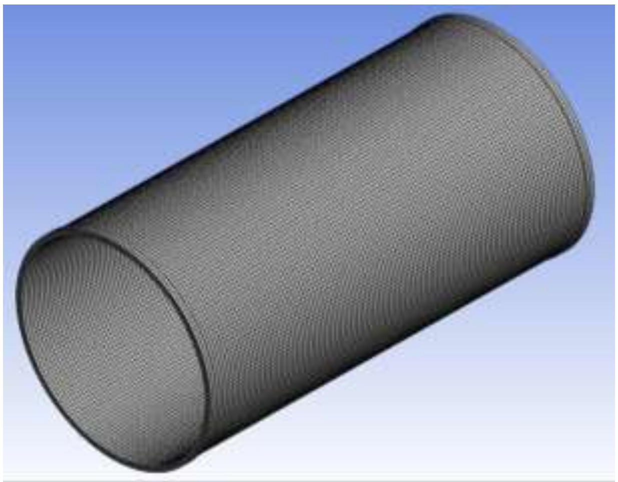

Fig 2 Meshed FE model

5.3 Different loading conditions

This study categorises the entire structural analysis into three cases depending on the boundary condition applied. The following cases studied are shown in Table 2

Table 2 different boundary conditions studied in this thesis work

CASES	BOUNDARY CONDITIONS
Case 01	Axial Load + Internal Pressure + External Pressure
Case 02	Torsional load + Internal Pressure + External Pressure
Case 03	Axial Load+ Torsional load+ Internal Pressure + External Pressure

5.4 Boundary Condition

An axial compressive load of 100 kN is applied along the longitudinal axis of the cylinder

The internal pressure of 100 kPa (1 atmospheric pressure), applied uniformly on the inner surface of the structure

An external pressure of 5 kPa is applied on the outer surface, simulating the atmospheric conditions 26 km above the Earth's surface.

A torsional moment of 1000 Nm is applied to induce shear stress due to twisting.

all degrees of freedom are fixed at the bottom end of the structure, ensuring that the bottom end is constrained and cannot undergo any translation or rotation.

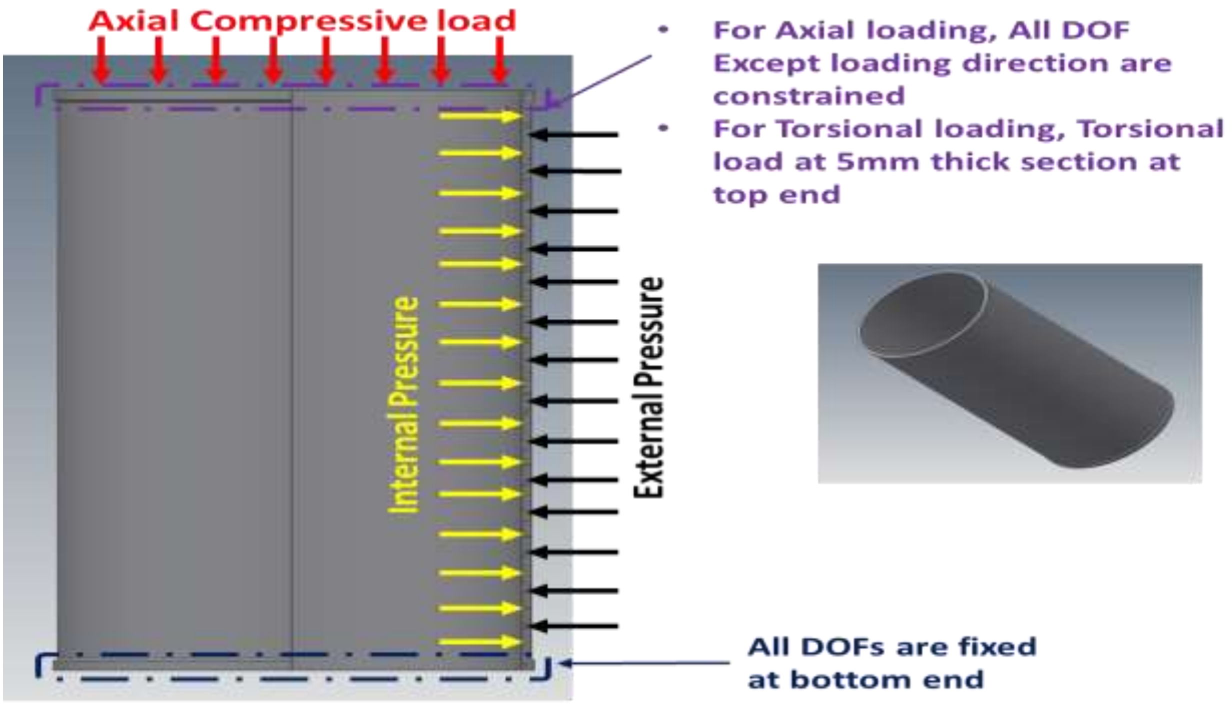

Fig 3 Boundary condition for structural and buckling analysis

5.5 Eigen Buckling Analysis

The eigenvalue buckling analysis is conducted on all three structural designs discussed i. For the eigenvalue buckling analysis, the same mesh and the boundary conditions used in the structural analysis are applied. From the buckling analysis, buckling mode shapes are extracted for each case

6. RESULT AND DISCUSSIONS

For validating the proposed model, the critical buckling load obtained from the proposed FE model is compared with that obtained from **Wang B. et al. (2018)**.

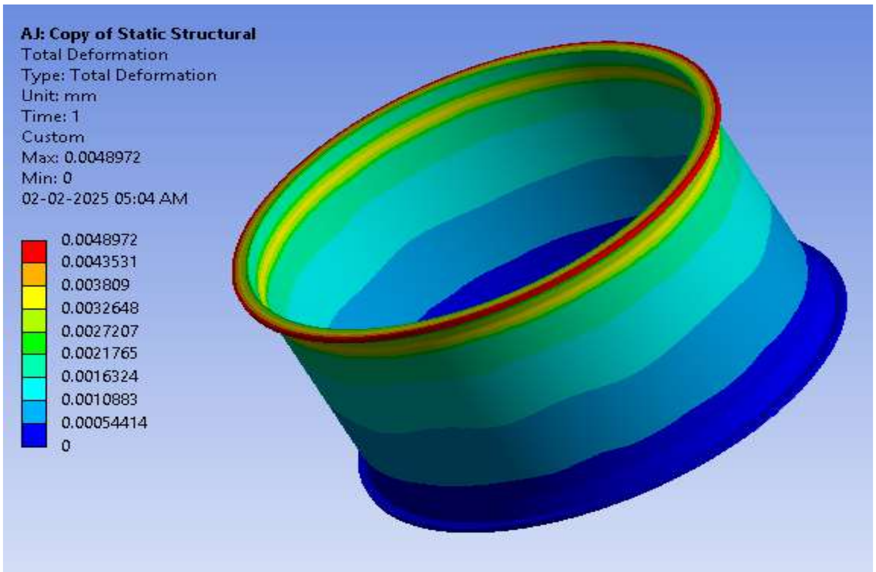

Fig 4 Deformation plot obtained from proposed FE model

Figure show the deformation contour plot obtained by conducting structural analysis on the proposed FE model and the maximum deformation predicted by the proposed FE model is 0.0049 mm.

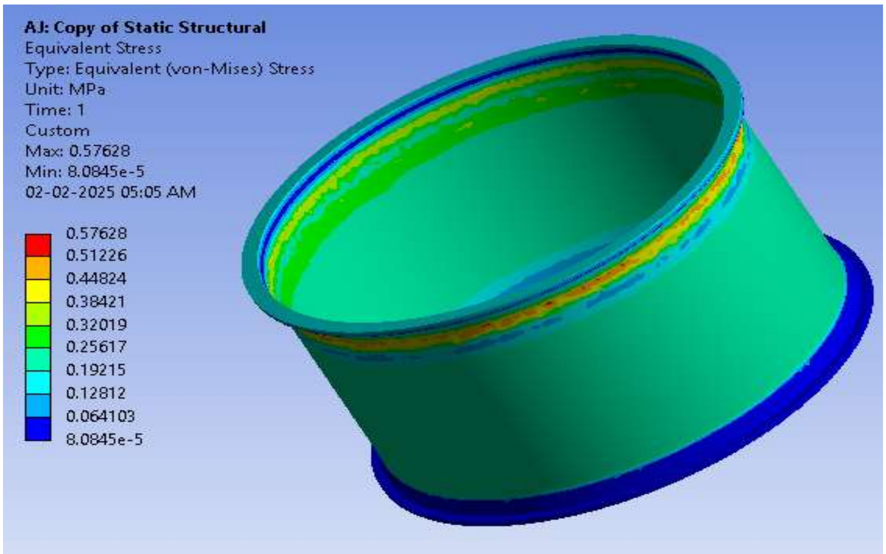

Fig 5 Von Mises Stress Distribution

Figure show the von mises stress contour plot obtained by conducting structural analysis on the proposed FE model and the maximum von Mises stress predicted by the proposed FE model is 576 KPa.

Table 3 Comparison of numerical result obtained from developed FE meshed model with result obtained from the Wang B et. al (2018)

Observations	Critical Buckling Load (KN)	Error %
Experimental Result obtained from Wang B. et al. work (2018)	482.24	-
Numerical Result obtained from Wang B. et al. work (2018)	544.1	12.827638
Numerical Result obtained from the developed newly developed model	536.9	11.334605

The observations from the FE validation are shown in Table. A maximum deviation (error) of 11.33% is observed for the proposed FE model compared with experimental results from **Wang B. et al.** Work (2018). The comparison of buckling mode shapes is shown in Table 3. The critical Buckling load of 536.9 KN is obtained from the proposed FE model and that from the numerical and experimental work by **Wang B. et al. (2018)** are 482.2 KN and 544.1 KN respectively. This observation shows that the proposed FE model with condition material properties is valid for the proposed boundary.

Table 4 Overall buckling result under case 1

Configuration `	Mass	Buckling Load Factor			
		Mode 1	Mode 3	Mode 5	Mode 7
Solid cylinder	1.3	22.83	23.48	24.1	24.2
Composite Cylinders with rectangular grid cores	1.029	16.63	16.9	17.04	17.17
Composite Cylinders with Isogrid cores	1.028	17.7	22.18	22.25	22.35

From the buckling analysis, the isogrid pattern performs better, showing a higher buckling strength under Case 01 boundary condition. Under Case 01 boundary conditions, the buckling mode shapes indicate that the isogrid structure allows buckling of both the shell and core together, signifying effective load transfer, whereas the rectangular grid shows local shell buckling, suggesting less efficient interaction.

Table 5 Overall Buckling Result under Case 2

Configuration `	Mass	Buckling Load Factor			
		Mode 1	Mode 3	Mode 5	Mode 7
Solid cylinder	1.3	51.384	51.385	57.451	57.451
Composite Cylinders with rectangular grid cores	1.029	66.714	66.724	82.431	82.44
Composite Cylinders with Isogrid cores	1.028	67.124	67.13	82.512	82.526

Buckling analysis shows that the isogrid structure performs slightly better than the rectangular configuration under Case 02 boundary conditions, with a slightly higher buckling load factor (BLF). For all design configurations, the buckling mode shapes indicate no local shell buckling.

Table 6 Overall Buckling Result under Case 3

Configuration `	Mass	Buckling Load Factor			
		Mode 1	Mode 3	Mode 5	Mode 7
Solid cylinder	1.3	10.704	10.704	11.108	11.108
Composite Cylinders with rectangular grid cores	1.029	11.747	11.749	12.808	12.81
Composite Cylinders with Isogrid cores	1.028	11.776	11.778	12.91	12.911

From the buckling analysis, the isogrid pattern performs better, showing a higher buckling strength under Case 03 boundary condition.

CONCLUSION

This thesis focused on evaluating the structural and buckling performance of composite cylindrical shells with different core designs under various loading conditions. The study found that composite cylinders provide increased natural frequency due to significant mass reduction, which helps reduce the risk of resonance and indicates improved dynamic stiffness. Among the configurations, the rectangular grid offered slightly better structural stability—reflected in lower stress levels—under Case 01 and Case 03 loading conditions. but, the isogrid core consistently demonstrated superior buckling resistance, showing higher buckling load factors (BLF) across all cases. Additionally, the global buckling behaviour of the isogrid under axial loading revealed improved structural integrity under critical conditions. The isogrid structure shows superior buckling performance due to its efficient triangular pattern, which offers high stiffness and stability. Unlike rectangular grids, the triangular layout distributes loads more evenly and resists deformation, making it more effective under axial and compressive loads. This configuration also provides a high strength-to-weight ratio and better resistance to both global and local buckling.

From the observation of thesis work, conclude that the isogrid configuration proved to be a more favourable design for aerospace vehicle structures and pressure vessels under the examined conditions, providing an effective combination of lightweight design and strong structural performance.

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