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INTERLAMINAR SHEAR STRESS DISTRIBUTION FOR LAMINATED COMPOSITE PLATE WITH A CENTER CIRCULAR HOLE UNDER TRANSVERSE LOADING WITH DIFFERENT BOUNDARY CONDITIONS

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ABSTRACT:

Stress concentration factor (SCF) for a laminated composite plate under transverse loading with four different boundary conditions are analyzed. This research aims to study the layer wise shear stress distribution in the laminate for all boundary conditions considered. Laminated composite plate is stacked with symmetric and anti-symmetric cross ply configurations consisting of four laminas or layers. The analysis has been done for different D/A ratios (where D is the diameter of the hole and A is the width of the plate) varying from 0.1 to 0.5 and for e-glass/epoxy composite materials. Composite materials selected elaborate the dependency of SCF with varying elastic constants. The analytical treatment of such type of problem is very difficult; hence the finite element method is adopted for whole analysis. Three dimensional finite element formulation and analysis is done on ANSYS package. The results are presented in graphical form and discussed.

KEYWORDS: Composites, Finite element method, Stress concentration factor, Transverse loading, Elastic constants.

1. INTRODUCTION

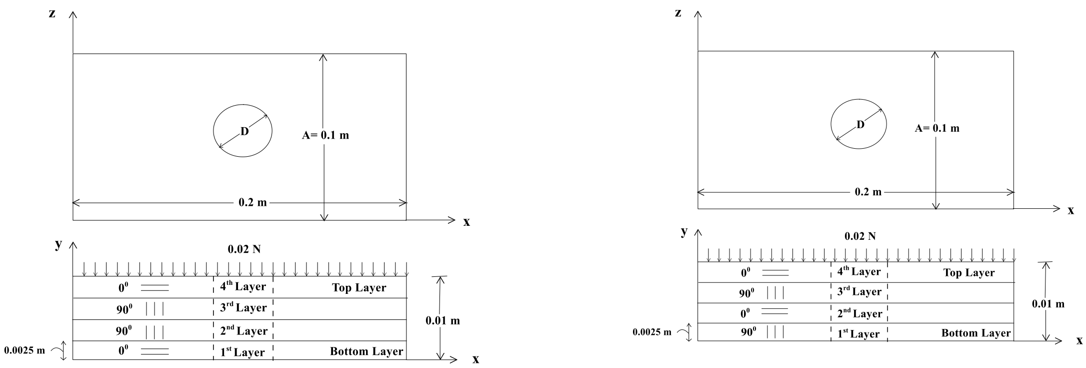
Laminated Composite plates with central circular hole were finding a wide range of applications in structural design of aerospace, marine, automobile, mechanical engineering especially for light weight structures that have stringent stiffness and strength requirements. Any abrupt change in geometry of plate under loading give rise to stress concentration, as a result stress distribution is not uniform throughout the cross section. Composite plates fail due to the failure of individual component (fibre or matrix) or their interface. It is well known that the presence of a notch in a stressed member creates highly localized stresses at the root of the notch. Various researchers analyzed different cases of stress concentration in plate with circular holes.

Hochard et al [1] evaluatedbehavior up to rupture of woven ply laminate structures under static loading conditions. A first ply failure model was developed based on continuum damage approach was developed for balanced woven ply laminates for plates with notches and saw cuts. This study concerns only structures in tension. Ghezzo et al. [2] performed a

numerical and experimental analysis of the interaction between two notches in carbon fibre laminates. The numerical analysis of the stress distribution in-plane stress assumption and within the fibrous plate theory framework has been conducted on two symmetric laminates. Ozben et al. [3] compiled FEM analysis of laminated composite plate with rectangular hole and various elastic modulus under transverse loads. Ozen et al. [4] presented the failure loads of mechanical fastened pinned and bolted composite joints with two serial holes. Tsai–Wu failure criterion was used to predict first failure loads by finite element analysis for the geometrical parameters. Kumar et al. [5] has studied the post buckling strengths of composite laminate with various shaped cut-outs under in plane shear. Jain et al. [6] have done finite element analysis for stress concentration and deflection in isotropic, orthotropic and laminated composite plates with central circular hole under transverse static loading.
The present work aims to study the effect of boundary conditions on SCF in laminated composite plates with central circular hole subjected to transverse static loading over the whole plate. The effect of D/A ratio where A is the plate width and D is the hole diameter on SCF for shear stress (τ_{xy}) is investigated by using three dimensional finite element analysis. Results are obtained for e-glass/epoxy material to find out the variation of SCF on different elastic constants also.

2. DISCRIPTION OF PROBLEM

The model of laminated composite plate of dimension 0.2 *m*x 0.1 *m* and 0.01 *m* thicknesswith a circular hole of diameter *D* under uniformly distributed loading of *P* (N) in transverse direction is taken for analysis. The laminated plate with circular hole are stacked in both symmetric [$0^0/90^0/90^0/0^0$]and anti-symmetric [$90^0/0^0/90^0/0^0$]cross-ply configuration as shown in figure1. The composite laminated plate consists of four orthotropic layers of constant thickness 0.0025 m for four different boundary conditions.



Symmetric cross-ply laminate

Anti-Symmetric cross-ply laminate

Fig.1Laminated plate with central hole under transverse loading.

Results evaluated for fixed T/A ratio of 0.10, and for three different D/A ratio of 0.1, 0.2 and 0.5 respectively.A transverse loading of 0.02 *N* in the form of uniform distributed loading is applied over the whole plate.

Table 1 Material properties of composite materials [7].

MATERIAL PROPERTIES	E_x GPa	E_y GPa	E_z GPa	G_{xy} GPa	G_{yz} GPa	G_{zx} GPa	μ_{xy}	μ_{yz}	μ_{zx}
E-glass- Epoxy	39	8.6	8.6	3.8	3.8	3.8	0.28	0.28	0.28

Where E, G, μ are representing modulus of elasticity, modulus of rigidity and poisson's ratio respectively.
E-glass/epoxy composite materials with its respective material properties selected for complete analysis is shown in table 1. The four different boundary conditions shown in figure 3 are plate (a) simply supported (b) all edges fixed (c) two edges fixed and two edges simply supported (d) two edges fixed and two edges free.

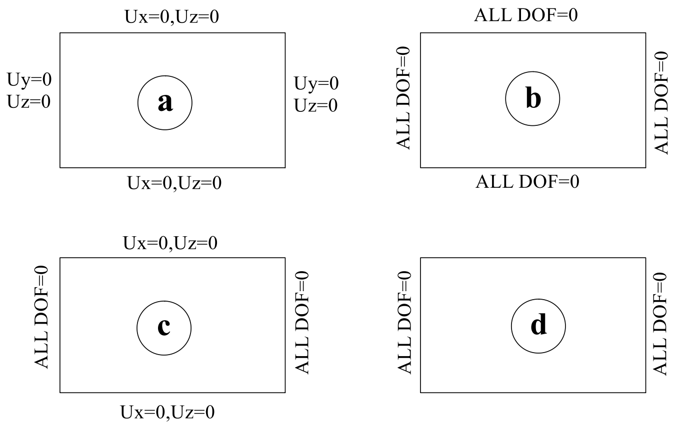


Fig.2. Four different boundary conditions of laminated plate

3. ANALYSIS

Finite element method was chosen for analysis of the model. The model was meshed using a 3-D solid element, Solid 191 with three degrees of freedom and 60 nodes per element in ANSYS. Typical mesh of the plate using the above element has been shown in Figure3. Mapped meshing is used so that more elements employed near the hole boundary. Element length is selected as 5mm after running the convergence tests. The example of the discretized three dimensional finite element model, used in study is shown in Figure 3. Results were then displayed by using post processor of ANSYS program.

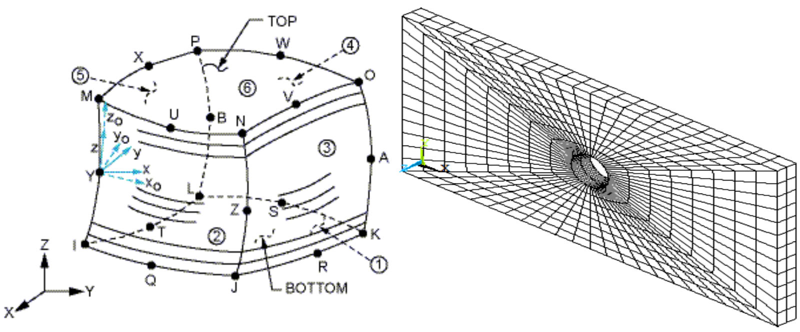


Fig. 3 Element used and generated mesh of the plate.

4. RESULT AND DISCUSSION

The present study demonstrates the shear stresses for the symmetric and anti-symmetric laminated plates with central circular under uniform static transverse loading. Results are evaluated for laminated composite plate containing four layers of equal thickness each of 0.0025 m. Also layer wise distribution for shear stresses (τ_{xy}) in both symmetric and anti-symmetric configuration for solid plate is shown in below table 2. Results are obtained for the bottom portion of each of four layers.

Table 2 Solid plate (plate without hole) results for with respect to different boundary conditions.

Solid Plate		**Plate (a)**		**Plate (b)**		**Plate (c)**		**Plate (d)**	
	Layer	**τ_{xy} (N/m^2) Symm**	**τ_{xy} (N/m^2) Anti**	**τ_{xy} (N/m^2) Symm**	**τ_{xy} (N/m^2) Anti**	**τ_{xy} (N/m^2) Symm**	**τ_{xy} (N/m^2) Anti**	**τ_{xy} (N/m^2) Symm**	**τ_{xy} (N/m^2) Anti**
E–glass/epoxy	**1**	18.8	18.0	3.2	3.0	10.8	10.3	13.7	13.2
	2	11.4	10.8	2.3	2.2	7.5	7.2	9.5	10.8
	3	9.0	8.4	2.3	2.2	6.6	6.4	9.3	9.6
	4	12.7	11.9	3.2	3.0	9.1	8.9	13.4	14.1

The absolute values of shear stresses (τ_{xy}) in the transverse direction for layer wise symmetric and anti-symmetric cross ply laminated solid plates (a), (b), (c) and (d) are listed in tables 2 respectively. The following observations are made:-

<u>E-glass/Epoxy</u>

For plate (a) and (b), both symmetric and anti-symmetric configuration shows maximum shear (τ_{xy}) stress for 1st layer and minimum stress for 3rd layer. For plate (c), both symmetric and anti-symmetric configuration shows maximum value for1st layer and minimum stress for in 3rd layer. For plate (d), symmetric configuration shows maximum value for 1st layer and minimum stress for in 3rd layer. Whereas for anti-symmetric configuration maximum stress for 4th layer and minimum for 3rd layer. In comparison with plates (a), (b), (c) and (d) maximum stress is coming for plate (a) of both symmetric anti-symmetric configuration. Thus, SCF (τ_{xy}) in plate (a) is significant for e-glass/epoxy material.

Variation of SCF for (τ_{xy}) versus D/A for a symmetric cross-ply laminated plate with a central circular hole loaded transversely over the whole plate for e-glass/epoxy composite materials is shown in figure 4. Following observations can be made:

<u>For plate (a)</u>

For all materials, SCF induced in the layers are maximum for the fourth layer and minimum in the first layer. Maximum SCF within the four layers are in following increasing order: first, second, third and fourth layer. SCF (τ_{xy}) continuously decreases with a corresponding increase in *D/A* ratio from 0.1 to 0.5 for all layers. The maximum SCF value of e-glass/epoxy is4.9 obtained from the fourth layer at *D/A* = 0.1 ratio. However the minimum SCF value of e-glass/epoxy is 2.1 for 1st layer at *D/A*=0.5 ratio.

For solid plate, e-glass/epoxy material shows maximum stress for 1st layer and minimum stress for 3rd layer. However, SCF for 3rd layer is having the maximum value of 4.70, which shows that for hollow plate, stress increases by 4.70 times in comparison to solid plate which is a significant outcome for design purpose. Similarly, SCF for 1st layer is having the minimum value of 2.63, which shows that for hollow plate, stress increases by 2.63 times in comparison to solid plate. For solid plate (a) made of e-glass/epoxy material, maximum stress of 18.82 MPa is obtained for 1st layer, whereas for hollow plate (*D/A*=0.1) stress of 49.50 MPa is obtained, attaining % increase in stress for 1st layer of hollow plate as 61.97. Similarly, % increase in stresses for 3rd layer of hollow plate is 78.71. Ratio of stresses in solid plate (a) made of e-glass/epoxy material for 1st layer to 3rd layer is 2.08, whereas for hollow plate ratio is 1.0, which shows that stresses in all layers due to hole is almost same.Similar behavior is shown by different composite materials considered.

<u>For plate (b)</u>

For all materials, SCF induced in the layers are maximum for first layer and minimum in fourth layer. Maximum SCF within the four layers are in following increasing order: fourth, second, first and third layer. Maximum SCF value for e-glass/epoxyis8.4 obtained for the first layer at *D/A* = 0.1 ratio. However minimum SCF value for e-glass/epoxyis 2.32for 2nd layer at *D/A*=0.5 ratio.

<u>For plate (c)</u>

For all materials, SCF induced in the layers are maximum for fourth layer and minimum in second layer. Maximum SCF within the four layers are in following increasing order: second, third, first and fourth layer. Maximum SCF value for e-glass/epoxyis5.4 for the fourth layer at *D/A* = 0.1 ratio. However minimum SCF value for e-glass/epoxyis 2.8 obtained for 1st layer at *D/A*=0.5 ratio.

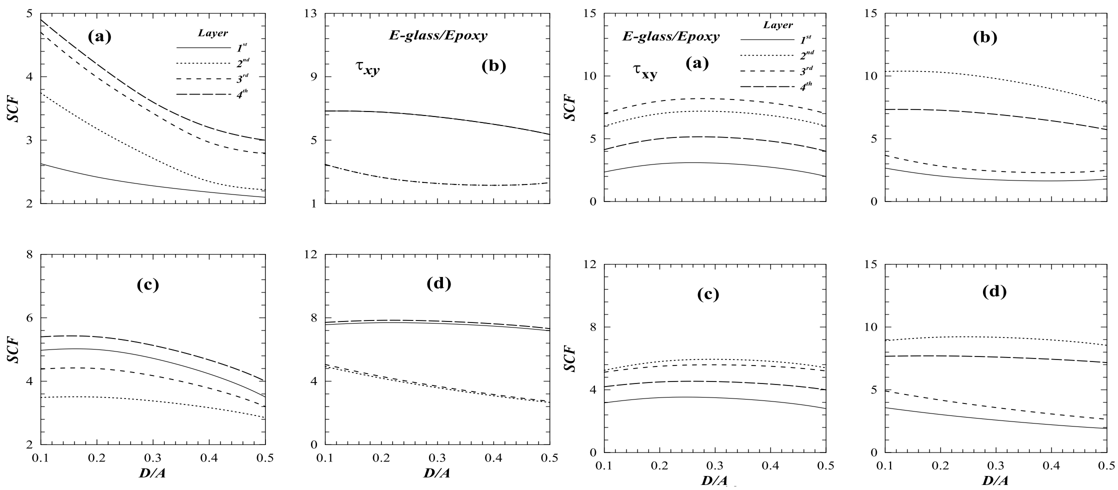


Fig. 4 SCF for (τ_{xy}) symmetric and anti-symmetric plate

<u>For plate (d)</u>

For all materials, SCF induced in the layers are maximum for fourth layer and minimum in second layer. Maximum SCF within the four layers are in following increasing order: second, third, first, and fourth layer. SCF (τ_{xy}) remains almost consistent with corresponding increase in *D/A* ratio from 0.1 to 0.5 for all layers. Maximum SCF value for e-glass/epoxy is 7.7 obtained for the fourth layer at *D/A* = 0.1 ratio. However minimum SCF value for e-

glass/epoxy is 2.6 obtained for 2nd layer at *D/A*=0.5 ratio.
From plate (a)-(d), maximum SCF values are obtained for plate (a).

4. CONCLUSION

Detailed investigations on the stress concentration factor for shear stress in both symmetric and anti-symmetric cross-ply laminate subjected to transverse loading is conducted for e-glass/epoxy composite material. Following conclusions can be with drawn:-

- The influence of geometric parameters shows a substantial role for shear stresses in both configuration of laminate considered.
- SCF (τ_{xy}) is seen maximum on the hole boundary along the width direction of the plate.
- Higher E_x/E_y& E_x/G_{xy} ratios, prominently effect SCF. Anti-symmetric laminates shows maximum values for all the materials as compared to symmetric configuration of laminates.

Additionally this can also be concluded that the results obtained are in line with other similar works.

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