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Analysis of Carbon Fiber Reinforced Composite Laminate under Different Cut-outs using FEM and Reflection Polariscope: A Review

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Abstract—*This paper highlights a review of Analysis of Carbon fiber reinforced composite laminate under different cut outs. Various failure modes like matrix cracking, delamination etc. have also been referred. Composite materials are widely used in various applications such as automotive industries, aircraft, marine etc. Many industries using composite structures as compared to metal structures, many of the structures have cut outs or opening to serve as doors, windows, or access ports. Composites are made of individual materials referred to as constitute materials. Panels with different cut-outs are often used in engineering structures. The understanding of effect of load bearing capacity and stress concentration of such plates is important. Hence it is important to study the buckling behavior of the laminates for different cutouts.*

Keywords: *Carbon FRC laminates, Cut-outs, failure modes, Stress concentration, Buckling behavior.*

1. INTRODUCTION

Fiber Reinforced composites fascinating the researchers, engineers due to their high strength and low weight. Composite laminates are composed of thin layers (plies) consisting of reinforcement and a matrix. The Reinforcement is usually a strong, stiff material, in the form of long fibers. The matrix is a material that is applied in a liquid form and then cured and hardened. The matrix is applied to support the reinforcement, and to distribute the load through the reinforcement and plies. It is common to have plies with fibers at one direction or several directions in a weave. The orientation of the fibers and stacking sequence has measure effect on the deformation and stress throughout the laminate. Composite laminates have been used increasingly in a variety of industrial areas due to their high stiffness and light weight, long fatigue life, resistance to electro chemical corrosion and other superior material properties of composites. A true understanding of their structural behavior is required, such as the deflections, buckling loads and modal characteristics, stresses and strains, the large deflection behavior and, of extreme importance for obtaining strong, reliable multi-layered structures, the failure characteristics. Finite element method is especially versatile and efficient for the analysis of complex structural behavior of the composite laminates [1]. Delamination is one of the largest damage feature, which may cause due to significant reductions in flexural stiffness and buckling loads. The effect of de-lamination has been a subject of extensive research, and fairly reliable methods are now available for prediction of growth of artificial single de-lamination [2].Cut-outs commonly appear in the structures due to the requirement of stability maneuverability, low weight optimization and accessibility of other systems. During operation, these structural elements may experience compressive loads and thus lead to buckling and post buckling. Their buckling and post buckling behaviors play an important role in determining safe operating conditions and effective design for these structures [3].

2. FAILURE MODES IN COMPOSITE PANELS

Failure modes in laminated composite panels are strongly dependent on ply orientation, loading direction and panel geometry. Laminated composite structures fails generally due to four basic modes. These failure modes are: matrix cracking, fiber-matrix shear failure, fiber failure and delamination.It is necessary to predict failure analysis to optimize the damage growth accurately, the failure analysis must be able to predict the failure mode in each ply and apply the corresponding reduction in material stiffness. Near the free edge, de-lamination also occurs due to low bonded strength. Matrix cracking in tension and compression occurs due to a combination of transverse and shear stresses, Fiber-matrix shear failure occurs due to a combination of axial stress and the shear stresses [7].

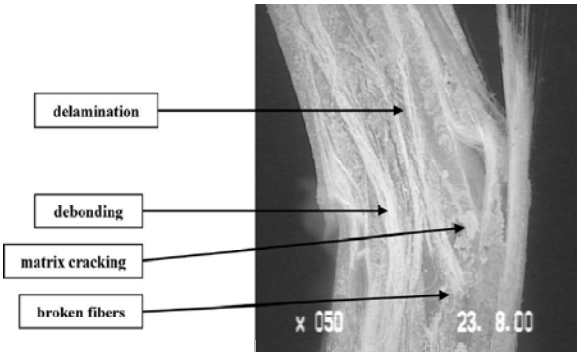

Fig. 1: Failure mechanism of plates with [0/90/0/0/90/0] angle orientation [3].

3. LITERATURE REVIEW

Various researches which have been done in the past over a time of period came out to be very useful and informative while initiating the above research work. Manoharan R.and Jeevanantham A. K.[1] highlights the analysis of stress-strain and displacement for compressive load on the fiber reinforced composite laminates They have analyzed three different orientations as [0°/90°/0°] ŝ, [0°/60°/30°] ŝ, [90°/45°/0°] ŝ of fibers with and without the circular cut-outs. . Also studied, changing the dimensions of circular cut-outs on the laminates four different cases of the plates such as without hole, circular holes at the center of the plates with diameter as 22mm, 28mm and 32mm respectively at different compressive loading conditions.

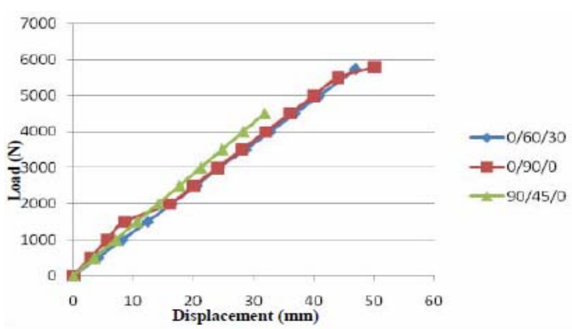

Fig. 2: Load vs displacement graph showing the comparison between three orientations [1].

After the analysis using ANSYS software, they found cross plies laminates better than that of angular ply laminates. Their results shows that, $[0°/90°/0°]_{ŝ}$ configuration is the best which carries the maximum load of 6.3kN without out, with cutout dia. 22,28,32mm carries maximum loads 5.84,5.42,4.0 kN respectively. For the same load, the plate with orientation $[0°/90°/0°]_{ŝ}$ has the least deflection indicating the best strength as compared to the others. As the diameter of the cut hole is increased the strength of the plate decreases due to the material removal from the plate which also reduces its strength and the load bearing capacity also reduces accordingly.

Robin Olsson *et.al* [2] studied Quasi-isotropic carbon/epoxy laminates with holes, polymer plugs and cut fibers analytically and for experimentation they had used. The optical non-contact measurement technique "digital speckle photography" (DSP) to measure the displacement and strain fields. The results were used to validate an inverse method, where elastic properties of inclusions were determined by matching computed and measured displacements. They also measured Tensile and compressive strength and the applicability of notch failure criteria to soft inclusions was examined. The elastic properties predicted by the inverse method are in fairly good agreement with data from coupon tests although predictions are sensitive to measuring errors. They have found laminate toughness in compression higher than in tension. They have concluded that Laminates with inclusions tougher than laminates with holes, which may indicate that inclusions restrain in-plane fiber kinking. Higher toughness was reflected in larger characteristic lengths.

Hakim S. Sultan Aljibori *et.al* [3] focused on the behaviour of woven glass fiber/epoxy composite laminated panels under compression. Compression tests were performed on to 16 fiber-glass laminated plates with and without circular cut-outs by comparing load versus displacement curves using the INSTRON machine. The maximum load of failure for each of the glass-fiber/epoxy laminated plates under compression has been determined experimentally. They have studied the effects of varying the centrally located circular cut-out sizes and fiber angle-ply orientations on to the ultimate load. Their experimental work shows that as the cut-out size increases, the maximum load of the composite plate decreases. They have observed that cross-ply laminates possess the greatest ultimate load as compared to other types of ply stacking sequences and orientations.

Tomo Takedaetal [4] worked on the deformation and progressive failure behaviour of glass/epoxy plain weave fabric reinforced laminates subjected to uni-axial tension at cryogenic temperatures. They have performed cryogenic tensile tests on the woven-fabric laminates, and measured the damage development during loading which characterized by AE (acoustic emission) measurements. They proposed A finite element model for progressive failure analysis of woven-fabric composite panels which was and applied to simulate the "knee" behaviour in the stress–strain responses and the damage behaviour in the tensile test specimens. They observed failure of the epoxy resin matrix in the transverse fiber bundle using the maximum strain failure criterion. The effect of strain concentrations due to the fabric architecture on the failure strain of the material was considered by incorporating the SVF (strain variation factor) from the meso-scale analysis of a woven-fabric composite unit into the macro-scale analysis of the specimens. They validated the finite element results using the experimental data.

Wu Zhen and Chen Wanji [5] Proposed a single-layer higher-order model for predicting the stresses at curved free boundaries of laminated composite plates subjected to in plane loading. The proposed model can automatically satisfy the continuity of transverse shear stresses at interfaces. They have developed a model which was based the proposed model and the methodology of the discrete Kirchhoff plate bending element, a triangular finite element also presented. Numerical examples of curved free-edge problems have been taken into account to illustrate the performance of the present approach. Based on numerical results they showed that the proposed model was capable of predict in plane and inter laminar stresses around the circular hole.

S.A.M. Ghannadpour *et.al* [6**]** addressed the effects of a circular /elliptical cut-out on the buckling behaviour of rectangular plates made of polymer matrix composites (PMC). The study was concentrated on the behaviour of rectangular symmetric cross-ply laminates. Finite element analysis was also performed to predict the effects of cut-out size on the buckling behaviour of these plates. They have also studied effect of buckling load on cut out dimensions. Effect of plate aspect ratio on buckling behaviour of plate also the boundary condition effect on the buckling load. The results indicates that as cut out diameter of circular cutout on the square plate increases the buckling load reduces, In the elliptical cutouts, one which aligned perpendicular to load direction represents higher buckling load than one aligned in the direction of load and buckling load increases by selecting the higher value for aspect ratio.

Damodar R. Ambur *et.al*.[7] Presented progressive failure analysis results for composite curved panels with and without a circular cut-out and subjected to axial compression loading well into their post buckling regime. They studied ply damage modes such as matrix cracking, fiber-matrix shear and fiber failure. Results from finite element analyses are compared with experimental data. Modelling of initial geometric imperfections may be required to obtain accurate analysis results depending on the ratio of the cut out width to panel width.There results shows that, The matrix failure mode occurs at or after panel buckling depending on whether panel geometric imperfections are considered or not, For the curved panel with a cutout, geometric imperfection may be important if the cutout size is small compared to the size of the panel and de-lamination does occur at the free edge of the hole.

M. Saha *et.al* [8] studied and presented Compressive behaviour of E-glass fiber/isophthalic polyester resin matrix pultruded composite sheet material is reported for two thicknesses. The effect of circular holes on compressive strength and failure strain was also investigated. In the first series of tests, compression tests were performed with plate specimens without any hole. The specimens were instrumented with several pairs of back-to-back axial strain gauges at different locations on the surface of the specimen to capture global buckling during compression. The plate specimens with circular holes were prepared. They chosen diameter to width ratio of D=W ¼ 0:075–0.75 was chosen. The open-hole specimens were also instrumented with several strain gauges (combination of single and strip gauges) in and around the surface of the hole to determine the strain distribution, strain concentration factor, transverse and through-the-thickness normal strain, etc. They had established a relationship between the compressive strength and hole-diameter compared with the base line material properties. Finally, they had determined the compressive failure initiation mechanisms and failure progression mechanisms in the presence of holes through sectioning and examining under a stereomicroscope.They found strain at the hole edge was found to be higher as the diameter of the hole increased.

D.K. Nageswara Rao *et.al* [9] proposed the solution for the stress distribution around holes in symmetric laminates as well as in isotropic plates and also to determine the failure strength of the laminate on first ply failure basis by Tsai-Hill, Hashin-Rotem and Tsai-Wu criteria. Square and rectangular holes in symmetric laminates of Graphite/epoxy and Glass/epoxy were studied. The maximum stress and its location are mainly influenced by the type of loading. They found for square holes due to the aspect ratio reaching unity, the maximum stress points at the corners for either directions of loading. For rectangular holes, the points of maximum stress are shifted onto the longer edges away from the corners.

M Mohan Kumar *et.al* [10] studied buckling behavior of woven glass epoxy laminated composite plate by considering effects of different parameters like length to thickness ratio, aspect ratio, cut-out shapes, Fiber orientation on buckling load. They concluded that due to the cutouts buckling load reduces.

4. DISCUSSION

From the literature review it is clear that the parameters such as the fiber angle orientation, cut-out shapes, size of Cutout affects the buckling loads. The stress concentration can vary according to the cutout shape. The results obtained from the Finite Element method and experimental results can be compared so as to predict the actual behavior of the composite laminates.

5. CONCLUSION

From the literature survey results it is found that, as the cutout size increases the buckling load decreases in case of circular cuts. In the elliptical cutouts, one which aligned perpendicular to load direction represents higher buckling load than one aligned in the direction of load. Maximum Stress point shifted in case of square and rectangular Cutouts. Stress strain behavior of the laminates depends on orientation of the fibers. The study of this review suggests that, stress concentration can be minimized by selecting proper cutout shape along with fiber angle orientations.

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