Buckling Response of Quasi-Static Compressive Loading of Six Layers Cross-Ply Laminated Composite Material

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Abstract- A numerical test of the buckling response of quasi-static compressive loading on six layers of cross-ply laminated composite material [0 degrees, 90 degrees, and 0 degrees] with centrally square and circular cutouts has been carried out in this work. Additionally, a finite element analysis has been performed in conjunction with the computational test. The computational methods were used in order to determine the connection between the size of the cut-out form and the buckling load. The buckling loads that were acquired through the numerical were compared with the literature results that were produced via the use of an ANSYS simulation software. There seems to be a high degree of concordance between the numerical findings. The buckling load of the composite plate has been seen to have reduced as the size of the cutout has increased. This is something that has been observed. The load of the cross-ply laminated composite plates is significantly impacted by a number of factors, including the cutout area, the cutout ratio (d/w), the weight of the fibers, the thickness of the plate, and the form of the fibers.

Keywords: Cut-out, Composite plate, Buckling load, Quasi-static compressive load, cross-ply laminated.

1. INTRODUCTION

The rapid expansion and heightened demands of the transportation and manufacturing sectors necessitate the fabrication of products using advanced materials, particularly fiber-reinforced composites, to satisfy requirements for innovative design, cost efficiency, and superior physical and chemical properties for safety purposes. Long fiber composite reinforcement has been utilized by various researchers, including Sandeep Olhan et al., who investigated the behavior of long glass fiber composite materials through scanning electron microscopy (SEM). The study observed brittle failure and deformation characterized by fiber and microcracks [1]. The utilization of composite materials is rapidly advancing in various industries, including aerospace, marine, automotive, biomedical, civil, and military sectors, due to their superior mechanical properties, such as high strength-to-weight ratio, high stiffness, exceptional tear resistance, ease of handling, and low fabrication costs. These industries have significantly contributed to the development of our most advanced composite systems now in use. An more intriguing research of composite tailoring involves cutout hole inside the framework. Cut-outs are often used in composite materials. These materials are used in composite structural components for isolation, ventilation, stability, mobility, and sometimes for reducing the structure's weight. Aerospace applications, such as airplane components including fuselage, wings, ribs, and spars, need cut-outs for the installation and inspection of hydraulic and electrical lines, fuel lines, and to reduce the overall weight of the aircraft [4]. During operation, various devices and components may be subjected to compressive stresses, resulting in buckling and post-buckling phenomena. Hakim S. Sultan Aljibori et al. investigated structural system instability and load-displacement behavior, which are critical considerations in the safe and dependable design of composite structures. Composite laminated structures are well recognized and prevalent in several applications, particularly within the engineering domain. Woven roving fabric fiber is a method of texture achieved by interlacing the fiber threads of the weft and warp. The appealing mechanical characteristics and buckling behavior of perforated structures, or the introduction of holes in these plates, have garnered the attention of several researchers in recent years. Numerous researchers have investigated the buckling modes of composite laminated plates by experimental, analytical, and finite element analyses. Xu et al. [3] investigated the stability of curved woven roving composite materials by linear and non-linear analysis. Jain and Kumar [4] reported another study using the finite element approach, examining the advanced or post-buckling effects of symmetric laminates with a central cut-out subjected to axial compression loads. The factors of cut-out size, shape, and location significantly affect the buckling loads, initial failure loads, and strength of composite laminates. Hakim et al. and Ghannadpour et al. [5,6] examined the buckling process of laminated composite plates including elliptical and circular cut-outs during compression testing. Both investigations have shown that the influences of form and size cut-outs, together with plate fiber orientations, stacking sequences, and boundary conditions, significantly influence the buckling behavior of the plates.

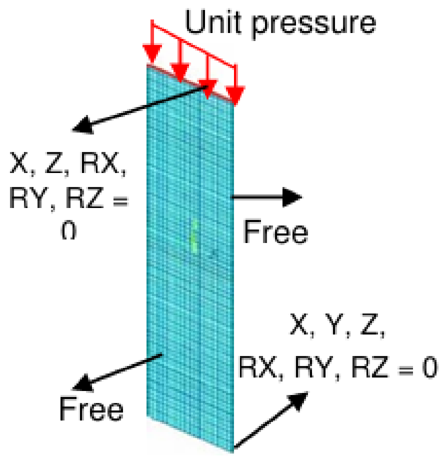
Numerous numerical studies have been conducted by Özben, T. Kremer et al., Zhong et al., and Aydin Komur et al. [7-10] to ascertain the buckling load of composite plates with diverse boundary conditions and cutouts subjected to changing in-plane loads. The presence of a cut-out in the composite plate significantly affects the buckling load of the plates during compression. Züleyha Aslan and Sahin M. [11] conducted computational and experimental research on the influence of delamination modes with several major delaminations on the critical load and compressive failure load of fiber/epoxy composite laminates. The magnitude of near-surface delamination affects the buckling load and compressive failure load of composite structures, but the size of subsurface delamination has no significant impact. Compressive buckling investigations on composite plates utilizing metal matrix composites were also conducted by M. Fateh. Altan and M. E. Kartal [12] examined the variations in buckling factors of symmetrically laminated plates with a central rectangular aperture under biaxial static compression, as reported by Damodar R et al. [14]. They analyzed the buckling behavior and failure mechanisms of compression-loaded quasi-isotropic curved panels, both with and without cutouts. The obtained results are contingent upon the existence of the cutout. Mevlüt Tercan and Aktas M. conducted another finite element study to examine the effects of various cutout shapes (including elliptical, center circular, rectangular, or square cuts) on the buckling behavior of knitted glass/epoxy composite laminated plates. The buckling loads are influenced by the degree of tightness and the cutout area. In addition to the relevant elements affecting the buckling behavior of composite plates already addressed, the impact of varying woven densities of the fiber on the buckling load is another intriguing topic for investigation. This study has been empirically investigated by Osman Asi [16]. The aim of the present work is to investigate the load-displacement characteristics and buckling load of a cross-ply laminated plate with a centrally located circular or square cutout under quasi-static stress, both experimentally and computationally. The influences of cut-out form, cut-out size, fiber type, and fiber thickness have been examined. Ultimately, the experimental and computational data have been juxtaposed to achieve optimal concordance. The conclusions of this research provide significant insights for engineers and designers involved in material selection, enabling the economical use of composite materials while enhancing maintainability, safety optimization, and dependability.

2. NUMERICAL BUCKLING ANALYSIS

In the present investigation, an Eigen-value buckling analysis was performed on the composite structure in the form of plates, both with and without center cuts that were round or square in shape. The ANSYS software was used in order to do the analysis on these plates. To determine the load, it was necessary to resolve the eigen-values and the eigenvectors that were representative of the buckling mode. A representation of the boundary conditions is shown in Figure 1, with the usual meshing being presumed to be the same as the experimental settings. The element type that was chosen was SHELL 99, which has six degrees of freedom. Additionally, an elastic structure and orthotropic material were also given consideration. All of the numbers for the number of layers, fiber angle orientations, and ply thickness were entered into the system in order to establish the real constant. All of the nodes had their X, Y, and Z displacements, as well as their RX, RY, and RZ rotations, set to zero in Figure 1. This was done so that the clamped loaded edges could be simulated and further explained. The number of plies, fiber orientations, and thickness of composite laminates are all explained in Figure 2. In order to mesh the shell, a "concatenating" process was used in conjunction with free and mapped meshing. It was essential to improve one's meshing skills in order to get better and more precise outcomes. Figure 3 features an illustration of the meshing of the test specimens that was generated by the ANSYS software. It was necessary to use a unit pressure in conjunction with the higher nodes in order to provide loading on top of the shell.

In order to carry out Eigen-buckling, the pre-bucking system was activated, and extraction mode was put into operation before moving on to the final outcome. Last but not least, the buckling load of the first buckling mode was consistently and generally considered to be our preferred outcome.

Figure 1 illustrates the boundary conditions that are associated with the normal meshing of a laminated composite plate. Figures 2 and 3 depict the number of plies, fiber orientations, and thickness of composite laminates, as well as the meshing of test specimens that have and do not have cutouts.



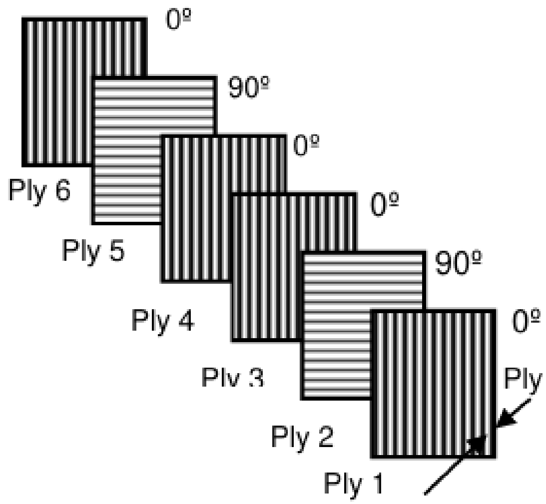


Fig. 1. The boundary conditions of laminated composite plate with typical meshing

Fig.2. Number of plies, fiber orientations and thickness of composite laminates

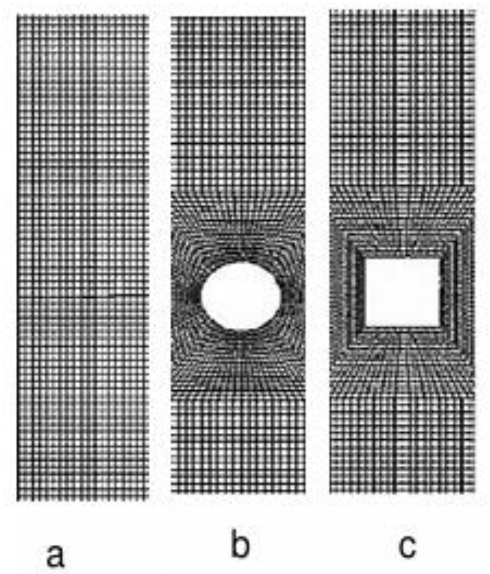


Fig. 3. The meshing of plate: (a) Plate without cutout, (b) Central circular cutout plate and (c) Central square cutout plate

3. RESULT AND DISSCUSION

In this study, the load findings were determined numerically for cross-ply laminated [0 degrees/90 degrees/0 degrees] composite plates with and without center circular or square cuts for the kinds of fibers that were used. The load-displacement curve of each of the specimens was created by the analytical results, whilst the numerical results were acquired from the nodal solution graphics that were simulated by the ANSYS software. It demonstrates a high level of acceptance of the numerical forecasts. The discrepancies may be found in the range of 0.52 to 2.70 percent for carbon fiber type plates, whereas the differences can be found in the range of 0.03 to 2.47 percent for glass fiber type plates. Furthermore, it has been shown that the load is highly dependent on the size of the cutout (preferably in terms of the cutout ratio, which is denoted by the symbol d/w). This ratio is increasing, which results in a decrease in the burden overall. In addition to this, it was observed that the load on the plate with the circular cutout was greater than the load produced by the plate with the square cutout. In addition, as long as the cutout sizes on the plates are the identical, the carbon fiber plate

3.1 Effect of fiber weight and plate thickness

In is the case even when the cutout size and fiber type are the same (E-glass). For a flat composite plate to be formed, a greater weight of fiber necessitates a greater quantity of matrix material, which ultimately results in a greater plate thickness. As a consequence of the increased buckling stress, plates with a greater thickness, which was brought about by the solid bonding of a greater number of fibers and matrix, had become more rigid when subjected to compressive force.

3.2 Effect the shape of cut-out

A variety of cut-out forms are available for usage because of the needs of the design. The fact that the plate with a central circular cutout has a larger buckling load (about 1.02 to 1.11 times) than the plate with a central square cutout indicates the influence that the form of the cutout has on the buckling load. This is the case when the fiber type and cutout size are the same. In order to provide an explanation for this behavior, it was seen that the primary reason is the center cutout region that was removed from the plate. The area of a square is more than that of a circle, even when the diameter or breadth of the cutout of the square is the same as shown in fig. 4. As a consequence, the greater the amount of area that is withdrawn, the greater the amount of mass that is lost in the center of the plate. This will result in a decrease in the central stiffness, which will ultimately cause the plate to buckle when subjected to far less force.

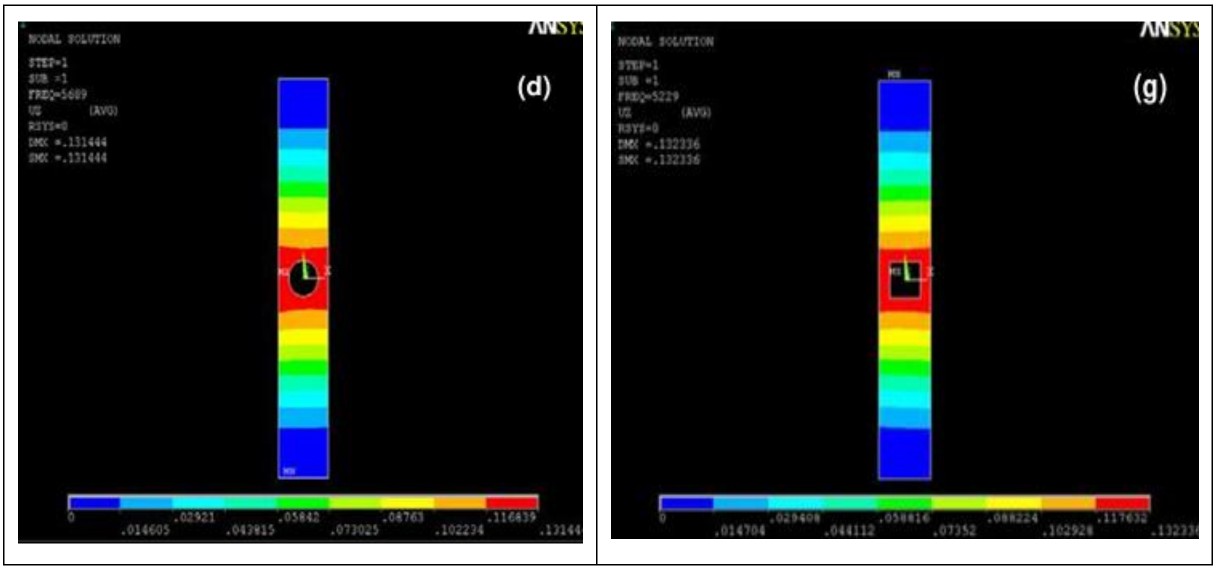


Fig. 4. Effect the shape of cut-out

3.3 Effect of stacking type

Engineers are devoted to improving composite qualities by altering fiber type in response to demands for structural effectiveness. The buckling loads of different kinds of fibers stacking are truly compared in this study. According to the findings, cross ply fibers are the best material to use for structures that need to be strong yet lightweight, rigid, and able to absorb a lot of energy. The strength, stiffness, and resistance to chemical corrosions of E-glass fibers are relatively excellent.

3.4 Effect of cutout size

A common way to express the ideal cutout size is as a ratio, where d is the width or diameter of the cutout and w is the width of the plate. The relationship between the cutoff ratio (d/w) and buckling load is often studied using this phrase. The results show that the strength of the plate is greater when it either has no cutout or a smaller cutout compared to the plate with a bigger cutout. This is because the interfacial link between the matrix and fibers is broken as a result of mass loss in the center, which leads to the effect. Most of the strength of a composite construction comes from the reinforced fibers, which are loaded from the matrix via the contact between the two. Therefore, the bonding is becoming loose, which reduces the plate's strength, as the cutout size increases. Because of its inherent design, a central cutout position reduces the bending rigidity of the plate, and this effect becomes more pronounced as the cutout size grows. Therefore, the buckling strength will decrease in direct proportion to the amount of bending stiffness lost due to an increase in the size of the center cutout.

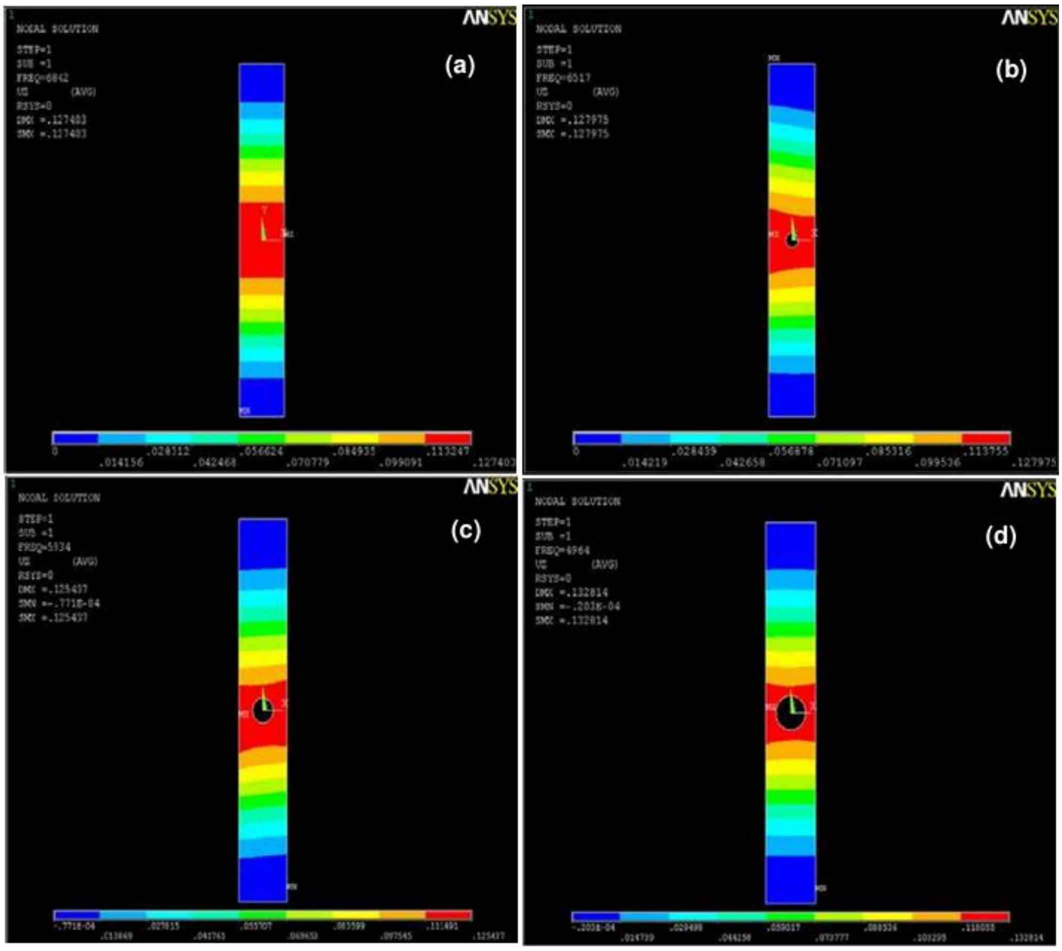


Fig. 5. Effect of cutout size

3.5 Buckling load versus cutout ratio(d/w)

There is a high degree of numerical predictions for the buckling load. The numerical findings of the specimens' buckling load versus cutoff ratio are compared in Figures 6 and 7, respectively. Values obtained from numerical buckling analysis closely match with the litareture buckling load values, as may be shown in the Figures. when shown before, when the cutout ratio increases, the plate's buckling load reduces.

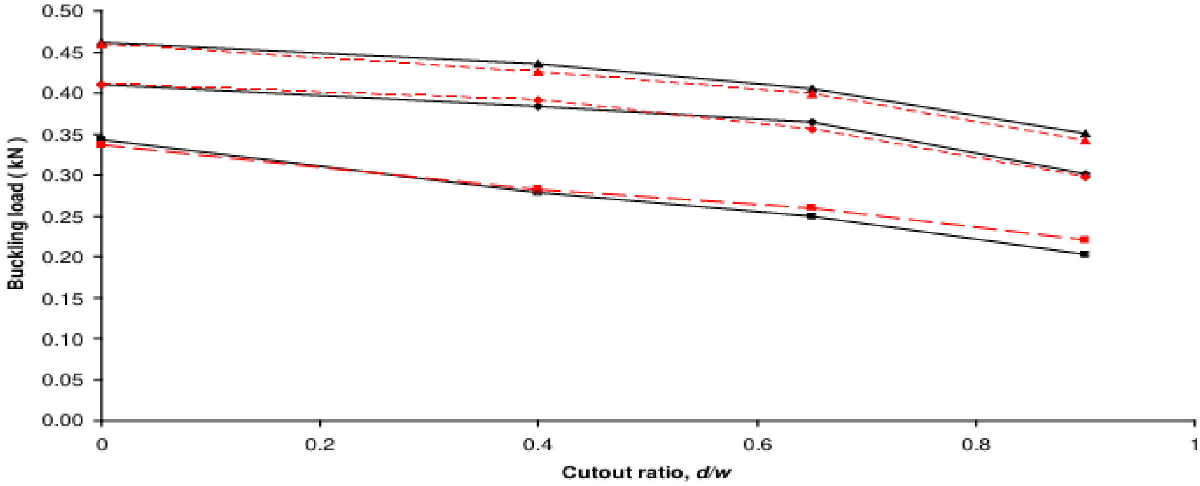


Fig. 6. Buckling loads versus cutout ratios for composite plates with and without central circular cutouts.

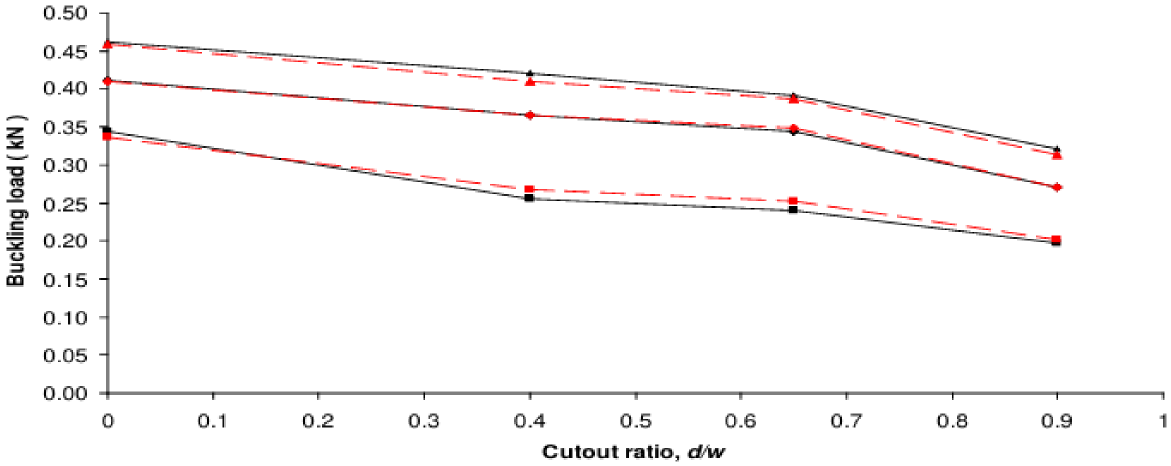


Fig. 7. Buckling loads versus cutout ratios for laminated composite plates with/without central square cutouts.

4. CONCLUSIONS

In every instance of symmetrical ply laminates, the cross-ply laminates [0˚/90˚/0˚] were able to absorb a significant amount of energy prior to fracture, and they were exposed to a large degree of inelastic deformation and pre-failure stress. The strain on the laminated plate is lowered and the cutout ratio grows correspondingly as the size of the center cutout rises. The matrix and fibers of a laminated plate become unbonded at the interface when there is a mass loss (hole) in the middle of the plate. Loosening the bonding weakens the plate. The process of producing composites involves combining more fiber with additional matrix material, which causes the plate thickness to rise. The resistance of a thicker plate against buckling under stress is greater.

As the size of the center cutout increases, the laminated plate's central bending stiffness decreases, resulting in a decrease in the composite plate's buckling resistance.

Plates with center circular cutouts have shown greater buckling strength compared to plates with central square cutouts, where both types of fiber and cutout sizes are kept same. Despite their light weight, they possess the greatest modulus of strength and maximum buckling load.

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