Journal Homepage: - www.journalijar.com
INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)
Article DOI: 10.21474/IJAR01/2255
DOI URL: http://dx.doi.org/10.21474/IJAR01/2255

RESEARCH ARTICLE

DEFLECTION AND STRESS STUDY OF LAMINATED COMPOSITE WITH MULTIPLE HOLES UNDER BENDING LOAD BY FEA

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Manuscript Info

Manuscript History

Received: 29 September 2016
Final Accepted: 30 October 2016
Published: November 2016

Key words:-
Deflection , Multiple circular cut out, FEM, Stress.

Abstract

The material "Composite" is considered as one formed by the combination of two or more different materials to create a superior material. The layers of composites stacked and united to get composite laminate. These composite laminates have great applications in many engineering domains like civil, marine, aerospace, biomedical etc because of their excellent properties likehigh strength to weight ratio, better mechanical properties and ease of handling and low cost of production. Most of the applications include composites. The presence of cut outs is a common and necessary feature in composite structures 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 .The present work represents Analytical and Finite Element Analysis of rectangular plate with and without multiple circular cut outs of various sizes . Various bending loads are applied and studied for deflection occurred and stress created. The material considered was Epoxy Polymer Woven Mat. The standard specimens used are rectangular plate without hole , rectangular plate with 3 holes of 5mm each, plate with 6mm holes and plate with 8mm holes. The analytical and numerical results were compared in Load – Deflection curves and found that both are in good agreement.

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Introduction:-

A composite material is a superior material with the combination of two or more dissimilar materials . A composite laminate is the combination of layers of materials. The application of composite materials in engineering is widespread. The wide application lies in it's unmatchable properties like high strength to weight ratio and high stiffness .The use of composites is inevitable in engineering applications and also there is a need of cut outs and joining elements in the composites to use them in the structures , the cuts may be of 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 sure in design and their presence 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 ,

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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 using bending load conditions.

F.Dalale et al. [1] has done work on a axisymmetric bending load applied to composite plate with a circular hole and stress analysis is carried out. An elasticity series solution of the axisymmetric bending problem is presented. This can be considered as the first component of the general bending problem. The stresses exhibit the expected singular behavior around the hole boundary. The results are also compared with those obtained by using the Finite Ele ment Method. It is observed that the two sets agree rather well with regard to trend and magnitude of interface stresses. Abdelhak Khechai et al.[2] has studied the stress concentration factors in cross-and-angle-ply laminated composite plates as well as in isotropic plates with single circular holes subjected to uniaxial loading is studied. The numerical results obtained are in closed match with theoritaical values .Deepanshu Bhatt et al [3] 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.

Problem, Material and Method:-

Rectangular laminate of Epoxy Polymer Woven Mat (EPWM) with the bending load setup (static analysis is considered) The analytical and FE analysis include the different cases
Case (i) Epoxy Polymer Woven Mat (EPWM) without hole
Case (ii) Epoxy Polymer Woven Mat with 3 holes of 5mm each and uniformly spaced
Case (iii) Epoxy Polymer Woven Mat with 3 holes of 6mm each and equally spaced
Case (iv) Epoxy Polymer Woven Mat with 3 holes of 8mm each and evenly spaced

Formula to calculate analytical deflection:-

$\delta = PL^3 / (48EI)$--------(1)

δ →deflection in mm, P→Load in N, L→Length in mm, E→Young's Modulus of composite in N/mm^2 , I→Moment of Inertia of the section in mm^4

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, νf	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, νm	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,ν12	0.245
Volume of composite, vc	4.13E-04 m3	Minor Poisson's ratio,ν21	0.245

Modelling of specimen for various cases:-

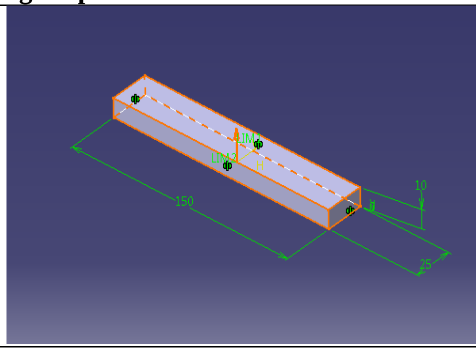


Fig.1:- Geometry of specimen composite laminate without holes.

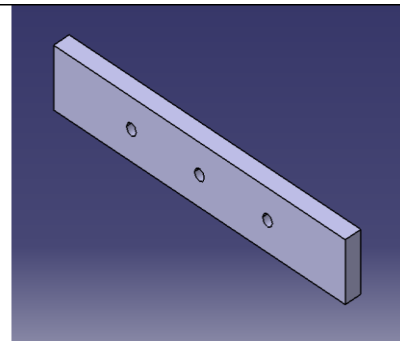


Fig 2:- Model of specimen composite laminate with holes of diameter 5mm

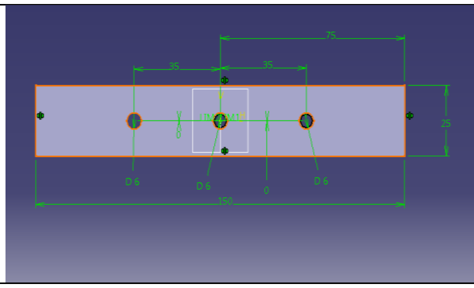


Fig 3:- Detailed geometry model of specimen composite laminate with holes of diameter 6mm

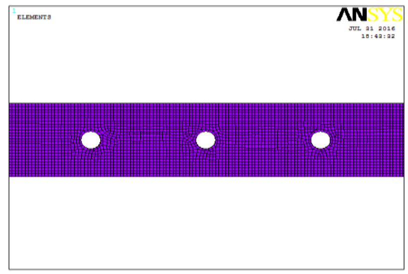


Fig 4:- Meshed model of specimen composite laminate with holes of diameter 8mm

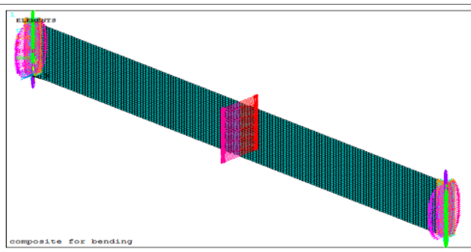


Fig 5:- Bending load and boundary conditions on specimen EPWM12 without hole

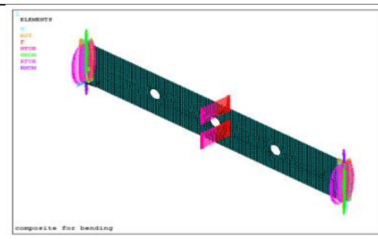


Fig 6:- Bending load and boundary conditions on specimen EPWM12 with holes of 5mm diameter

Method:-
1. Determining deflection and stress values from analytical method for the different cases under consideration
2. Modeling of the specimen 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. Obtaining Solution.
5. Post processing and view of results
6. Validatiing and writing conclusion

Result and Discussion:-

Table 3.1 Analytical Calculation for Bending Load of Load for 4000N

Load 4000N	Without hole I=2083.33 mm4	With5mm holes I=2030 mm4	With6mm holes I=1975 mm4	With8mm holes I=1742 mm4
$\delta=PL^3$ /(48EI)	$4000X150^3$ / (48X85000X2083.33) =3308.82/2083.33 =1.5882 mm	3308.82/2030 =1.62996 mm	3308.82/1975 =1.67535 mm	3308.82/1742 =1.8994 mm

Table 3.2:- Values of all the parameters of EPWM without hole under bending load

S.N	Load in N	Deflection in mm	Analytical deflection In mm
1	500	0.122	0.198
2	1000	0.349	0.397
3	1500	0.360	0.596
4	2000	0.476	0.794
5	2500	0.598	0.992
6	3000	0.721	1.191
7	3500	0.953	1.389
8	4000	1.087	1.588

3.1:- Deflection and stress for EPWM without hole

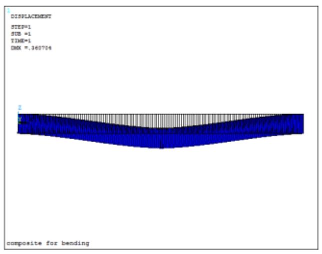
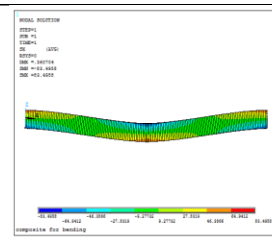
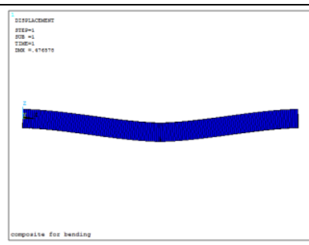
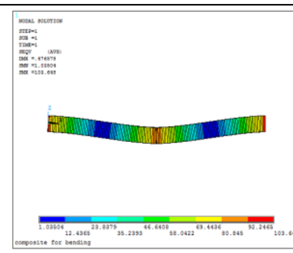
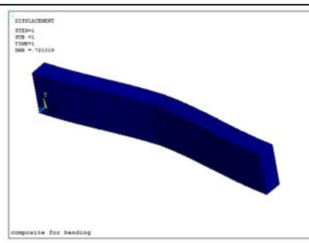
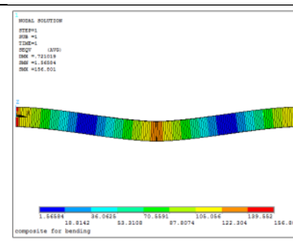
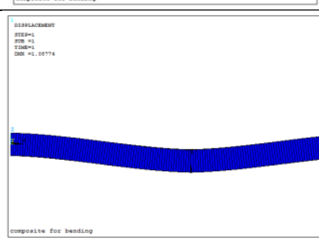
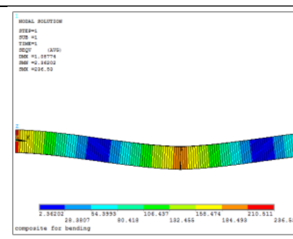
Load in N	Deflection in mm	Bending Stress in N/mm^2
1000		
2000		
3000		
4000		

Fig 7:- Deflection and Stress plots for EPWM without holes

The bending load for the case (i) varies from load step of 500 N to 4000 N , the deflection obtained for analytical varies between 0.1985 mm to 1.5884mm and for FEM it varies between 0.122mm to 1.087mm, the difference in deflection between the two methods is of minimum difference of 0.0821mm and the maximum difference is 0.5014mm and hence very near values for both the methods is obtained.

From the FE analysis of the specimen without hole for bending load it shows the stress distribution in the above plots and as load increases from 500 N to 4000N in steps altogether the stress also increases The stress distribution is shown in the plots where the average stress value from the first load step to the last load step varies from 12Mpa to 106.7Mpa. Stress values shows more at the corner and the load applied area because of the stress concentration at corners and stress affected areas and higher stress found to be 236Mpa for load of 4000N.

Deflection and stress for EPWM holes of 5mm, 6mm and 8mm:-

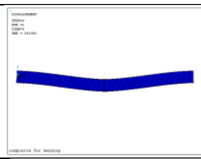
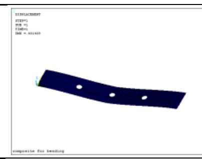
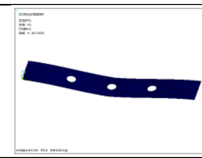
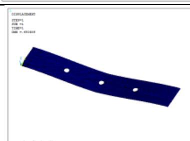
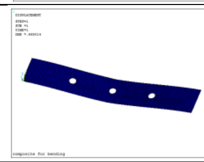
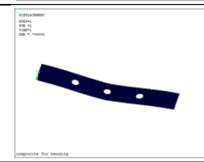
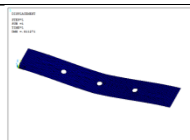
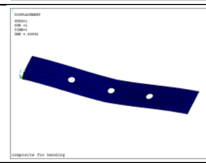
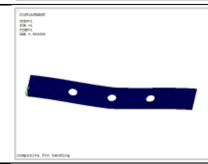
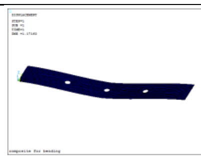
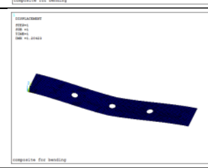
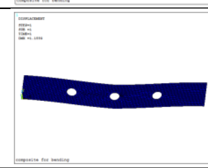
Load	Material 5mm holes	Material 6mm holes	Material 8mm holes
1500 N Deflection			
2500 N Deflection			
3500 N Deflection			
4500 N Deflection			

Fig 8:- Deflection plots for EPWM with5mm,6mm and 8mm holes for various loads

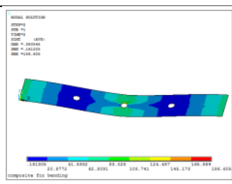
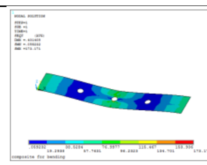
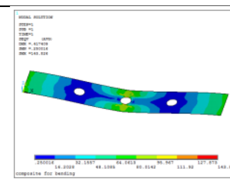
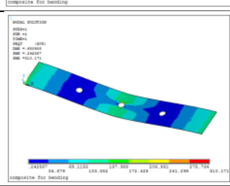
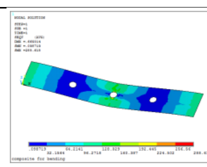
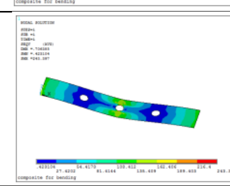
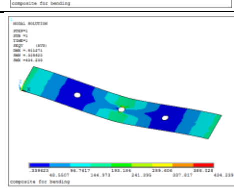
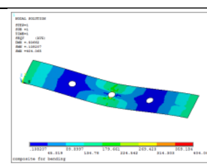
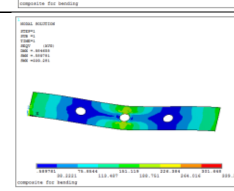
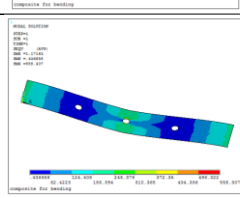
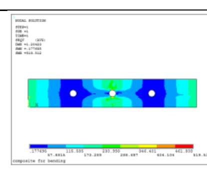
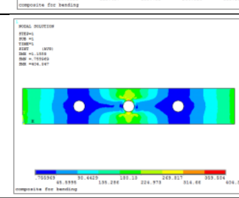
Load	Material 5mm holes	Material 6mm holes	Material 8mm holes
1500 N Stress			
2500 N Stress			
3500 N Stress			
4500 N Stress			

Fig 9:- Stress plots for EPWM with5mm,6mm and 8mm holes for various loads

Table 3.3:- Bending simulation parameter of EPWM with hole of 5mm diameter

S.N	Load in N	Deflection in mm(FE)	Analytical deflection In mm
1	500	0.130	0.2037
2	1000	0.260	0.4074
3	1500	0.391	0.6112
4	2000	0.520	0.8149
5	2500	0.650	1.0187
6	3000	0.781	1.2224
7	3500	0.911	1.4262
8	4000	1.041	1.6299
9	4500	1.175	1.8337

The specimen considered with 3 holes of 5mm each reduces the material by 1.6% .The bending load for the case (ii) varies from load step of 500 N to 4000 N , the deflection obtained for analytical varies between 0.19852037 mm to 1.8337mm and for FE it varies between 0.13mm to 1.175mm, the difference in deflection between the two methods is of minimum difference of 0.0737mm and the maximum difference is 0.5899mm and hence very near values for both the methods is obtained.

From the FE analysis of the specimen without hole for bending load as in figure 8 it shows the stress distribution in the above plots and as load increases from 500 N to 4500N in steps altogether the stress also increases . Here the stress variation contours for the load case 1 and 9 has been shown in the above picture where the average stress value from the first load step to the last load step varies from 28.7Mpa to 248Mpa.

Table 3.4:- Bending simulation parameter of EPWM with hole of 6mm diameter

S.N	Load in N	FE Deflection in mm	Analytical deflection In mm
1	500	0.133	0.209419
2	1500	0.401	0.628258
3	2500	0.669	1.047096
4	3500	0.936	1.465934
5	4500	1.204	1.884773

The material with 3 holes of 6mm each accounts to 2.3% reduction in material . As per Table 3.4 the minimum difference in deflection between analytical and FE is 0.07642 and maximum difference is 0.068077 mm. Referring Figure 8 the stress variation contours for the load is shown where the average stress value from the first load step to the last load step varies from 26.9Mpa to 230.99Mpa. Maximum stress found to be 519Mpa for load case of 4500N.

Table 3.5:- Bending simulation parameter of EPWM with hole of 8mm diameter.

S.N	Load in N	FE Deflection in mm	Analytical deflection in mm
1	500	0.139	0.2374
2	1500	0.417	0.7122
3	2500	0.706	1.1871
4	3500	0.984	1.6620
5	4500	1.159	2.1368

The presence of 3 holes of 8mm each in a material accounts to 4% reduction in material.
Refering Table 3.5 the deflection FE varies from 0.139mm to 1.159mm and corresponding analytical variation is 2.1368. The maximum difference in deflection between 2 methods in consideration is 0.0984 to 0.9778mm. Here the stress variation contours for the load case 1 and 5 has been shown in the above picture where the average stress value from the first load step to the last load step varies from 21.3Mpa to 180Mpa. Maximum stress found to be 404Mpa for load case of 4500N.

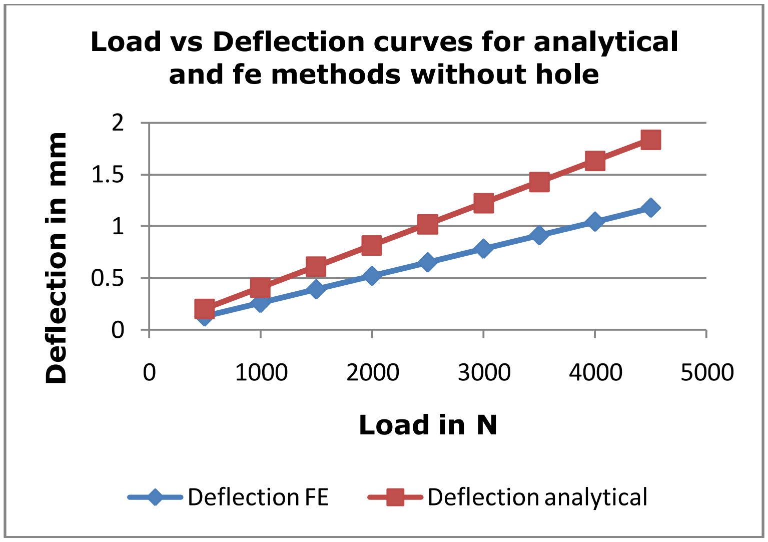


Fig 10:- Load vs deflection cures without hole

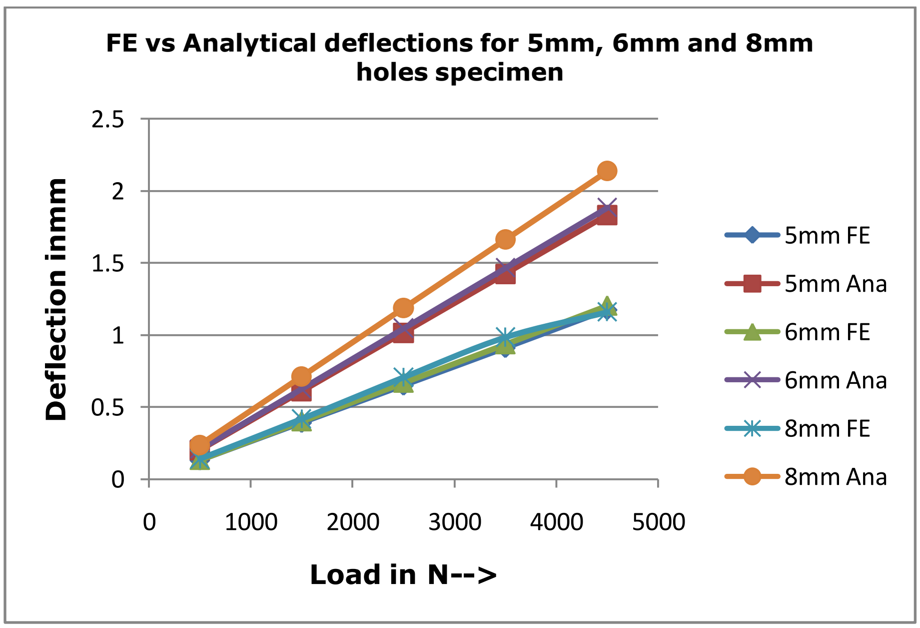


Fig11:- Load vs deflection cures with different size holes

Conclusion:-

1. Finite Element Analysis and Analytical calculations work for Epoxy Polymer Woven Mat with bending load is carried out successfully with the cases of without hole and with different size holes and defined objectives have been met.
2. when the load increases the deformation and stress values increases in all cases
3.The deflection and stress values for analytical and FEM for all cases are in good agreement with each other.
4. Presence of cut out increases deflection and stress values
5. When the cut out size increases it leads to increase in the deflection and failure load is reduced.
6.The present work is done for epwm material and the work can be extended to other materials.
7.The work cannot be generalised and need extensive work on other materials.
8.The future work may include different shapes and sizes of cuts their orientation, plies orientation , different loading and boundary conditions.

Acknowledgement:-

Thanks to almighty and padmashri

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