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Effect of Fiber Orientation on Buckling Characteristics of Laminated Ceramic Composites

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Abstract:
Ceramic composite plates that are laminated consist of multiple layers of bonded materials, each with distinct chemical compositions, integrated together in a macroscopical arrangement. Plates constructed from laminated composite ceramic material featuring holes exhibit reduced stiffness, diminished resistance to inertia, and lower strength compared to plates without holes. This research focuses on the optimization and nonlinear behavior of square and cylindrical laminated plates, both with and without cuts, as well as their performance under buckling stresses when no cuts are present. Cutouts serve multiple purposes, such as facilitating ventilation, enabling cable attachments, and contributing to weight reduction. They are crucial for achieving the objective of minimizing weight. During the evaluation process, factors such as the cutout location, fiber orientation angle, length-to-thickness ratio, boundary conditions, and Young's Modulus Ratio are being analyzed. The laminated plates under investigation were composed of ceramic fiber reinforced composites, which represent the types of materials examined. Laminated composite plates with circular cutouts exhibit a reduced buckling load when compared to plates without such cutouts.

Keywords: *Fiber Orientation, Finite Element Method, Buckling Characteristics, Ceramic Composites.*

I. Introduction

Buckling is a property that ceramic composite laminated plates exhibit when they are subjected to compression. Composites are made up of two or more materials that, when mixed, combine to provide qualities that would have been difficult to achieve with just one of those components alone. The majority of the weight that is carried by these kinds of materials is carried by the fibers. Matrixes that have a low modulus and a high elongation enable structures to function in a flexible manner while also shielding fibers from the pressures of the environment and ensuring that they remain in their proper position. Composite materials, which are made up of two or more components, provide a significant decrease in the weight of the structure while yet retaining a high level of strength via their composition. When it comes to building, fiber-reinforced composites often take the form of a lamina, which is a thin layer. Laminae are the most common kind of material macrounit. It is possible to modify the stacking sequence of the layers and the orientation of the fibers in each lamina in order to get the required level of strength and stiffness for a specific job. It is the unique combination of attributes that are brought about by the composition, distribution, and orientation of the components that make up a composite that is responsible for the material's properties. There are a number of reasons why cutouts are necessary, including but not limited to the reduction of weight, the facilitation of air circulation, and the establishment of connections with other units. Carbon-fiber reinforced plastic is a composite material that is created by combining a number of different kinds of carbon fibers with thermosetting resins. A material that is extraordinarily durable, ceramic fiber reinforced plastic (CFRP) is lightweight, nonconductive, and reinforced with fibers. It is also feasible to boost the material's strength and stiffness attributes in an effective manner by stacking a large number of fiber layers with a variety of desired orientations. The finite element method was used by Parth Bhavsar and colleagues in order to investigate the buckling behavior of glass fiber reinforced polymer (GFRP) when it was subjected to linearly varying loading.

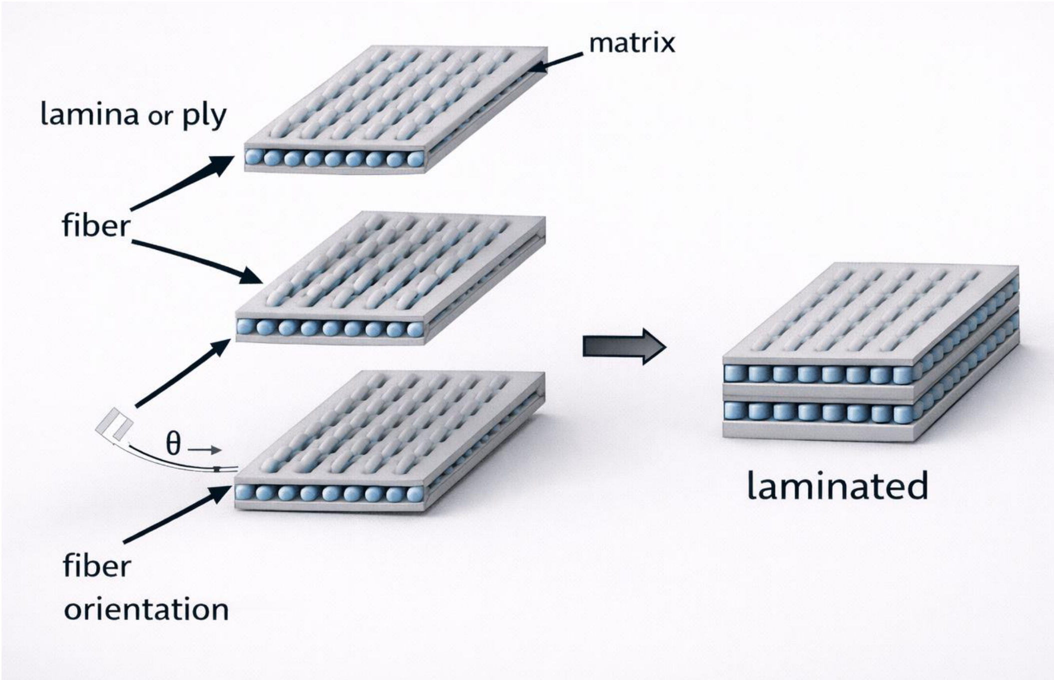

Figure 1: Ceramic Laminated Composite Plate

Researchers have investigated several parameters to ascertain their influence on the buckling stress of rectangular plates with an aspect ratio of 1. Joshi et al. employed two-dimensional finite element analysis to ascertain the buckling load per unit length of a rectangular plate featuring circular cut-outs, which was subjected to bi-axial compression. The evaluation of buckling factors can be conducted by modifying the length-to-thickness ratio and the placement of the holes. Nagendra Singh Gaira and colleagues conducted an investigation into the buckling response of laminated rectangular plates under clamped-free boundary conditions. The presence of a cut-out results in a reduction of the buckling load. With an increase in the aspect ratio, there is a corresponding decrease in the buckling load factor, which aligns with the intended outcome. Hamidreza Allahbakhsh and Ali Dadrasi conducted a buckling analysis utilizing a laminated composite cylindrical panel featuring an elliptical cut-out of varying sizes and locations. The objective was to examine the influence of an axial load on the buckling load of the panel. Container Okutan Baba investigates the influence of various cut-out geometries, length/thickness ratios, and ply orientations on the buckling stress of rectangular plates. The researchers employed a combination of computational and experimental methodologies to assess the impact of these hits on the buckling behavior of E-glass/epoxy composite plates subjected to in-plane compression stress. Hsuan-Teh Hu and colleagues conducted a finite element buckling analysis of composite laminate skew plates under uniaxial compressive loads. Their findings indicate that the failure criterion and nonlinear in-plane shear significantly influence the ultimate loads of the composite laminate skew plates when compared to the linearized buckling loads of the skew plates.

II. Numerical Analysis Using Finite Element Method and Material

In order to satisfy the requirements of the conference paper format, a method that is uncomplicated is required. Using finite element analysis, the buckling load factors of square and cylindrical carbon fiber composite plates will be found in order to meet the goal of this study. This will be done in order to ensure that the research is successful. Version 14.5 of ANSYS is the APDL version. L x t are the dimensions of the plate when it is exposed to three distinct boundary conditions: fixed, clamped, and unclamped situations. These conditions are specified in the equation. inside the first scenario, there are two levels, however inside the second scenario, there are three levels. This is because the stacking sequence that is used is $[0^0/90^0]$ and $[0^0/90^0/0^0]$ respectively. This is the reason why this particular result occurs. It is necessary to punch the plate with a number of center holes that are of the same volume in order to carry out the investigation. Round, square, triangular, or star-shaped patterns are all viable options for the center holes, which may be fashioned in any of these ways. An inquiry is now being conducted to determine the nature of the buckling load factor.

III. Element Description

The SHELL281 element type is being used during the period of time that this investigation is lasting. With the help of this shell element, it is possible to conduct research on shells that are either very thin or reasonably thick. In addition, due to the fact that it can be applied in layers, it is an ideal material for mimicking sandwich structures as well as laminated composite coatings. This material is ideal for use in applications that entail high strain nonlinearity, linearity, or rotation. Applications will benefit greatly from its use. At each of the eight nodes that comprise the element, there are six degrees of freedom that are potentially possible. Because of these degrees of freedom, it is possible to rotate around the three axes and to translate along the axes of x, y, and z inside the element. Studies that include cylindrical plates make use of the nonlinear element S8R5, which is made up of eight nodes and has five degrees of freedom for each of the nodes that are involved.

IV. Geometric Modelling

The dimensions of square plates can start at a minimum length of 500 mm. The diameter of the central hole is specified as fifty mm. For cylindrical specimens, the nominations may range from L500 to R200. The numerical value following the letter L indicates the length of the panel, while the numerical value following the letter R indicates the radius of the panel. The plate is available in four specific thicknesses: 2 mm, 2.5 mm, 3 mm, and 3.5 mm.

Table 1: Properties of composite material

Young's modulus (Pa)	E_{11}= $1.397x10^{11}$	E_{33}= $1.139x10^{11}$
Poisson's ratio	ν_{12}= 0.3236	ν_{13}= 0.3236
Rigidity modulus (Pa)	G_{12}= $4.753x10^{9}$	G_{13}= $4.753x10^{9}$

V. Model of Ceramic Composite Plate

There is no limit to the length of square plates; the minimum length is 500 mm per square. It is believed that the hole of fifty mm in diameter is located in the center of the object. When it comes to cylindrical specimens, nominations might range anywhere from L500 to R200 according to the circumstances. The number that follows the letter L indicates the length of the panel, and the number that follows the letter R indicates the radius of the panel. Both of these numbers are denoted by subsequent numbers.

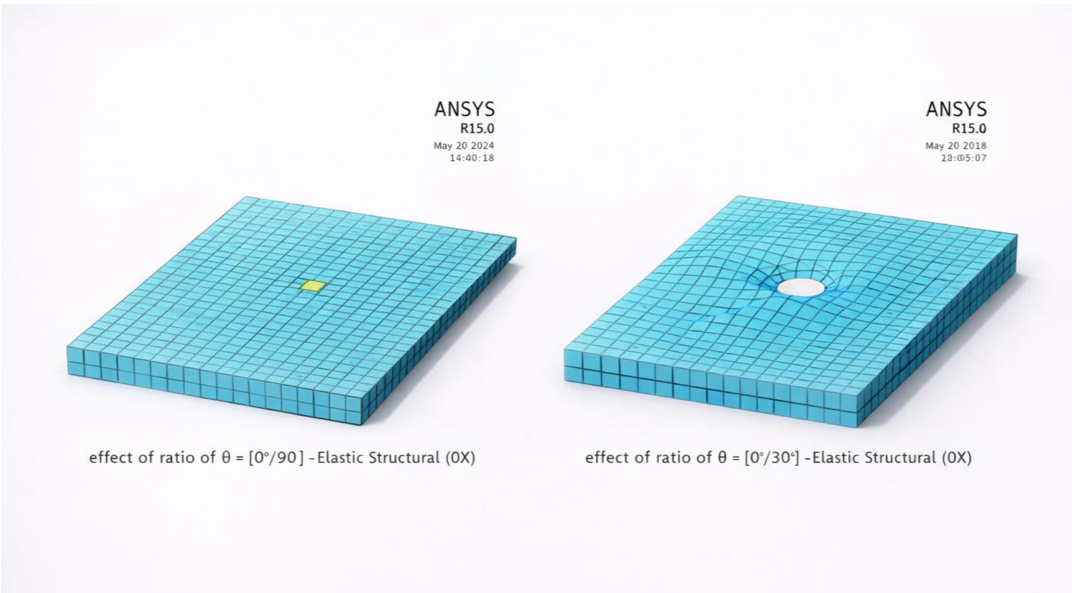

Figure 2: Model of square plate without and with cut-out

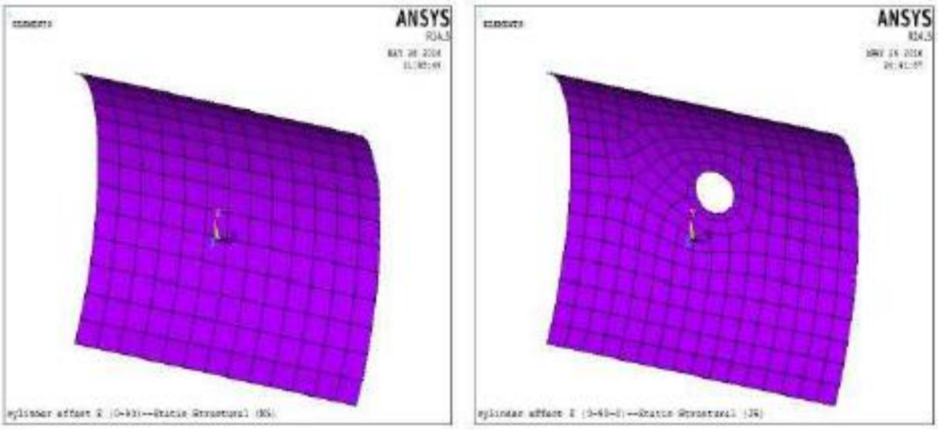

Figure 3: Model of cylindrical plate without and with cut-out

VI. Results and Discussion

The purpose of this part is to investigate the impact that various ply orientations of the plate have on the plate when it is subjected to the same boundary condition. This will be done at the same time. This specific case is a condition that is fixed at the border, and it is being taken into account. There are a number of different ply orientations that are used in this section, and the following is a list of them: ($0^0/0^0/0^0$), ($0^0/30^0/0^0$), ($0^0/45^0/0^0$), ($0^0/90^0/00^0$), ($90^0/90^0/90^0$), and ($90^0/0^0/90^0$). Both of them are subjected to analysis, and a study into the repercussions of the situation is carried out.

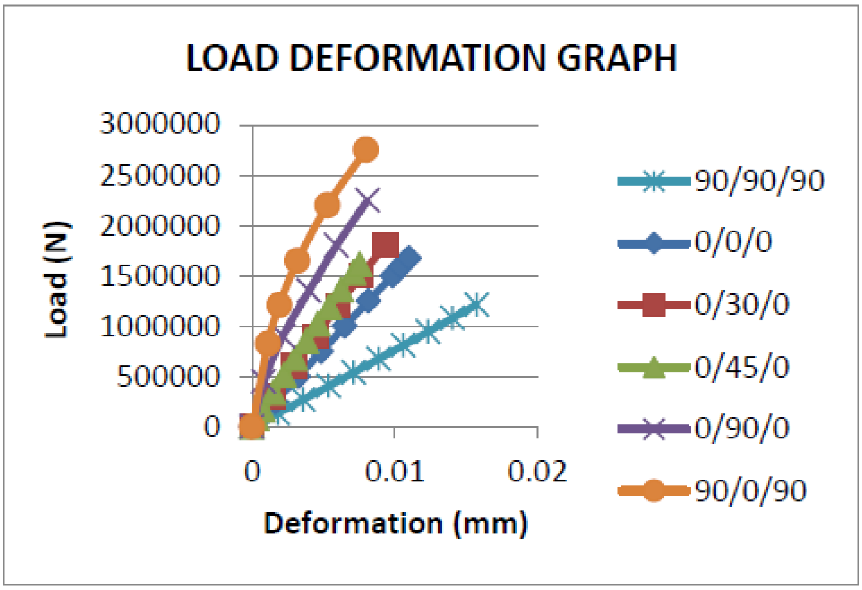

Figure 4: Buckling load deformation graph of plates with ply orientations

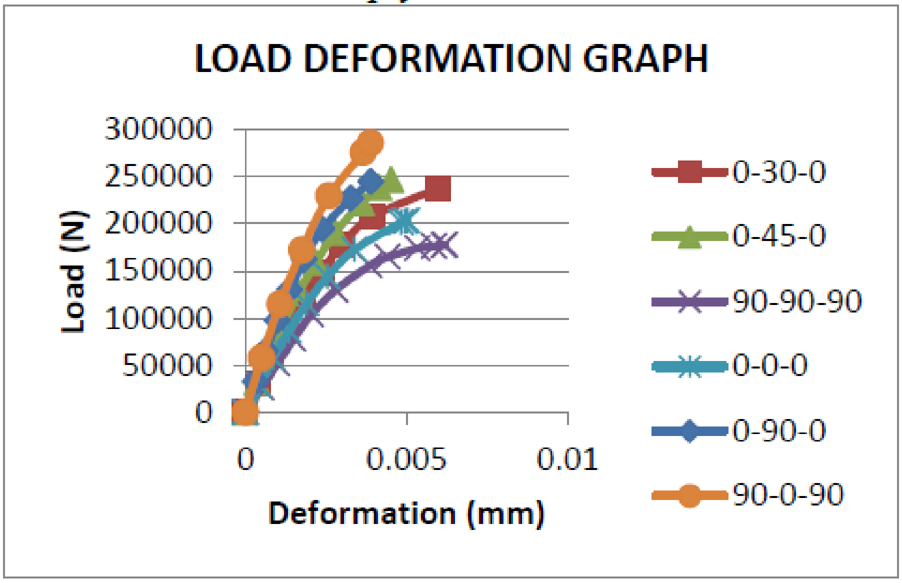

Figure 5: Buckling load deformation graph of cylindrical plates with ply orientations

In light of the fact that it is generally accepted that the fixed boundary condition has the highest load bearing capability, the fixed condition is being used as the border in this instance. This occurs due to the fact that the border is comprised of the fixed condition. The standards that are being discussed here are applicable to laminated plates that are either square or cylindrical in shape, and they are deemed to fall within the territory of this section. The load deformation graph of plates that have ply orientations that are distinct from one another is shown in Figures 4 and 5, respectively. We are able to get a comprehensive comprehension of the buckling effect that takes place when plates are exposed to loads with the aid of this graph. The buckling load that is shown by the ($90^0/0^0/90^0$) ply angle is the one that provides the most substantial contribution, in contrast to the other ply angles that are used. The buckling load bearing ply orientation is deemed to have the lowest possible value, which is ($90^0/90^0/90^0$). This is the value that is believed to be the most practical. To be more specific, we concentrated our analysis on a laminated composite plate that had a circular cut-out in the center of the plate. Our investigation, which was published in the section that came before this one, reveals that a square laminated composite plate with a center circular cut-out has a positive buckling load effect under cut-out plates. This is the reason why this is the case. This is the reason why things are the way they are.

VII. CONCLUSIONS

This investigation involves an examination of the buckling response of laminated composite plates under various ply orientation conditions. Simultaneously, it is crucial to consider that laminated composite plates exhibit a variety of aspect ratios, differing width to thickness ratios, various cut-out shapes, and diverse hole placements. The current study yields numerous conclusions, including the following: The buckling load rises as the ratio of L to t diminishes. The presence of a cut-out results in a reduction of the buckling load. The presence of a cut-out results in a decrease in surface area, consequently reducing the load necessary for the plate to buckle and distort its shape. The reason for this is that the plate is compelled to buckle due to the applied strain. This results in a reduction of the buckling load. With an increase in the number of layers, the buckling load exhibits a proportional rise corresponding to the layer count. With the increase in the number of layers, the interactions among each layer also intensify. This explains why this situation occurs. As a result, a significant amount of load is necessary to achieve the critical buckling load. The amount of weight that is buckling can vary depending on the cut-out shapes utilized. The analysis reveals that the buckling load for circular cut-outs represents the maximum value that can be attained. The buckling load represents the minimum viable value for star cuts of identical dimensions. This is an important aspect to take into account.

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