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Finite Element Analysis of Glass/Epoxy Composite Laminates with Different Types of Circular Cutouts

KEYWORDS: laminate, finite element method, composite

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ABSTRACT *This paper is focused on the analysis of stress-strain and displacement for compressive load on the fiber- reinforced composite laminates. Three different orientations of fibers are analyzed with and without the circular cut-outs. Also different dimensions of circular cut-outs are applied on the laminates at different compressive loading conditions. This analysis is carried out using the finite element software ANSYS. From the result, it is identified that cross-ply composite laminates possess the highest strength as compared to other types of angle orientations. Also it is concluded that the maximum load bearing capacity decreases as the cut-out size increases.*

1 INTRODUCTION

In recent years, it would appear that progress has been in the development of engineering advanced materials, especially composite laminated materials. Composite laminates are composed of thin layers (plies) consisting of reinforcement and a matrix. The reinforcement is typically a strong, stiff material, in the form of long fibers. The matrix is typically 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 a large 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 stifness and strength-to-weight ratios, 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, the through- thickness distributions of 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 efcient for the analysis of complex structural behavior of the composite laminates.

The largest damage future is usually delamination, which may cause significant reductions in flexural stiffness and buckling loads. The effect of delamination has been a subject of extensive research, and fairly reliable methods are now available for prediction of growth of artificial single delamination [1]. 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 designs for these structures [2].

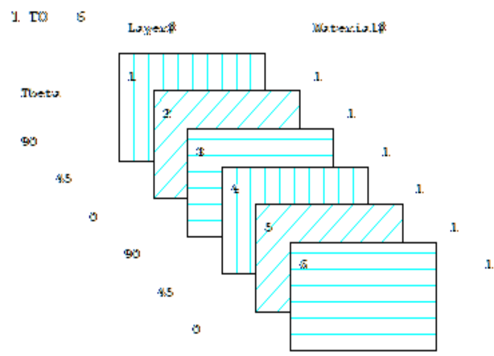

Figure.1: Composite laminate with different stacking sequence

An experimental study of the behavior of woven glass fiber/epoxy composite laminated plates under compression is explained by Hakim S. Sultan Aljibori and W.P. Chon [2]. Compression tests were performed on to 16 fiber-glass laminated plates with and without circular cut-outs using the compressed machine. The maximum load of failure for each of the glass-fiber/epoxy laminated plates under compression has been determined experimentally. According to M. de Freitas and L. Reis [3], impact loading in composite plates lead to damage with matrix cracking, inter-laminar failure and eventually fiber breakage for higher impact energies. Even when no visible impact damage is observed at the surface on the point of impact, matrix cracking and inter-laminar failure can occur, and the carrying load of the composite laminates is considerably reduced.

2.0 OBJECTIVES

Composites are found to have great strength to weight ratio. It can be further increased by making use of perforated plate in case of complete composite sheet. This results in the loss of strength but increase in strength to weight ratio. A study of the stress-strain and displacement of woven glass fiber/epoxy composite laminated plates under compression load is presented. The maximum load of failure for each of the glass fiber/epoxy laminated plates under compression load has been determined through simulation software (ANSYS). The effects of varying the centrally located circular cut out sizes and fiber angle ply orientations under the ultimate load has been simulated. The crack propagation in the drilled laminate sheets is focused. The study of stress-strain development and displacement on composite plate with circular hole of three different diameters and three different orientations

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under varying compression load is per

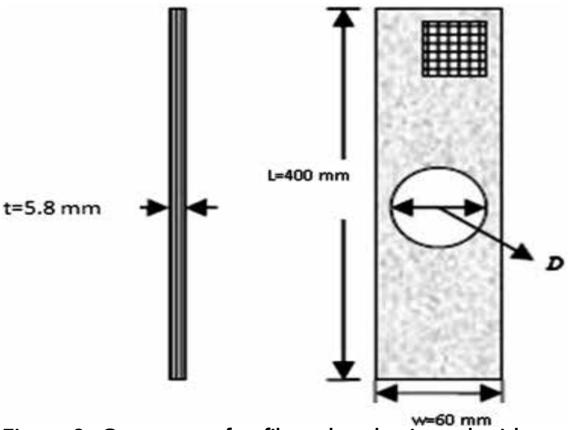

Figure.2: Geometry of a fiber-glass laminated with centrally cut hole

3.0 STRESS-STRAIN AND DISPALACEMENT ANALYSIS

The finite element analysis (FEA) software ANSYS is used to simulate and analyze stress-strain and displacement behavior of glass fiber/epoxy composite laminated plates. The laminates of the composite plates is designed and analyzed under gradually varying compression load. Proper element type is chosen to design our composite laminate. These plates have 6 ply laminates symmetric from the center. One side of the laminate is kept fixed and other is applied with the load increasing gradually. For the analysis, the load is increased in the steps of 500N. For each application of load values stress-strain and displacement values are noted. The load and boundary conditions are selected as shown in Figure-3.

The two different cases of the plates are considered as shown below

a) With circular hole of dia. 22 mm at the center
b) With circular hole of dia. 28 mm at the center

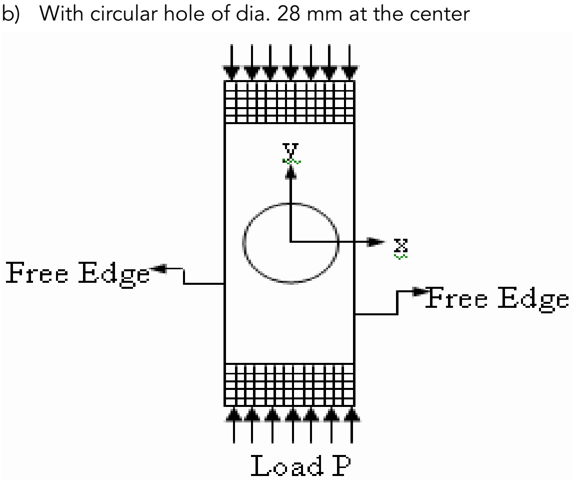

Figure.3: Load and boundary condition for the specimen

The three different orientations of the plates are considered.

a) [00/600/300] ŝ
b) [90°/45°/0°] ŝ

A material property has been chosen from the Wu Zhen [4] and Det Norske Verit [5]. Orthotropic material has been chosen for the analysis as their property varies in different direction which is true for fiber reinforced composites. Two plates of different orientation with same dimension but varying dimensions of the cut hole located centrally in the plate are designed.

Table.1: Material properties of glass/epoxy composite

property	value
Young's modulus ,E11	145 GPa
Young's modulus E22, E33	10.7 GPa
Young's modulus,E33	10.7 GPa
Shear modulus, G12	4.5 GPa
Shear modulus, G13	4:5 GPa
Shear modulus, G23	3.6 GPa
Poisson ratio, v12	0.31
Poisson ratio, v13	0.31
Poisson ratio, v23	0.49
Element type	Solid 86 (20-node solid element)
Thickness of ply	0.9mm

Solid 86 is a higher node 3-D 20- node solid element that exhibits quadratic displacement behavior. It is defined by 20 nodes having three degrees of freedom per node. It supports plasticity, hyper elasticity, creep, stress stiffening, large deflection and large strain capabilities. It also has mixed formulation capability for simulating deformations of nearly incompressible hyper elasticity materials. It allows up to 250 different layers.

4.0 RESULTS

The results obtained from the ANSYS analysis are presented in the following Tables. The compressive load is increased gradually in steps of 500N starting from zero. Thus the values of the displacement, stress and strain are noted for the load of 500N, 1000N, 1500N and so on till the maximum load is achieved.

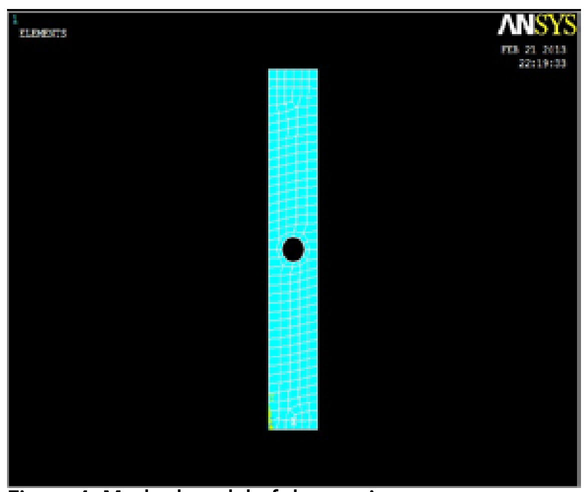

Figure.4: Meshed model of the specimen

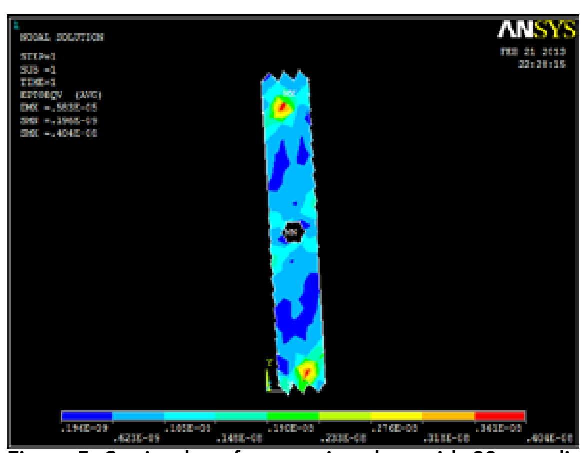

Figure.5: Strain plot of composite plate with 28 mm dia hole at orientation [0°/60°/30°] ŝ

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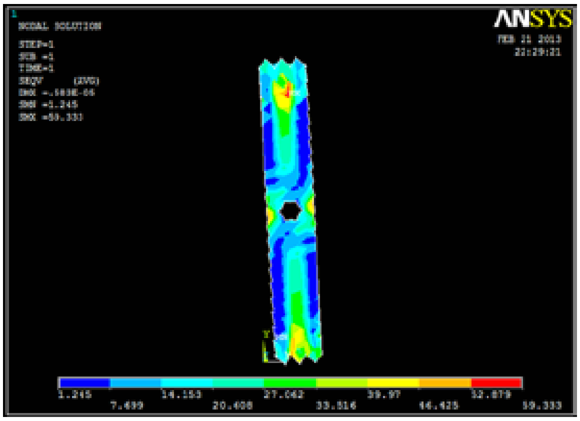

Figure.6: Stress plot of composite plate with 28 mm dia hole at orientation [0°/60°/30°] ŝ

Table.2: Values of the displacement, stress and train for the load varying from 500N for plate at orientation of [90°/45°/0°] ŝ with 28 diameter hole

Load	Displacement	Stress	Strain
500	3.997	2592	0.040039
1000	7.993	5184	0.080079
1500	11.99	7776	0.120118
2000	15.987	10368	0.160157
2500	19.984	12960	0.200197
3000	23.98	15553	0.240236
3500	27.977	18146	0.280276

Table.3: Values of the displacement, stress and train for the load varying from 500N for plate at orientation of [90°/45°/0°] ŝ with 38 diameter hole

Load	Displacement	Stress	Strain
500	4.525	3919	0.057723
1000	9.05	7839	0.115445
1500	13.567	11758	0.173162
2000	18.101	15678	0.230891
2500	22.626	19597	0.288614
3000	27.151	23517	0.346336
3500	31.677	27436	0.404059

Table.4: Values of the displacement, stress and rain for the load varying from 500N for plate at orientation of [0°/60°/30°] ŝ with 28 diameter hole

Load	Displacement	Stress	Strain
500	4.5	3009	0.045999
1000	9.001	6017	0.091998
1500	13.501	9026	0.137997
2000	18.001	12035	0.183996
2500	22.501	15043	0.229995
3000	27.002	18052	0.275994
3500	31.502	21061	0.321993

Table.5: Values of the displacement, stress and train for the load varying from 500N for plate at orientation of [0°/60°/30°] ŝ with 38 diameter hole

Load	Displacement	Stress	Strain
500	5.072	4341	0.064678
1000	10.143	8681	0.129356
1500	15.215	13022	0.194034
2000	20.286	17362	0.258712
2500	25.358	21703	0.32339
3000	30.43	26043	0.388068
3500	35.501	30384	0.452746

From the above data, it is clear that as the central hole diameter increases, the plate breaks or its displacement and stress increases for the same load compared to the plate with lower diameter hole. This can be clearly shown by comparing the graphs drawn between load-displacements for the orientation with varying diameters of centrally located hole.

5.0 STRESS VS. STRAIN GRAPH IS FOUND TO BE LINEAR

Graphs to the stress versus strain for different diameter of holes at each orientation are plotted and shown in Figures. It is the material property of the composites that as the stress increases their strain also increases linearly. Thus the stress strain curve for the composite material is a straight line which is one of the characteristics of a composite material.

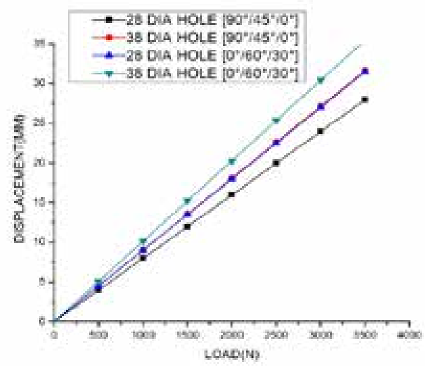

Figure.7: Load vs. displacement for different dia. Of hole and different orientation

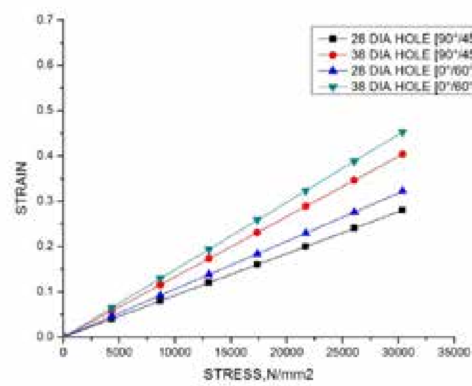

Figure.8: Stress vs. Strain for different dia. of hole and different orientation

6.0 CONCLUSION

Thus fiber orientation is very important in determination of the strength of the composite. In this paper, the different fiber orientation like [90°/45°/0°] ŝ, and [0°/60°/30°] are analyzed under different compressive loading with different circular cut-out conditions. Out of these orientations, it is found that the [90°/45°/0°] ŝ configuration is the best and has the

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maximum load bearing capacity and strength than the other orientations. i.e., the cross plies have maximum load carrying capacity as compared to angular plies As the diameter of the cut hole is increased the strength of the plate decreases. It is because of the material removal from the plate reduces its strength and the load bearing capacity also reduces accordingly.

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