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Analysis of Stress Concentration of Laminated Composite Plate With Circular Hole

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Abstract

Composite materials are finding a wide range of applications in structural design, especially for lightweight structure that have stringent stiffness and strength requirements. They are attractive replacement for metallic materials for many structural applications. By finding efficient composite structure design that meets all requirements of specific application. This is achieved by tailoring of material properties through selective choice of orientation, no. of stacking sequence of layers that make up composite material. Composites are used more and more often for load carrying and safety structures in all kind of applications foe aviation and space technology, for vehicles etc.Composite materials have been introduced progressively in automobiles, followingpolymer materials, a few of which have been used as matrices. It is interestingto examine the relative masses of different materials which are used in theconstruction of automobiles. Even thoughthe relative mass of polymer-based materials appears low, one needs to take intoaccount that the specific mass of steel is about 4 times greater than that of polymers.This explains the higher percentage in terms of volume for the polymers.

Introduction

Composite materials are commonly used in structures that demand a high level of mechanical performance. Their high strength to weight and stiffness to weight ratio have facilitated the development of lighter structures, which often replace conventional metal structures as shown in fig 1.1. Due to structural requirements, these applications require joining composites either to composites or to metals. Also, for the convenience in manufacture or transportation and limitations on material size, it is rarely possible to produce a construction without joints. All connections or joints are potentially the weakest points in the structures so can determine its structural efficiency. Although leading to a weight penalty due to mechanical fasteners, these are widely used in industry. In which stress concentration is created by drilling a hole in the laminate. In fact mechanically fastened joints (such as pinned joints) are unavoidable in complex structures because of their low cost, simplicity for assemble and facilitation of disassembly for repair. Thus joint efficiency has been a major concern in using laminated composite materials. Relative inefficiency and low joint strength have limited widespread application of composites. The need for durable and strong composite joint is even urgent for primary structural members made of laminates. Because of the anisotropic and heterogeneous nature, the joint problem in composites is more difficult to analyze than the case with isotropic materials.

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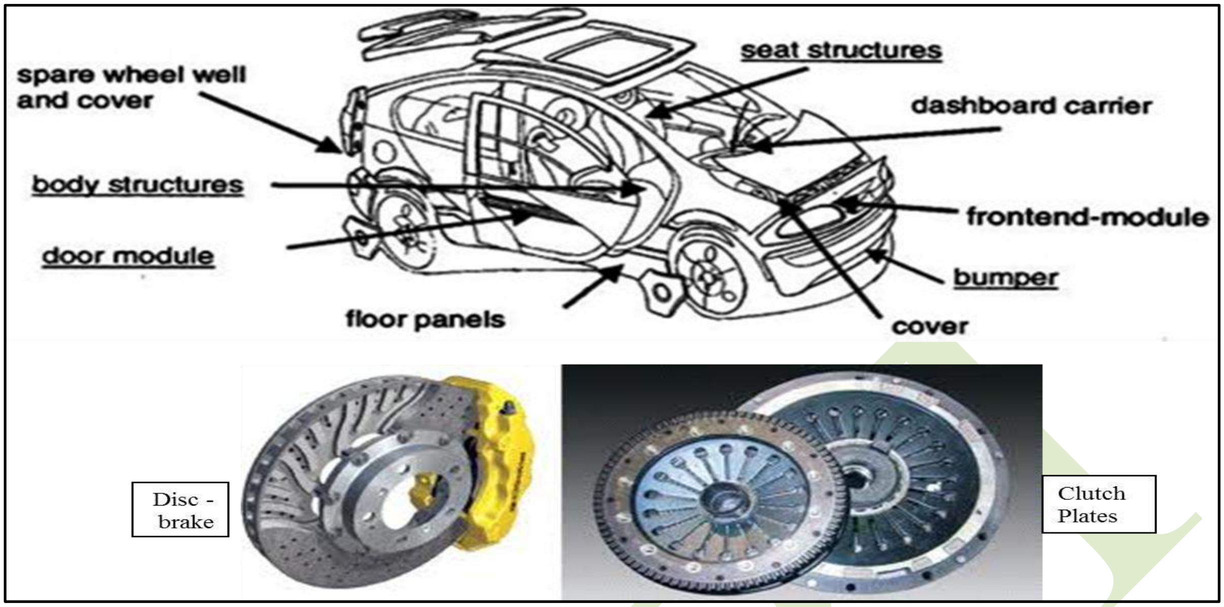

Fig 1.1 Applications of Composites in Automobile

Mechanical fasteners remain the primary means of load transfer between structural components made of composite laminates. As, in case of incremental effectiveness of the structure, the functional load persist to increase, the load carried by each fastener increases consequently. This increases probability of failure. Therefore, the assessment of the stresses around the fasteners holes becomes critical for damage design. The correct prediction of the stress distribution along the hole edge is essential for authentic strength valuation and failure prediction. An unskillful design of joints in the case of mechanical fasteners often causes a reduction of load capability of the composite structure even though the composite materials possess high strength.

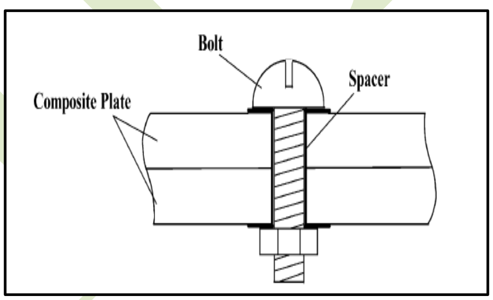

Fig 1.2 Schematic diagram for spcer in bolted composite plate

With advances in design, the discontinuities in composite sheets are increasing (E.g. Holes in the front bumper of a car to allow for ventilation for the engine cooling process). These discontinuities act as stress concentration locations in the design, and could be locations where fracture is initiated.Since Composites have directional properties, the locations of these stressconcentrations are not easily located by theoretical calculations as in the case ofmetals. In composites, the orientation of the fiber along the ply makes a difference to the behavior of the composite. The objective of the project is to understand the effect of discontinuities oncomposites, and establish a relation between the nature of composite and the nature of stress concentration. This will be done by analyzing the laminated composite rectangular plate with dimensions 100mm x 300mm and, having central hole of radius of 5mm, by varying the force angle and varying the composite fiberorientation.

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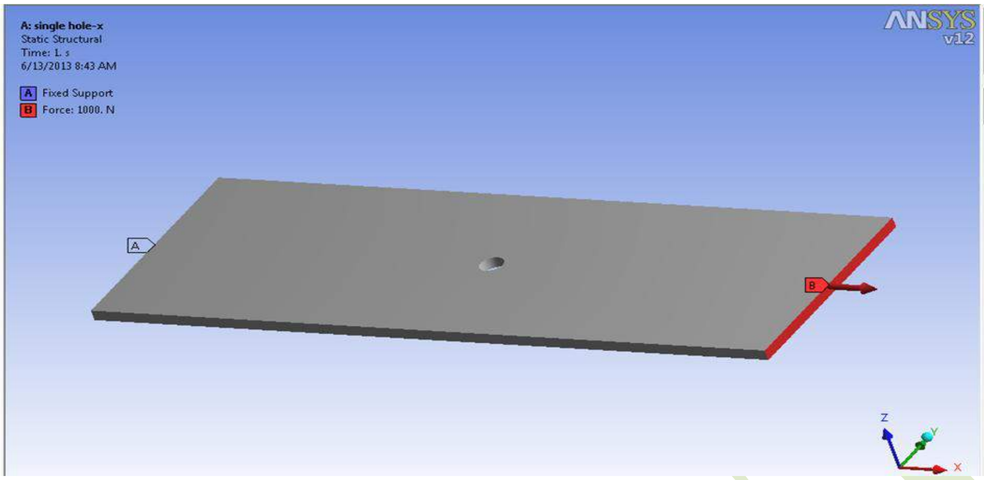


Fig. 1.3 Plate with circular hole

PROBLEM STATEMENT

- Determine effect of stress concentration due to holes in composite materials.

Test dimensions

1. Plate	100 x 300 x t mm t = 1 to 5 mm	
2. Hole dimension	D = 10 mm	
3. Hole patterns	Single hole	Central
		20% length offset
		15% width offset
	Two holes	Central, (separation between holes 30 mm)
		Length alignment
		Width alignment
	Star pattern	Central square, (4 holes, 45^0 degree inclination, 50 x 50 mm)
		+10% variation in square pattern
		-10% variation in square pattern
	Circular pattern	6 holes , Central radius R45 mm

Material Specification

The orthotropic material properties of lamina are:

Table 4.1 Material specification

E_{11}	158.5 GPa
E_{22}	7.17 GPa
E_{33}	7.17 GPa
ν_{12}	0.32
ν_{23}	0.5
ν_{13}	0.34
G_{12}	3.44 GPa
G_{23}	2.82 GPa
G_{13}	3.44 GPa

FINITE ELEMENT ANALYSIS

The finite element method is a numerical tool for determining approximate solutions to a large class of engineering problems.The finite element method is receiving considerable attention in engineering education and in industry because of its diversity and flexibility as an analysis tool. It is often necessary to obtain approximate numerical solutions for complex industrial problems, in which exact closed-form solutions are difficult to obtain. An example of such a complex situation can be found in the composite material. Also, the dispersion of pollutants during non-uniform atmospheric conditions, metal wall temperatures in the case of gas turbine blades in which the inlet gas temperatures exceed the melting point of the material of the blade, cooling problems in electrical motors, various phase-change problems, and so on, are a few examples of such complex problems. Although it is possible to derive the governing equations and boundary conditions from principles, it is difficult to obtain any form of analytical solution to such problems. The complexity is due to the fact that either the geometry, or some other feature of the problem, is irregular or arbitrary. Analytical solutions rarely exist; yet these are the kinds of problems that engineers and scientists solve on a day-to-day basis.

Steps InFEA

1. **Discretize the continuum:**
   Divide the solution region into non-overlapping elements or sub-regions. The finite element discretization allows a variety of element shapes, for example, triangles, quadrilaterals. Each element is formed by the connection of a certain number of nodes the number of nodes employed to form an element depends on the type of element (or interpolation function).
2. **Select interpolation or shape functions:**
   The next step is to choose the type of interpolation function that represents the variation of the field variable over an element. The numbers of nodes form an element; the nature and number of unknowns at each node decide the variation of a field variable within the element.

3. **Form element equations (Formulation):**
   The matrix equations are to be determined in this section that expresses the properties of the individual elements by forming an element left hand side (LHS) matrix and load vector. For example, a typical LHS matrix and a load vector can be written as:

$$[K]_e = \frac{AE}{l}\begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \ldots\ldots stiffness\ matrix$$

$$\{f\}_e = \begin{Bmatrix} f_i \\ f_j \end{Bmatrix} \ldots\ldots\ldots\ldots\ldots force\ matrix$$

   Where the subscript *e* represents an element; *f*is the total heat transferred; *E*is the young's modulus; *l* is the length of a one-dimensional linear element and *i* and *j* represent the nodes forming an element. The unknowns are the deflection values of the nodes.
4. **Assemble the element equations to obtain a system of simultaneous equations:**
   To find the properties of the overall system, we must assemble all the individual element equations, that is, to combine the matrix equations of each element in an appropriate way such that the resulting matrix represents the behavior of the entire solution region of the problem. The boundary conditions must be incorporated after the assemblage of the individual element contributions, that is,

$$[\mathbf{K}]\{\mathbf{D}\} = \{\mathbf{f}\}$$

   Where, [**K**] is the global LHS matrix, which is the assemblage of the individual element LHS matrices{**f**} is the global load vector, which is the assemblage of the individual element load vectors {**D**} is the global unknown vector.
5. **Solve the system of equations:**
   The resulting set of algebraic equations may now be solved to obtain the nodal values of the field variable, for example, displacement.
6. **Calculate the secondary quantities:**
   From the nodal values of the field variable, we can then calculate the secondary quantities, for example, stresses.

   The process of analyzing a structure using FEM is divided into three steps.

Element Description: Plane82

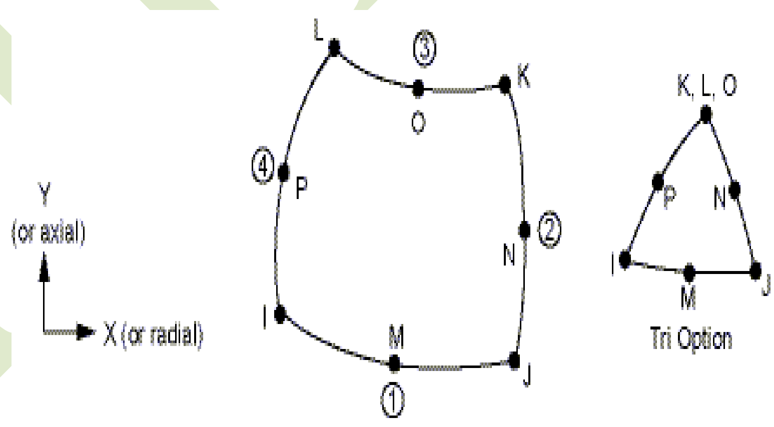
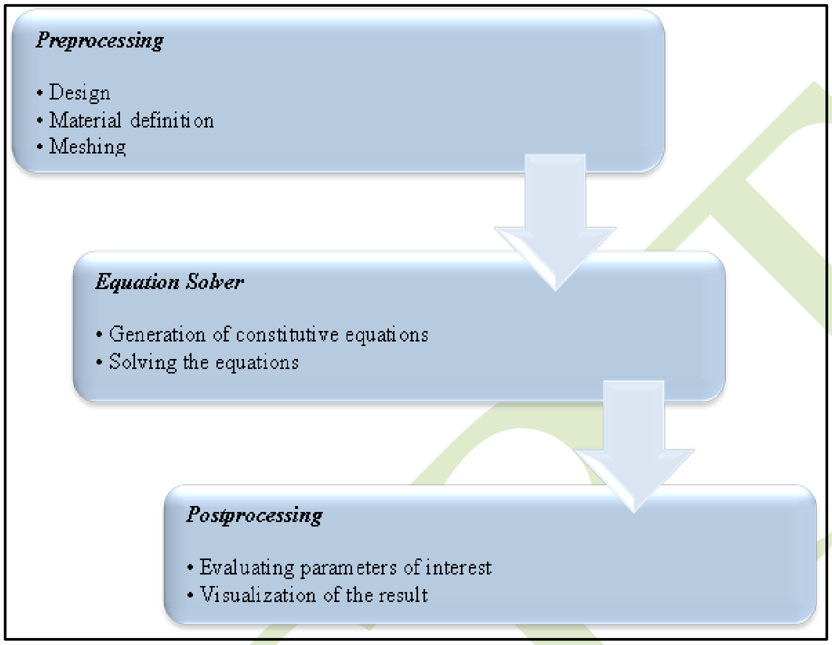


Fig. Plane 82 Geometry

PLANE82 provides accurate results for mixed (quadrilateral-triangular) automatic meshes and can tolerate irregular shapes without as much loss of accuracy. The eight-node elements have compatible displacement shapes and are well suited to model curved boundaries. The 8-node element is defined by eight nodes having two degrees of freedom at each node: translations in the nodal x and y directions. The element may be used as a plane element or as an axisymmetric element. The element has plasticity, creep, swelling, stress stiffening, large deflection, and large strain capabilities.

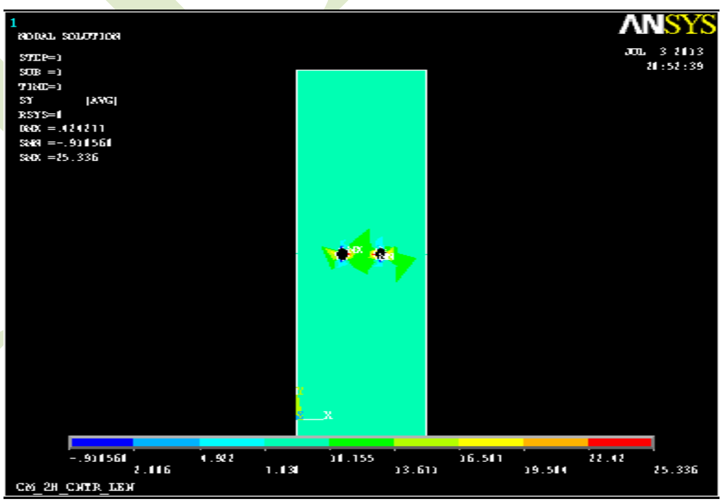


RESULT AND DISCUSSION

The finite element model is now used to the stresses developed in composite plate with hole. It clearly signifies that hole in structure can lead to failure due to significant increase in stresses. Hence, reducing stresses in vicinity of hole is essential to make structure safe. The following results are obtained by various ply orientation of composite plate with hole by changing the hole pattern.

Two holes: Central, Separation between holes 30 mm

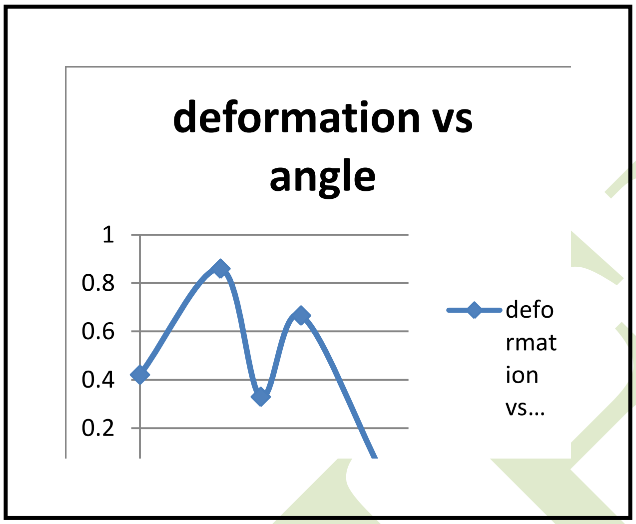
1. **± 20 % Length offset**



Hole pattern:-20 % Length offset		
Angle	**Dmx**	**Smx**

0 degree	0.421118	25.444
30 degree	0.860023	23.527
45 degree	0.329922	28.988
60 degree	0.666254	25.449
90 degree	0.019434	41.809

As we see that pattern of (45 Degree) inclination of hole the most suitable pattern which are having deformation & stress is low.



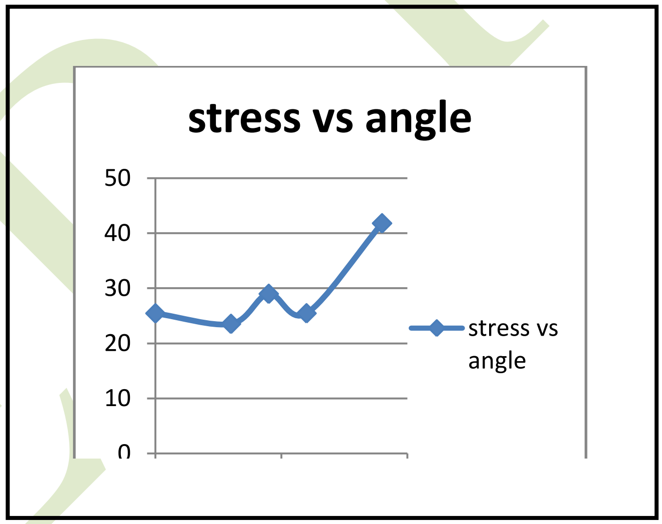


Plate with hole having different pattern	Angle	Stress (MPa)	Deformation (mm)
Single hole: Central	45 degree	0.330476	27.863
Two holes: Central, Separation between holes 30 mm ± 20 % Length offset	45 degree	0.329922	28.988
Dice Pattern: 4 holes, central square (40 x 40)	45 degree	00.336794	28.039
Star Pattern: 4 holes 45 degree inclination, (50 x 50)	45 degree	00.337695	33.476
Circular Pattern: 6 holes, Central radius 45 mm.	45 degree	0.337579	30.969

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