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Stress Concentration Study of Laminated Composite with Multiple Holes by Finite Element Analysis

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ABSTRACT: *A "Composite" is considered as one material when two or more different materials combined together to create superior material. A composite laminate is a composite with combination of layers. They have great applications in many engineering domains like civil, marine, aerospace, biomedical etc. because of their excellent properties like low weight, better mechanical properties and ease of handling and low cost of production. The practical applications of composites enables that the composite structures usually consist cut-outs in it in order to get the required design. Thus it is essential to study the behaviour of composites with multiple holes with respect to different applications in order to provide structural stability and to attain better design and mechanical Properties. This work presents Analytical and Finite Element Analysis of rectangular plate with and without multiple circular cut-outs of various sizes. The work is checked for deformation and stress obtained for various loads .The material considered was Glass/Epoxy laminate. The deformation and stress distribution for various loads is analysed by Ansys software. The specimens used are plate without hole, plate with 3 holes of 5mm each, plate with 6mm holes, plate with 8mm holes and plate with 10mm holes. The analytical and numerical results are compared in Stress - Strain curves and Load - Deformation curves and found that both are in good agreement.*
Keywords: *Deformation, FEM, Multiple circular cut out, Stress.*
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I. INTRODUCTION

A composite material is a superior material with the combination of two or more dissimilar materials. A composite laminate is made up by layers of materials. The application of composite materials in engineering is widespread and almost more than 50% of the structures are made up of composites. The wide application lies in its unmatchable properties like high strength to weight ratio and high stiffness .Since the use of composites is enormous in engineering applications there is a need of cuts and joining elements in the composites to use them in the structures, the cuts may be different types of holes for accommodating bolts ,nuts ,rivets and others and cuts may also be due to different required shapes in structures. The presence of cuts are inevitable and their presence are sure to reduce load carrying capacity and hence strength. The amount of reduction in strength or load bearing is definitely a parameter of interest. Extensive studies need to be taken in this regard considering multiple holes, different shape of holes, orientation of holes, different orientation of plies , different thickness , different materials etc. In this work such one concept is selected that is Epoxy Polymer Woven Mat (EPWM) composite laminate with 12 layers of rectangular shape without and with multiple holes of different size and loading conditions. Average stress obtained in the FEM is used. These geometries have been developed using Ansys mechanical APDL along with knowing the standards of the ASTM the model has been built with key point concept in Ansys.Shell 181 element is used in FEM.

Deepanshu Bhatt et al [1] performed Analysis of Centre Circular Cutout of Laminated Composite Plate and Square Skew Plate by using FEM. They showed that the fundamental natural frequency changes only marginally if a small cutout (either of the two cut out ratios being small) is made in the plate. Their observation also showed that for intermediate and large size cutouts, the fundamental natural frequency increases rapidly and this amount of increase depends on cutout ratios in two directions. Harsh Kumar Bhardwaj, Jyoti Vimal, Avadesh Kumar Sharma [2] in Journal of Civil Engineering and Environmental Technology ,Non-dimensional frequencies increase with increasing the cut-out size, number of laminates of the plate and modulus ratio of the plate. M.S.R. Niranjan kumar, M.M.M. Sarcaar and V. Balakrishna [3] in Indian journal of Engineering and Material science presented that the ellipses are cut out in laminated plates and normal stresses are to be affected with loading conditions. K.anand babu [4] in Indian journal of applied research has done Finite Element Analysis of Glass/Epoxy Composite Laminates with Different Types of Circular Cutouts shown that fiber orientation is very important in determination of the strength of the composite.

II. PROBLEM, MATERIAL AND METHODOLOGY

2.1 Tensile loading of rectangular laminate of Epoxy Polymer Woven Mat (EPWM12) with the tensile setup (static analysis is considered) , the different cases include

Case (i) EPWM without hole (both analytical and FEM for all cases)
Case (ii) EPWM with 3 holes of 5mm each and uniformly spaced
Case (iii) EPWM with 3 holes of 6mm .
Case (iv) EPWM with 3 holes of 8mm
Case (v) EPWM with 3 holes of 10mm

2.2 Material properties

Mass of one lamina	50 gms	Volume fraction of fiber, Vf	0.55
No of Laminas	12	Volume fraction of matrix,Vm	0.45
Mass of total lamina(Fiber)	600 gms	Density of composite,	1915Kg/m3
Mass of Laminate	810 gms	Elastic modulus of Fiber,Ef	85 Gpa
Mass of Filler(Aluminum)	5 gms	Poisson's ratio of fiber, vf	0.2
Mass of Resin	205 gms	Shear modulus of fiber, Gf	7 Gpa
Density of E-glass, ρf	2500Kg/m3	Elastic modulus of Matrix, Em	7 Gpa
Density of Epoxy, ρm	1200Kg/m3	Poisson's ratio of matrix, vm	0.245
Density of Aluminum, ρfr	2400Kg/m3	Shear modulus of matrix, Gm	7 Gpa
Volume of Fiber, vf	2.40E-04 m3	Longitudinal elastic modulus,E1	49.90 Gpa
Volume of Matrix, vm	1.71E-04 m3	Transverse elastic modulus,E2	49.90 Gpa
Volume of Filler, vfr	2.08E-06 m3	Major Poison's ratio,v12	0.245
Volume of composite, vc	4.13E-04 m3	Minor Poisson's ratio,v21	0.245

Note: Volume fractions are considered to arrive at young's modulus E

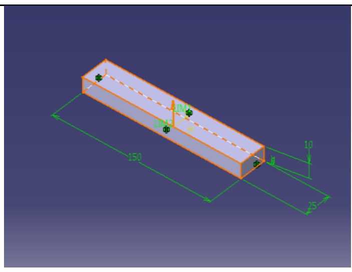


Figure1. Geometry of specimen composite laminate

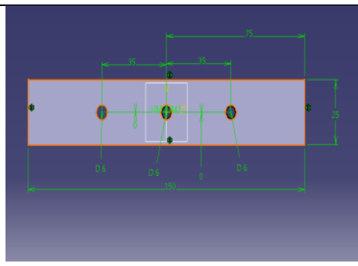


Figure2. Detailed geometry model of specimen composite laminate with holes of diameter 6mm

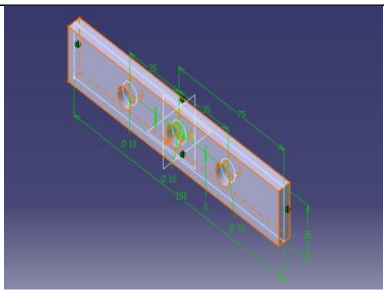


Figure 3. Isometric detailed geometry model of specimen composite laminate with holes of diameter 10mm

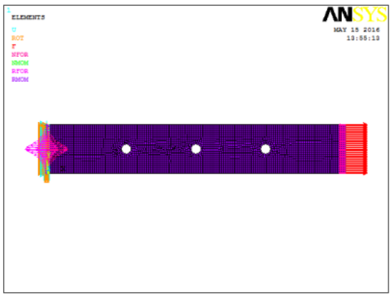


Figure4. Geometry model of specimen composite laminate with holes of diameter 10mm applied with load and boundary conditions

2.3 Equations

1. $\boldsymbol{\delta = \frac{PL}{AE}}$ -----(1)
2. $\boldsymbol{\sigma = \frac{P}{A}}$ -----(2)

δ →Deformation in mm, P→Load in N, L→Length in mm, A→Area in mm^2, σ→Stress in Mpa

2.4 Methodology

1. Determining deformation and stress values from analytical method for the different cases listed above

2. Modelling in ansys,
3. Pre-processing/ Meshing, assigning boundary conditions and loads. The geometry has been meshed with element shell 181 with size being 1mm and quad shape.
4. Finding solution
5. Post processing , results view, Validation and conclusion

III. RESULT AND DISCUSSION

Table 3.1 : Deformation table of EPWM considering without hole(case 1)

Sl. No.	Load in N/mm2	Area in mm	Load in N	FE Deformation in mm	Stress from FE In Mpa	Analytical deformation in mm	Stress from analytical In Mpa
1	15	250	3750	0.041	16.33	0.04509	15
2	30	250	7500	0.093	31.99	0.09018	30
3	45	250	11250	0.140	47.88	0.135271	45
4	60	250	15000	0.187	63.97	0.180361	60
5	75	250	18750	0.234	110.82	0.225451	75
6	90	250	22500	0.281	133.69	0.270541	90
7	105	250	26250	0.328	155.21	0.315631	105
8	120	250	30000	0.375	177.55	0.360721	120
9	135	250	33750	0.421	199.60	0.405812	135
10	150	250	37500	0.469	221.90	0.450902	150

Table 3.2 : Analytical Calculation for Load of 37500N

Load 37500N	Without hole $A=250mm^2$	With5mm holes,A=200	With6mm holes,A=190	With8mm holes,A=170	With10mm holes,A=150
δ =PL/AE (1)	(37500X150)/ (250X49900) =0.4509mm	(37500X150)/ (200X49900) =0.5636mm	(37500X150)/ (190X49900) =0.593mm	(37500X150)/ (170X49900) =0.6631mm	(37500X150)/ (150X49900) =0.7515mm
σ =P/A (2)	37500/250= $150N/mm^2$	37500/200= $187.5N/mm^2$	37500/190= $197.37N/mm^2$	37500/170= $220.59N/mm^2$	37500/150= $250N/mm^2$

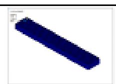
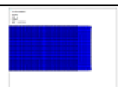
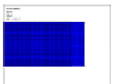
Load N/mm^2	Deformation	Load N/mm^2	Deformation	Load N/mm^2	Deformation	Load N/mm^2	Deformation
15		90		30		105	
45		120		75		150	

Figure 5 .Deformation for EPWM without hole

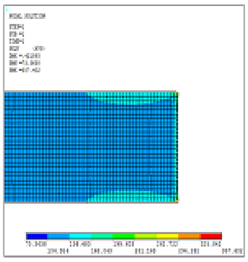
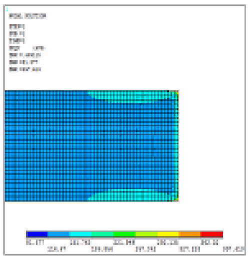
Load N/mm^2	Stress Distribution	Load N/mm^2	Stress Distribution
135		150	

Figure 6 Stress Distribution for EPWM without hole

The tensile load for the above case referring to Fig.5, Fig. 6 varies from load step of 3750 N to 37500 N, the deformation obtained for analytical varies between 0.04509mm to 0.4509mm and for FEM it varies between 0.041mm to 0.469mm, the difference in deformation between the two methods is of minimum difference of .0028mm that is 3.1% and the maximum difference is .0181mm that is 4.01% and hence very near values for both the methods is obtained. The stress for the analytical varies from 15 MPa to 150 MPa for the loads mentioned and for FEM 16.33MPa to 221.9 MPa where the minimum difference between the two methods is 1.33MPa to a maximum difference of 71.9MPa, this is due to in FEM the average stress obtained is engineering stress where the areas are considered at that instant. The stress contours also show that the stress values are more at that corners where load is applied and because of that maximum stress concentration is seen at the corners . The strain from the analytical varies from 0.0003 to 0.0027 and for FEM it varies from 0.00027 to 0.0031, the difference in strain values varies from 3.1% to 4% and are in very acceptable range between the two methods.

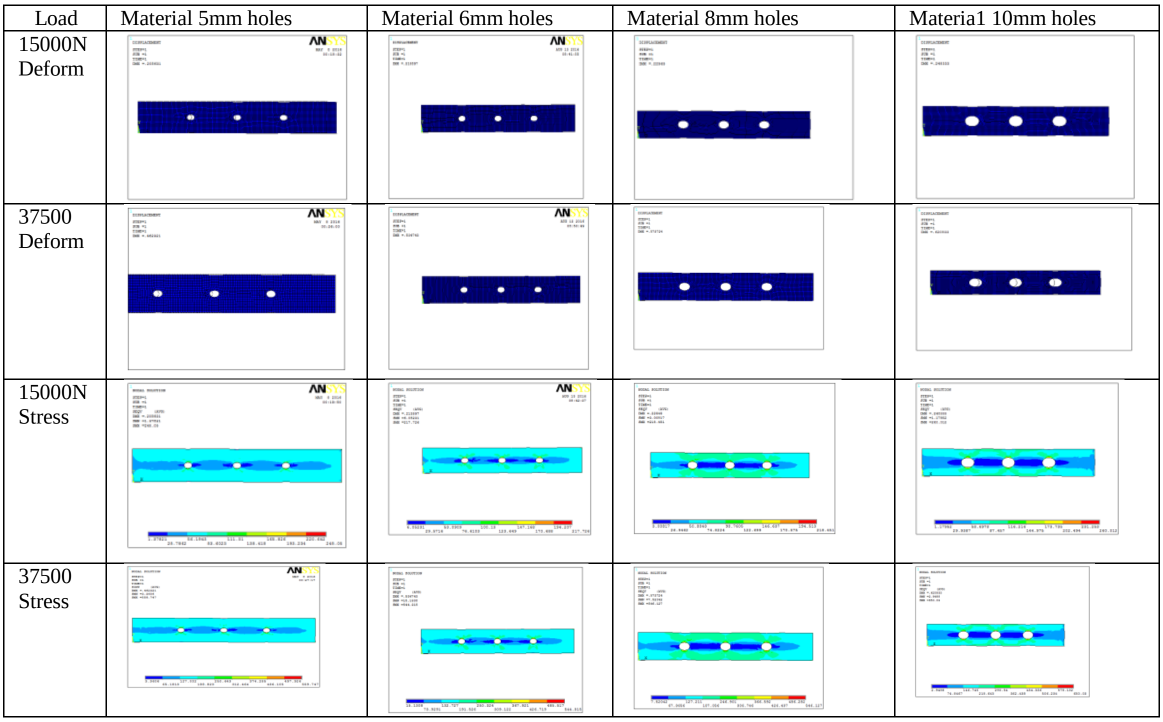


Figure 7 Deformation and Stress distribution for EPWM with holes

Table 3.3 shows the tabulated values of all the parameters of EPWM12 with 5mm diameter (case 2)

Sl. No.	Area in mm	Load in N	FE Deformation in mm	Stress from FE In Mpa	Analytical Deformation In mm	Stress from analytical In Mpa
1	200	3750	0.051	27.67	0.056	18.75
2	200	15000	0.205	111.01	0.225	75
3	200	26250	0.375	180.7	0.395	131.25
4	200	37500	0.462	250.	0.450	187.5

The material with 3 holes of 5mm diameter accounts 1.6% reduction in material .Table. 3.3shows the minimum and maximum deformation for analytical is 0.051mm to 0.462mm. and for FEM it is 0.051mm to 0.02mm and the maximum difference between the two is 0.02mm. The corresponding minimum and maximum stresses for the two materials are 18.75MPa , 187.5MPa and 27.57MPa and 250MPa respectively but the difference in stress between the two methods due to the engineering stress taken in two methods.The strain values varies from 0.00037 to 0.003 for analytical and for FEM it is 0.00034 to 0.0031.

Table 3.4 shows the tabulated values of all the parameters of EPWM12 with 6mm diameter (case 3)

Sl No.	Area in mm	Load in N	FE Deformation in mm	Stress from FE In Mpa	Analytical Deformation In mm	Stress from analytical In Mpa
1	190	3750	0.053	25.32	0.059	19.74
2	190	15000	0.213	100.3	0.237	78.95
3	190	26250	0.373	175.3	0.415	138.16
4	190	37500	0.534	250.	0.593	197.37

The material with 3 holes of 5mm diameter accounts 2.3% reduction in material .The Table3.4 shows minimum and maximum deformation for the analytical is 0.059mm and 0.539mm and for FEM it is .053 to 0.534mm. The maximum difference between the two is 0.059mm. The corresponding minimum and maximum stresses for the two methods is 19.74MPa and 197.37MPa and 25.32MPa and 250MPa respectively. The strain varies from 0.0039 to 0.0039 for analytical and for FEM it is 0.00035 to 0.0035 respectively.

Table 3.5 Values of all the parameters of EPWM12 with 8mm diameter (case 4)

Sl. No.	Area in mm	Load in N	FE Deformation in mm	Stress from FE In Mpa	Analytical Deformation In mm	Stress from analytical In Mpa
1	170	3750	0.056	24.52	0.066	22.06
2	170	15000	0.229	98.76	0.265	88.24
3	170	26250	0.401	172.6	0.464	154.41
4	170	37500	0.573	246.9	0.663	220.59

The material with 3 holes of 8mm diameter accounts 4% reduction in material. The Table 3.5 shows deformation varies from 0.066mm to 0.663mm for analytical and 0.056mm to 0.573mm and the maximum difference between the two is 0.09mm. The stress values for the two methods varies from 22.6MPa to 220.59MPa for analytical and for FEM is 24.52MPa to 246.9MPa.The minimum and maximum strain values are 0.0004 and 0.0044 for analytical ,0.0037 to 0.0038 respectively

Table 3.6 Values of all the parameters of EPWM12 with 10mm diameter (case 5)

Sl. No.	Area in mm	Load in N	FE Deformation in mm	Stress from FE In Mpa	Analytical Deformation In mm	Stress from analytical In Mpa
1	150	3750	0.061	28.85	0.075	25
2	150	15000	0.248	116.6	0.301	100
3	150	26250	0.434	203.1	0.526	175
4	150	37500	0.620	290.5	0.752	250

The material with 3 holes of 10mm diameter accounts 6.3% reduction in material. The Table 3.6 shows the deformation varies from 0.075mm to 0.572mm for analytical and 0.061mm to 0.62mm and the maximum difference between the two is 0.09mm and the difference between the two is 0.132mm which is in the acceptable range. The stress values varies from 25MPa to 250MPa for analytical and 28.85MPa to 290.5Mpa for FEM. The strain values varies from 0.0005 to 0.005 for analytical and 0.004 to 0.0041 for FEM.

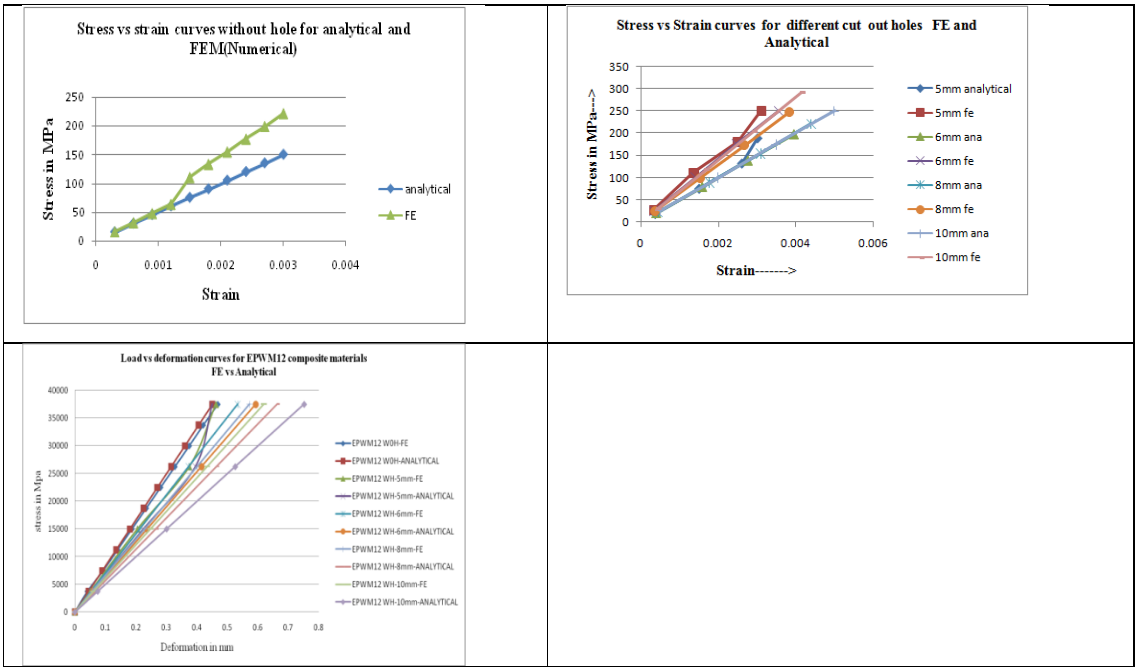


Figure 8 (a) Stress- Strain curves for EPWM without hole (b)Stress-Strain curves for EPWM with different holes (c) Deformation curves For all cases

IV. CONCLUSION

1. Finite Element Analysis and Analytical calculations work for Epoxy Polymer Woven Mat with tensile load is carried out successfully with the cases of without hole and with different size holes and defined objectives have been met.
2. It is seen when the load increases the deformation , stress and strain values increases in all cases

3. The deformation, stress and strain values for analytical and FEM for all cases are in good agreement with each other.
4. Due to the presence of cut out the deformation, stress and strain values increase. When the cut out size increases it leads to increase in the deformation, stress and strain values and the failure load is reduced.
5. The work is done for EPWM and cannot be generalised for all materials and work on other materials before applying
6. The future work may include different shapes and sizes of cuts , orientation of cuts and orientation of plies.

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