IOSR Journal of Research & Method in Education (IOSR-JRME)
e-ISSN: 2320–7388, p- ISSN: 2320-737x Volume 11, Issue 3 Ser. I (May – June 2021), PP 61-68
www.iosrjournals.org

Analysis of Buckling in Laminated Composite Plates with Various Cutout Shapes for Optimization

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Abstract
Layers of at least two distinct materials are fused together to form laminated composite materials, which function as a single unit. Lamination may highlight qualities including strength, rigidity, low weight, resistance to corrosion and wear, acoustical insulation, and more. Although cutouts are unavoidable in buildings, the gaps made when necessary result in a reduction in strength and stiffness. This study uses numerical techniques to compare the critical buckling load of the laminated composite plate with cutout by altering the cutout shapes of the laminate's optimal fiber orientation. The buckling load bearing capability of laminated composite plates with square and rectangular cuts is lower than that of plates with circular cutouts. The combination of fiber orientations 0/90/15/-15/15/-15/0/90 with circular cutting produced the highest buckling load. The buckling load rises as the fiber angle in the inner layers increases.

Keywords: *Finite Element, Buckling Analysis, Fibre Orientation, Laminated Composite Plate, Cutouts.*

I. INTRODUCTION

A composite material is made up of two or more components, providing considerable weight reduction in structures due to its high strength and impressive stiffness-to-weight ratio. Laminated composite materials consist of fiber-reinforced laminae that exhibit varying properties. It is postulated that each lamina functions as a continuum, meaning there are no empty spaces, voids, internal delaminations, or material defects present, and it exhibits behavior characteristic of a linear hyperelastic material. The characteristics that can be enhanced through the formation of composite materials encompass strength, stiffness, corrosion resistance, wear resistance, weight, and temperature-dependent behavior, among others.

The laminates can exhibit symmetry, anti-symmetry, or unsymmetry. They are also referred to as crossply or angle-ply based on the fiber orientations of laminae. When the fiber orientation in a lamina is at 0° or 90°, it is referred to as cross-ply, whereas any other fiber orientations are classified as angle-ply.

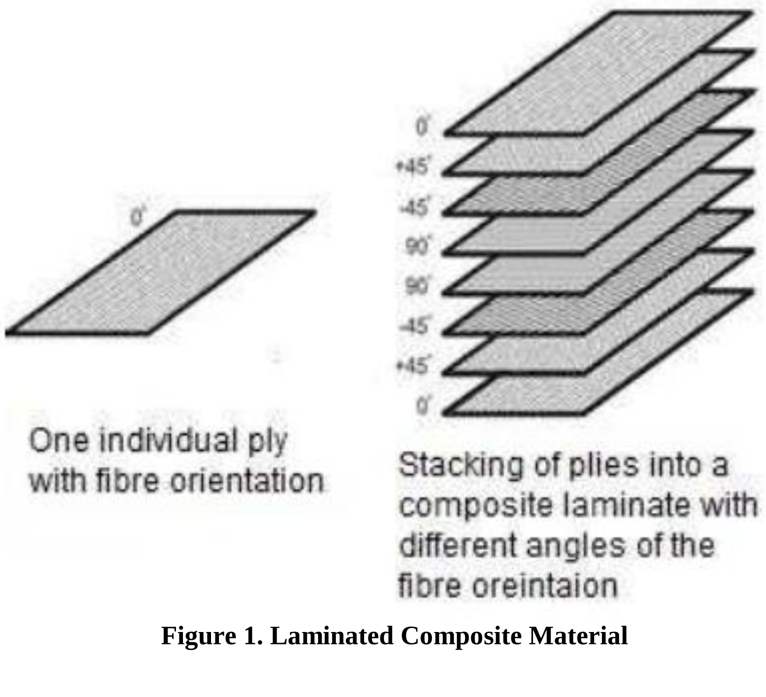

Figure 1. Laminated Composite Material

Cutouts are an essential aspect of structures. In practical scenarios, the presence of cutouts can lead to a decrease in strength, stiffness, and inertia. Cutouts are essential in various aeronautical, mechanical, and civil structures. In aircraft components, cutouts are implemented to minimize weight, facilitate the routing of fuel and electrical lines, and alter the resonant frequencies of the structures. Access to and servicing of interior components in aircraft necessitates the inclusion of openings like doors and windows. In structures designed to retain liquids, it is essential to incorporate cutouts in the bottom plate to facilitate the flow of liquid. Cutouts are necessary for ventilation purposes as well.

This study focuses on the impact of cutout shapes and fiber orientation on the buckling analysis of glass/epoxy laminated composite plates. The plate is composed of glass for reinforcement, while the matrix is made up of Araldite LY 556 as the epoxy resin and Aradur HY 951 as the hardener. Here, bidirectional glass fibres are utilized. Most fabric constructions prefer bidirectional tapes over straight unidirectional ones. In the realm of aerospace structures, the selection of tightly woven fabrics is often preferred to achieve weight reduction, reduce resin void size, and ensure proper fibre orientation throughout the fabrication process. In structural applications, the fabrics utilized consist of fibres or strands that maintain uniform weight or yield in both the longitudinal (warp) and transverse (fill) directions. Figure 2.

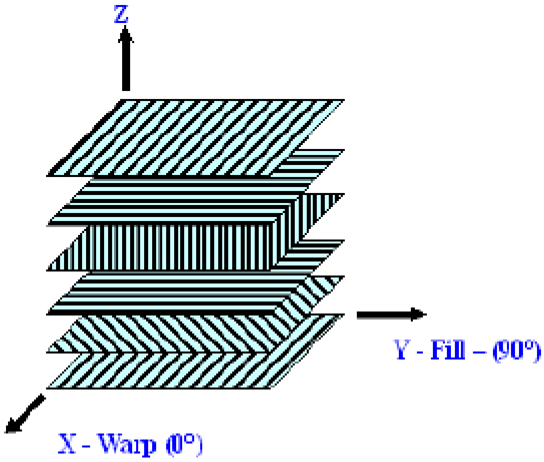

Figure 2. Schematic Representation of Woven Fabric

This study examines the buckling analysis of laminated composite plates through the application of finite element software, specifically ANSYS.

II. FINITE ELEMENT ANALYSIS

A composite plate made of glass and epoxy, measuring 250 mm in both length and width, was chosen for the investigation. The thickness of each layer measured 0.3 mm. The characteristics of materials were determined through laboratory testing of the fibers. Table 1 presents the properties of the materials used in the fibres. Cutouts measuring 1964 mm2 are incorporated at the center.

Table 1 Material Properties of Fibre

Material Property	Value
Density	1.2 g/cm^3
Modulus of Elasticity	10GPa
Poisons Ratio	0.12

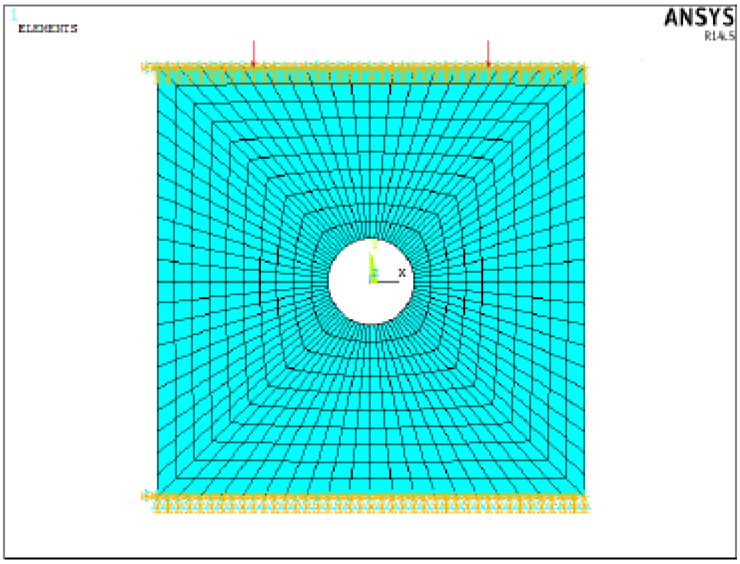

Figure 3. Boundary Condition of Plate with Circular Cutout

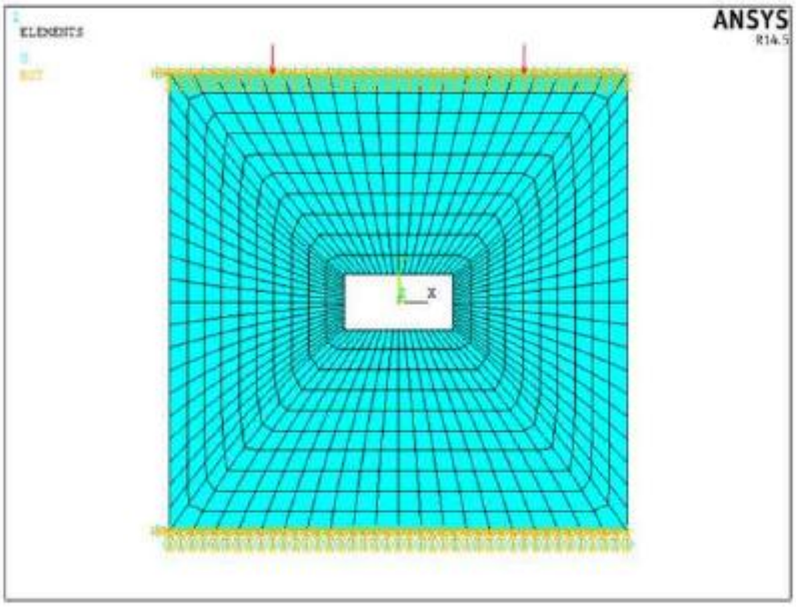

Figure 4. Boundary Condition of Plate with Rectangular Cutout

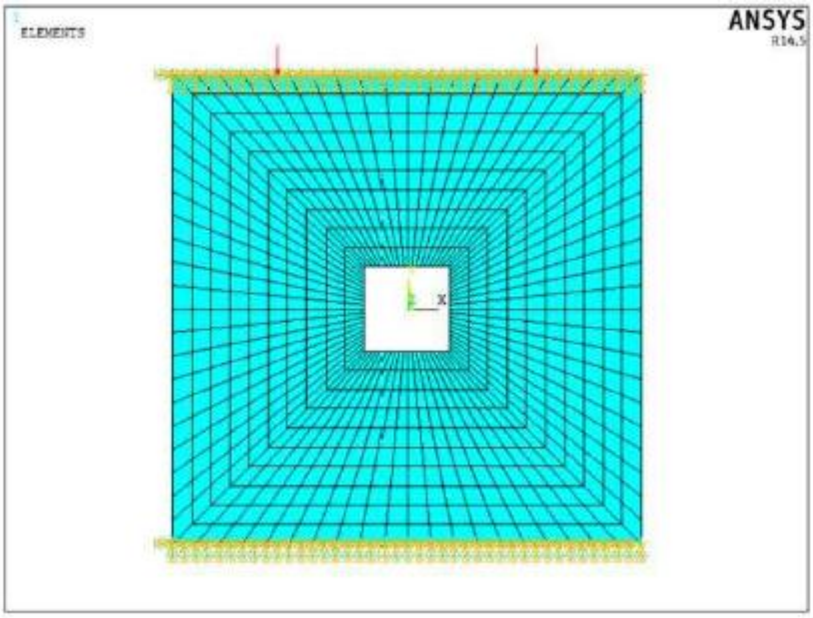

Figure 5. Boundary Condition of Plate with Square Cutout

The buckling analysis of the plate was conducted using ANSYS 14.5, employing shell 181 as the element type. Plates were designed with various cutout shapes and fiber orientations. Optimized fibre oriented laminated plates include cutout shapes in circular, rectangular, and square forms. The upper and lower sections of the plate were constrained as boundary conditions. Following the assignment of material properties, a pressure load of 1 N/mm2 was applied for the linear buckling analysis.

III. RESULTS OF THE BUCKLING ANALYSIS

3.1 Optimization of Fibre Orientation

The theoretical buckling load of an ideal elastic structure may be computed using the Eigen value buckling analysis that is supported by the program. In addition, it provides the eigen value for the limitations and loads of the system. For the purpose of optimizing the orientation of the fibers, the study was carried out using ten different combinations of fiber angle with circular cutout. Table 2 presents the findings that were acquired from the study.

Table 2 : Buckling Load Values of Different Fibre Orientations with Circular Cutout

Sl. No.	Fibre Orientation (in degrees)	Buckling Load (kN)
1	30/-30/30/-30/30/-30/30/-30	2.943
2	15/-15/15/-15/15/-15/15/-15	4.307
3	60/-60/60/-60/60/-60/60/-60	2.94
4	0/90/30/-30/30/-30/0/90	4.712
5	0/90/15/-15/15/-15/0/90	5.141
6	0/90/60/-60/60/-60/0/90	4.712
7	15/30/15/30/0/90/0/90	3.554
8	45/90/45/90/0/90/0/90	3.96
9	0/90/15/30/15/30/0/90	4.356
10	0/90/45/90/45/90/0/90	4.771

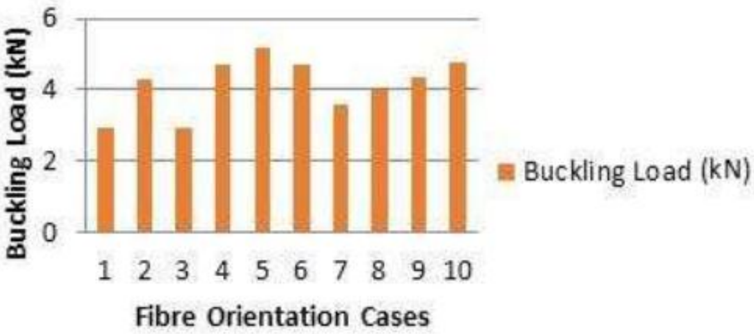

Figure 6. Graph showing the Buckling Load versus Fibre Orientation

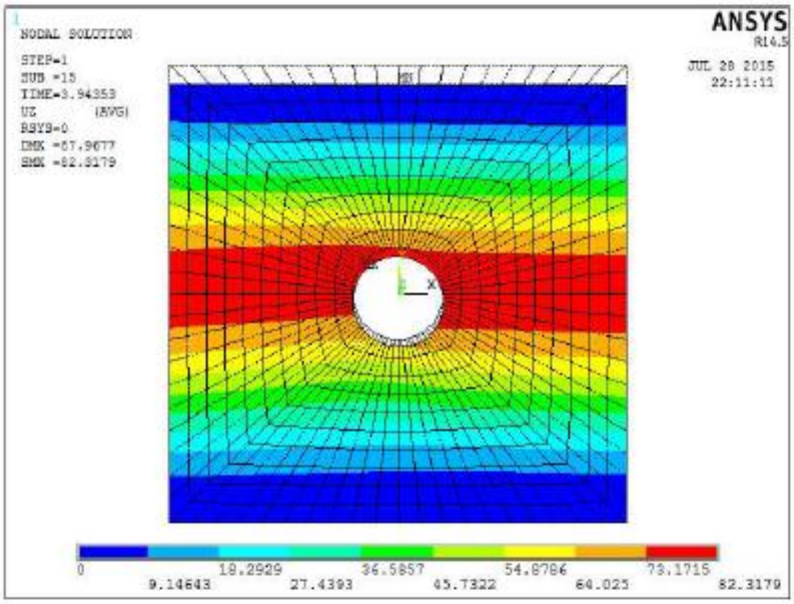

Figure 7. Lateral Deflection of Optimized Laminated Composite Plate

3.2 Optimization for shape of Cutout

In order to better optimize the cutout shape of the laminated composite plate, buckling analysis was performed using both rectangular and square cutouts, with the fiber orientation being specifically tuned. 6.9 kN was the buckling load that was determined to be available for the optimal fiber-oriented laminated composite plate that did not have any cutouts.

Table 3 : Buckling Load Values for Different Cutouts with Optimized Fibre Orientation

Cutout Shape	Buckling Load (kN)	% Reduction in Buckling Load due to Cutout
Plate with Circular Cutout (PWCC)	5.141	25.5
Plate with Rectangular Cutout (PWRC)	4.58	33
Plate with Square Cutout (PWSC)	4.835	30

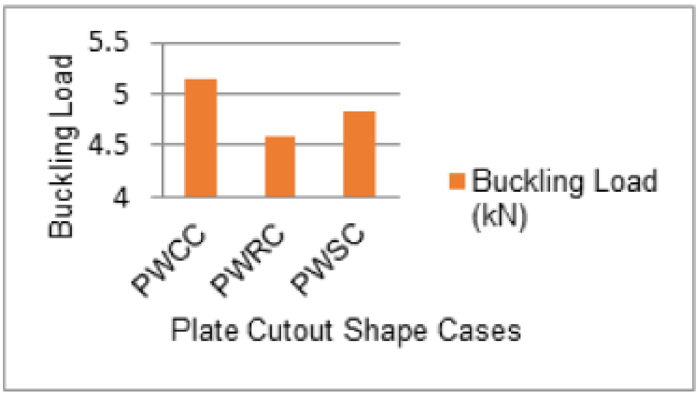

Figure 8. Graph Showing Variation of Buckling Load versus Different Cutouts

IV. CONCLUSIONS

Laminated composite materials consist of layers with varying properties that are bonded together to function as a cohesive unit. This numerical method study, which examines various fibre orientations and cutout shapes, leads to the following conclusions.

 The buckling load value decreases as the fibre angle in the inner layers increases.

The maximum buckling load was determined for a laminated composite plate subjected to a circular load. The highest buckling load combination was achieved with a fibre orientation of 0/90/15/-15/15/-15/0/90, incorporating a circular cutout. The circular cutout results in a 25.5% reduction in buckling load.

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