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EFFECT OF THE FIBRE ORIENTATION ANGLES ON STRESS CONCENTRATION AROUND VARIOUS SHAPES OF HOLE IN LAMINATED COMPOSITE PLATE SUBJECT TO IN - PLANE LOADING

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Abstract

The current study employs the finite element method to compare stress concentration pertaining to a graphite / epoxy rectangular laminated composite plate that possess holes in different shapes. The hole enables redistributing in-plane stresses, impacts the stress concentration factor (SCF), and focuses maximum stress near the hole. The ANSYS program has been designed to be employed for parametric studies pertaining to plates that have a hole under uniaxial in-plane load. Analysis was done for angle-ply, four-layered symmetrically laminated rectangular plates that include different stacking sequences ± θ.

Keywords:

Hole;
Fibre orientation angle;
SCF;
FEM;
Rectangular plates.

1 Introduction

Laminated composites usage in engineering applications has been steadily increasing thanks to its properties such as high strength and stiffness to weight ratios, good corrosive resistance and low maintenance costs. Laminated composites consist of several layers or plies (called lamina) of fibres (unidirectional or woven) embedded in a matrix [1]. A lamina is a layer of unidirectional or woven fibres in a matrix. To create a multidirectional laminate, stacking of laminas is done on top of each other at various angles. Commonly employed fibres include Boron, Carbon, Kevlar, Graphite and E-glass. Examples of matrices are epoxy, polymer, metal, carbon, and ceramic [2]. Moreover, the structural properties of these composites such as ply orientation, fibre volume fraction and stacking sequences can be tailored for specific applications. These superior properties make laminated composites suitable for several high-performance structures such as aerospace, automotive, aerospace, and marine applications.

[3] studied the stress distribution in laminated composite plates that possessed a central circular hole by considering various stacking sequences as well as various geometric dimensions that were exposed to in-plane tension loading for nonlinear as well as linear material behaviours. Angle-ply, four layered symmetrically laminated composite plates were analysed. The problem was analysed by employing the FEA software (ANSYS). As per the study results, the size of holes causes a significant impact on stress concentration around the edge of the hole. [2] evaluated the impact cast by nonlinear material behaviour on four-layered, symmetric, angle-ply laminated composite plate that possessed different fibre-orientation angles 30°, 45° and 60° with central square hole, exposed to out-of-plane load that is uniformly distributed based on the ANSYS-computer program. The impact of stress concentration factor (SCF) due to redistribution of in-plane stresses near the hole has been considered. [4] employed ABAQUS via FEM to evaluate the impact caused by the size of the hole, plates' aspect ratio and fibre orientation angle with regards to the creation of composite laminates that incorporate in-plane stresses and a hole. The layout suggested by the rectangular plate's aspect ratio and fiber orientation angle selections for laminated composite plates. [5] studies the stress concentration as well as strength prediction pertaining to 2 × 2 twill weave carbon fibre that has been reinforced with composite specimens along with various hole sizes, analytically and numerically. The

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others showed applicability pertaining to point stress criteria as well as average stress criteria strength prediction methods with regards to open hole specimens for 2×2 twill weave material. The performances were compared for the point stress criteria as well as average stress criteria methods with regards to eccentric tension loading. These were verified based on all numerical and analytical results via experimental study.

[6] employed both low elastic modulus fibre (LM) as well as high elastic modulus fibre (HM) in hybrid composite materials, wherein the sheet length was infinite and the lamina had tensile force applied on matrix and fibres, while the fibres in the layers are deemed one directional. The stress concentration factor (SCF) surrounding an elliptical hole was calculated by Lorzadeh and Pedram based on the finite element method (FEM) modelling, crack modelling and geometrical investigation, which was compared with the results attained for the reference. Based on the classical laminated plate theory along with an anisotropic multiple connected plate, [7] considered a finite composite plate that has been weakened by an elliptical hole. An analytical solution was obtained accounting the stress concentration surrounding an elliptical hole present in a finite composite laminated plate based on the least squares boundary collocation technique as well as Fabor series expansion. They also evaluated the impacts of hole sizes, loading conditions and layups surrounding the stress distribution in an elaborate manner. [8] put forward approximate stress analyses pertaining to orthotropic composite laminates that possessed an elliptical opening experiencing uniaxial normal loads. The evaluation was based on the use of exact elasticity solution demonstrating excellent accuracy for the approximate solutions, after which the solutions were generalised regarding the point stress fracture criterion as well as the average stress fracture criterion pertaining to the strength prediction concerning fibre-reinforced composite laminates that possessed an elliptical opening. [9] demonstrated the finite-width correction factors pertaining to anisotropic and orthotropic plates that possessed an elliptical opening in a closed-form and tractable solution. Based on the evaluation of finite element solutions and experimental data, the present theory was found to be highly accurate for a wide range of opening-to-width ratio, $2a/W$, as well as opening aspect ratio, a/b. The sensitivity pertaining to the finite-width correction factors as a function pertaining to the opening aspect ratio was also explained.

On the other hand, [10] calculated the flexural strength and deformation parameters of isolated. ANSYS-based models are used for simulations based on FSDT and APDL codes. In addition, [11] developed a suitable modeling method for simulating intralaminar damage in laminated composite under combined loading. Intralaminar damage is modeled by stiffness reduction controlled by thermodynamic forces, as defined in the continuum damage mechanics model proposed by Ladeve ze, and the influence of lateral stress in the identification process of damage modeling is explained.

[12] evaluated the notched strengths with regards to three types of braided composite plates possessing a central hole. First, both average stress criterion (ASC) as well as point stress criterion (PSC) were applied to identify the characteristic length pertaining to each braided composite plate possessing various hole sizes. Then, the characteristic lengths were determined by applying the concept of three-parameter criterion. Then, both criteria were put forward to be expressed as functions of hole size and plate width. Finally, it was demonstrated that both modified ASC and modified PSC offered better predictions pertaining to the notched strength when compared with traditional ASC and PSC for all types of braided composite plates. [13] evaluated the stress concentration factors (SCF) with regards to cross and angle-ply composite plates and with regards to the isotropic plates exposed to uniaxial loading. Different parameters, like hole sizes a/b, cut-out shape (elliptical or circular) or cut-out orientations, which impacted the SCF and stress distributions pertaining to the perforated plates, were considered. Finally, these were compared versus the numerical results based on the present element, which favoured the analytic findings found in literature, backing up the present element's accuracy.

The current study's key objectives include comparing the impact cast by rectangular, circular, and elliptical holes on the redistribution of stress as well as SCFs in composite laminated plates. The plates are exposed to in-plane axial forces towards the plate end. The composite material with a symmetrical lamination sequence $\theta/-\theta$ used to make the laminated plates is fibrous. Finally, the stress concentration factors (SCFs) for the various situations with various plate dimensions are determined. The stress-concentration as well as resulting stresses distribution due to the presence of various hole shapes have been analysed based on ANSYS-computer program [14].

2 Materials and methods

2.1 Stress concentration factor

In the present paper, the factor of stress concentration (SCF) can be defined as the stress concentration factor maximum stress σ_{max} to that of nominal stress σ_{nom} ratio. It is the ratio of the calculated maximum stress to that of the nominal stress, which is present if there is uniform distribution of stress and can be calculated based on the following equation:

$$SCF = \frac{\sigma_{\max}}{\sigma_{\text{nom}}}. \quad (1)$$

Here, the stress concentration factor can be equal to the ratio of the maximum in-plane tensile stress with regards to the case in which the hole is present with that of the nominal stress with uniformly distributed in-plane tensile stress even when the hole is not present. Also known as theoretical stress concentration factor.

2.2 Properties of composite lamina

With regards to brevity, one composite material has been accounted, along with Graphite / Epoxy (AS/3501) possessing various fibre-orientation angles (θ). Graphite / Epoxy is regarded to be significant as well as widely known types of composite materials possessing these material properties: G_{12} = 6.9 GPa, E_1 = 138 GPa, E_2 = 9 GPa *and* v_{12} = 0.3.

2.3 Geometrical model

The laminate for all models consists of 4 layers with staking sequence of *[+θ, -θ, -θ, +θ]*° and the fibre orientation angle θ can be 0°, 30°, 45°, 60° and 90°, each layer has a thickness of 2.5 mm.

Various examples concerning four-layered symmetric angle-ply laminated plates have been presented, with different stacking sequences [*+θ°/-θ°/-θ°/+θ°*] which, in short, can also be defined as [± θ°]. Composite layers possess uniform thicknesses of 2.5 mm each along with a total 10 mm thickness for the entire laminate, a fibre orientation of θ° and composite material plate width of b = 100 mm. The impact of fibre-orientation angle θ is also accounted when employing five values: 0°, 30°, 45°, 60° and 90°. At θ = 0°, fibres tend to be aligned in a unidirectional manner along with the plate's geometric x-axis, which is also usually termed as the axial load direction. The conditions of the plate boundary have been set as U_x = 0 towards one end, while uniform load distribution is applied towards the other end. With regards to ellipse hole plate cases, the plate geometry ratios a/b = 1.0 possessing constant hole size ratio d_2/b = 1/5 are considered along with ratio d_1/d_2 = 1.5. In circular hole plate cases, the same plate geometry ratios are considered, a/b = 1.0, wherein the hole size ratio is D/b = 1/5. For the case of rectangular hole plate, plate geometry ratio is a/b = 1.0, while the hole a = b = 10 mm. Fig. 1 - 3 demonstrates the lamination details as well as geometric dimensions pertaining to the problems with different hole sizes.

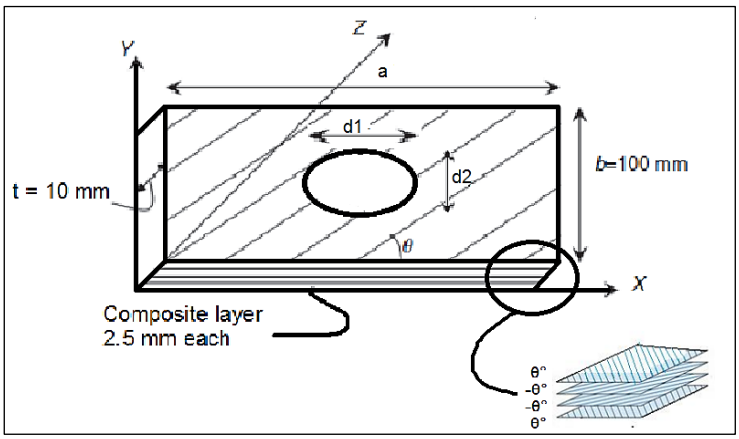


Fig. 1: Geometry of a plate with central ellipse hole and the staking sequence of laminate.

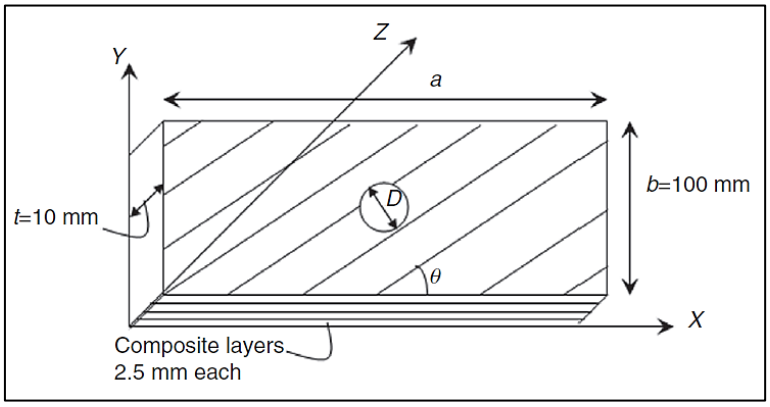


Fig. 2: Geometry of a plate with central circle hole with staking sequence ± θ°.

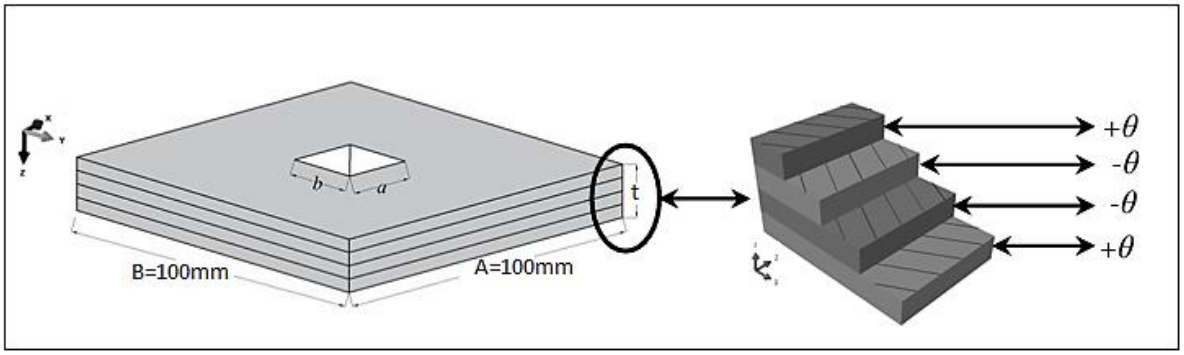


Fig. 3: Geometry of a plate with central rectangle hole and the staking sequence of laminate.

2.4 Finite element model

The finite element method can be defined as a numerical technique to determine approximate solution with regards to different engineering problems. This approach employs segmentation of a given solid model into various numbers of simple shape that are of small size and referred as elements.

The evaluation of plates is done by employing ANSYS in circular and ellipse hole plate cases. An four-node shell element (referred as Shell181 in the ANSYS package) along with six degrees of freedom for each node has been employed, translations in the *x*, *y*, and *z* directions, and rotations about the *x*, *y*, and *z* axes, which gives a total of 24° of freedom for each element. ABAQUS is employed for rectangular hole plate case to build the finite element model. For linear analysis, higher order 3D shell elements pertaining to S8R have been employed. For all models, mapped meshing is employed to use more elements close to the hole boundary.

3 Numerical results and discussion

The impact cast by the fibre orientation angle on the SCF with regards to the in-plane stresses with holes in rectangular sizes has been showed in Fig. 4. The maximum in-plane stresses are for θ = 45° and minimum for θ = 0°. As same as the minimum stresses around the circular hole is for θ = 0° but the maximum is for $\theta \geq 60°$, these results are shown in Fig. 5.

Fig. 6 shown that in plate with elliptical hole the results are opposite, the maximum stresses is for θ = 0° and the minimum is for θ = 45°. So, for the suggested design, this result should be taken into consideration.

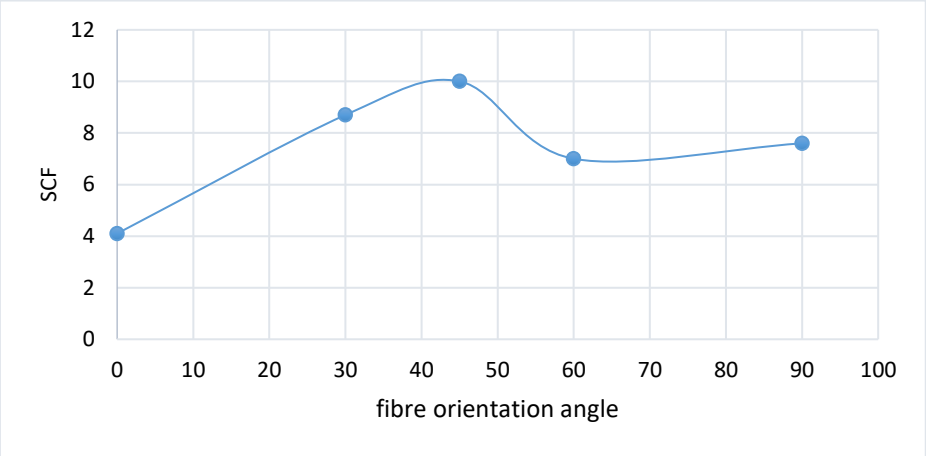


Fig. 4: Effect of fibre orientation angle $\theta°$ on SCF around rectangle hole for the in-plane stresses in plate A/B = 1 and a/b = 1.0.

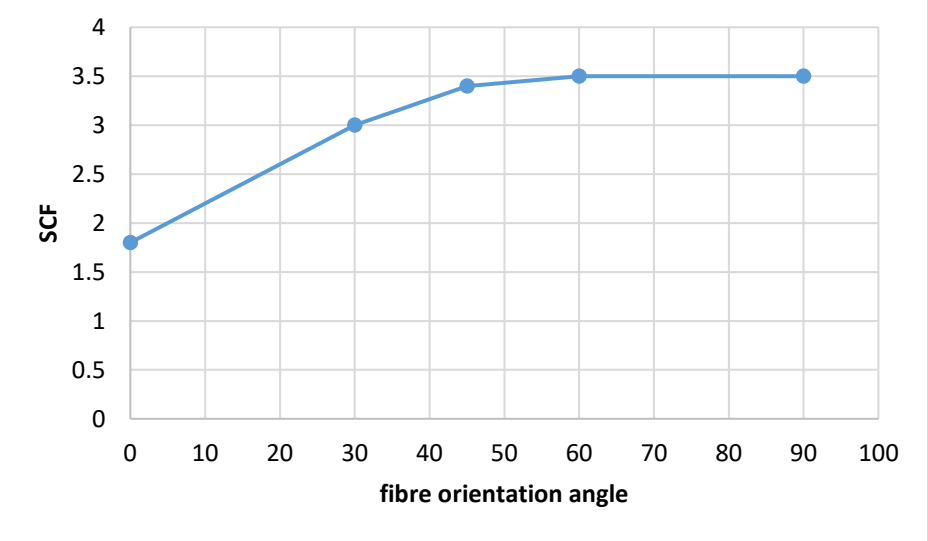


Fig. 5: Effect of fibre orientation angle θ on SCF around circular hole for the in-plane stresses in plate a/b =1 and D/b = 1/5.

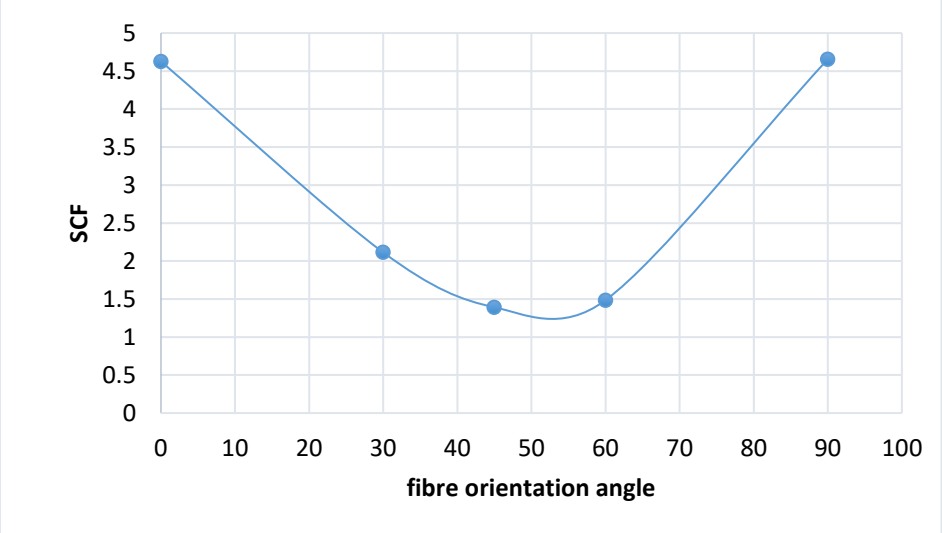


Fig. 6: Effect of fibre orientation angle $\theta°$ on SCF around elliptical hole for the in-plane stresses for plate size a/b = 1 and hole sizes d_2/b =1/5.

4 Conclusions

A finite element modelling has been conducted using ANSYS computer program to study the impact cast by rectangular, circular, and elliptical holes on the redistribution of stress as well as SCFs in composite laminated plates, and the stress concentration factors (SCFs) for the various situations with various plate dimensions. The following points can be concluded from this paper:

- Maximum stresses were found towards the hole's corner area.
- The fibre-orientation angle determines the SCF pertaining to fibre composite laminated plates possessing a hole as well as exposure to in-plane axial uniform tensile loading, in which it could decrease or increase based on the shape of the hole.
- A considerable impact is cast by the problem of material on the SCFs, which is also impacted by the orientation angles of the fibre in the range of 0° – 90°.

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