Effect of Fibre Angle on Stress Concentration Factor in Woven E-Glass/Epoxy Composite

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***Abstract*-Glass fibre reinforced plastics (GFRP) are widely used in the construction of aerospace, marine, corrosion resistant system, transportation systems, consumer goods, electrical appliances etc. The understanding of mechanical behaviour of the composite materials with stress concentration is of greater importance because of the resulting reduced strength of components and higher amount of damage around this region. The objective of this study is to investigate the effect of fibre orientation on the stress concentrationfactor (SCF) in a composite reinforced with woven E-Glass fabric. Theoretical results and finite element results were compared for the lamina's having different fibre angles such as 0°,15°,30°,45°,60°,75° and 90°.From these results, laminates of stacking sequences [(0, 90)]3s and [(0,90)/(+45,-45)/(0,90)]s was prepared with a central notch and there stress concentration factor wasstudied.From the results obtained for the lamina'sit can be found that the peak stress occurs at the periphery of the hole for all the lamina's and as the fibre angle increases from 0º to 45º the stress concentration regionat the hole periphery will be approximately perpendicular to the specifiedfibre angle with respect to the loading direction and for the fibreanglefrom 45º to 90º, the stress concentration region will be approximatelyparallel to the specified fibre angle with respect to the loading direction.A 45º lamina will have a least stress concentration value. From the results of the laminate it can be found that [(0,90)/(+45,-45)/(0,90)]s laminate hasslightlyless load carrying capacity compared to [(0, 90)]3sbut this laminate exhibit less stress concentration at the notch.**

Keywords—Woven E-Glass, Stress concentration factor (SCF), fibre angle, fibre orientation, notched laminate

I. INTRODUCTION

Composite materials are manufactured using two or more different materials in order to take advantage of desirable characteristics of the components. A composite material consists of two elements, one is the fibre which gives the required mechanical property in a particular direction and other is the matrix which adhere the fibres together.

Glass fibre reinforced plastic or GFRP is a composite material made up of plastic matrix reinforced by continuous fibres of glass. GFRP is very light weighted and strong material hence they are used in automobiles, aerospace, electrical appliances etc.

Laminated plates are widely used in aircraft and space systems. So in structural assemblies joining two composite structures by fastening has been one of the most commonly used methods. Hence the behaviour of the composite material with stress concentration is of greater importance. The stress concentration factor (SCF) for an anisotropic material is different from an isotropic material. The SCF value for an isotropic material depend only on the geometry of the component , but for an anisotropic material it depends on the geometry of the component, stacking sequence and number of layers in the laminate because in an anisotropic materials the material properties are different in all directions[1].

In this study, theoretical calculation and finite element analysis is carried out for the lamina having different fibre orientation with a centre notch. From these results two laminates of stacking sequences $[(0,90)]_{3s}$ and $[(0,90)/(+45,-45)/(0,90)]_s$ are prepared with a centre notch and their strength were compared experimentally. Also, for these laminates theoretical results and finite element results were found out and compared.

II. SPECIMEN PREPARATION AND THEORETICAL CALCULATION

All the specimens were prepared as per ASTM D5766. The required volume fraction for the laminate is 60:40.The woven E-Glass fabrics are available in the standard form of 10mil (or 0.2mm) thickness. This woven cloth was cut to the required size and shape. The matrix was prepared by mixing the epoxy resin LY 556 and hardener HY 951 in a volume ratio 10:1.Once the matrix is prepared it is applied on the fabric thoroughly, then another layer of fabric is placed on it. This process was carried out for total 6 layers in order to achieve the 2mm thickness of the laminate. Then the laminate was left to cure at room temperature for 24 hours. After this process, post curing was carried out at 100ºC for 2 hours. The completely cured laminate plate is cut to the required standards, and then end tabs were attached to it using glue (AW106 and HY913).

The prepared laminates are initially cut to a length of 250mm and width of 36mm.Then using a 6mm diameter twist drill made up of high speed steel, a centre hole was drilled on the laminateat 450 rpm with feed of 0.02mm/rev as shown in fig -1.

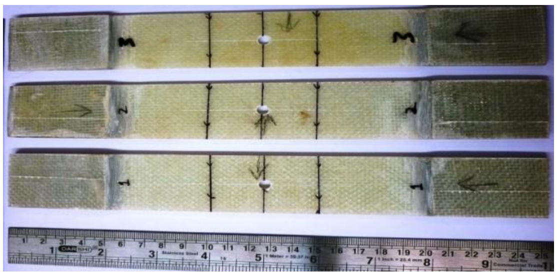


Fig.1 Prepared specimens

In this study, the fibre used is woven E-Glass fibre in fabric form; the matrix material used is epoxy resin. The mechanical property of the laminatewithout notch is given in table -1.

TABLE I
MECHANICAL PROPERTIES OF THE LAMINA

Properties	Values
E_1(Gpa)	16.84
E_2(Gpa)	16.84
▯$_{12}$	0.15
G_{12}(Gpa)	2.46

The stress concentration factor at the edge of the hole of an infinite plate is given by[1],

$$K_T^{\infty} = 1 + \sqrt{\frac{2}{A_{22}}\left[\sqrt{A_{11}A_{22}} - A_{12} + \frac{A_{11}A_{22} - A_{12}^2}{2A_{66}}\right]}$$

Where K_T^{∞} denotes the stress concentration factor at the edge of the hole: A_{ij}, i.j=1, 2, 6, are the components of the in-plane stiffness matrix with 1 and 2 parallel and transverse to the loading direction, respectively.

Approximate orthotropic finite width correction factor for circular hole in the centre is given by [1],

$$\frac{K_T^{\infty}}{K_T} = \frac{3\left(1-\frac{2a}{W}\right)}{2+\left(1-\frac{2a}{W}\right)^3} + \frac{1}{2}\left(\frac{2a}{W}M\right)^6 (K_T^{\infty} - 3)\left[1 - \left(\frac{2a}{W}M\right)^2\right]$$

Where,
K_T= stress concentration at the hole in finite plate.
a = radius of the hole.
W = width of the finite plate.
M = magnification factor, it is given by

$$M^2 = \frac{\sqrt{1 - 8\left[\frac{3\left(1-\frac{2a}{W}\right)}{2+\left(1-\frac{2a}{W}\right)^3} - 1\right]} - 1}{2\left(\frac{2a}{W}\right)^2}$$

III. FINITE ELEMENT MODELLING

Finite element analysis is carried out using AnsysAPDL. Initially a3D model is developed,this model is map meshed using plane 183 and solid 186 elements as shown in fig.2 and boundary conditions are applied, i.e. 100MPa remote tensile stress is applied to the plate as shown in fig.3.

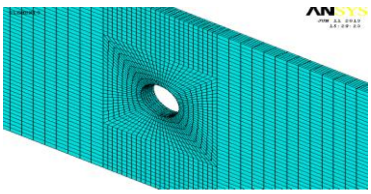


Fig.2 Meshed model

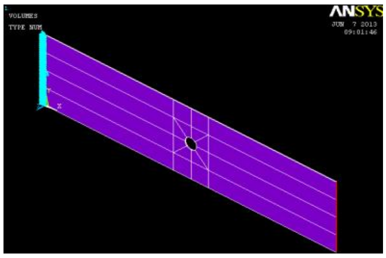


Fig.3Boundary condition applied.

IV. RESULTS AND DISCUSSION

.Table.2 gives the theoretically calculated and finite element results of stress concentration factor for the laminas with a centre notch having different fibre orientation angles

TABLE II
THEORETICAL AND FEA RESULTS FOR STRESS CONCENTRATION FACTOR

Fibre orientation	Stress concentration factor	
	Theoretical	FEA
0°	4.054	3.6
15°	3.482	3.44
30°	2.775	2.93
45°	2.45	2.5
60°	2.775	2.93
75°	3.482	3.44
90°	4.054	3.6

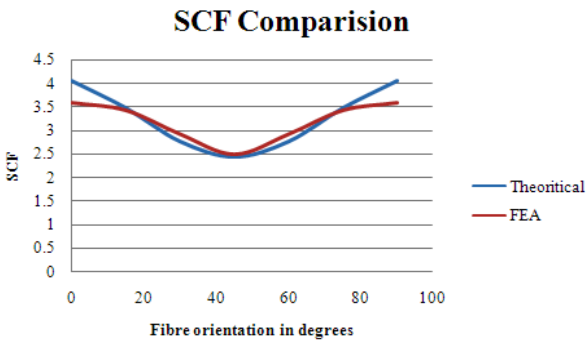
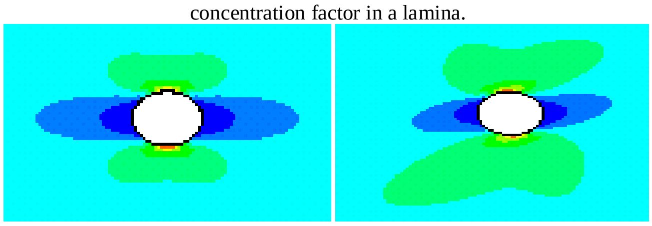
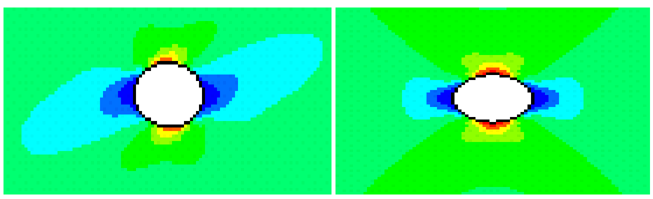


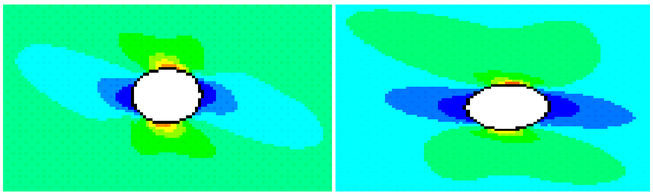
Fig.4Comparison for theoretical results and FEA results for stress concentration factor in a lamina.



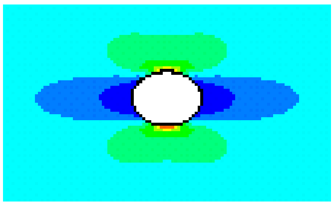
0° ply 15°ply



30° ply 45°ply



60° ply 75°ply



90°ply

Fig.5Stress contour of all the lamina's of different fibre angles

From fig.4 it can be seen that the theoretical results and FEA results both satisfy each other. Hence from theoretical results, we can see that, as the fibre angle increases from 0° to 45° the stress concentration factorreducesbut further increase in fibre angle from 45° to 90° the stress concentration factor increases. A 45° lamina will have the least stress concentration factor; this is because in 45° lamina at the notch region both the warp and weft fibres of the woven fabric lamina participate in carrying the load. Fig.5 shows the stress contours of all the laminas having different fibre angles. It can observed that,as the fibre angle increases from 0º to 45º the stress concentration region at the hole periphery will be approximately perpendicular to the specified fibre angle with respect to the loading direction and for the fibre angle from 45º to 90º, the stress concentration region will be approximately parallel to the specified fibre angle with respect to the loading direction.

With the help of this results, strength of the laminates of stacking sequence's [(0,90)]3s and [(0,90)/(+45,-45)/(0,90)]s are prepared and their strengths are compared which is shown in table.3.Fig.6 shows the stress strain curve of the two laminates.

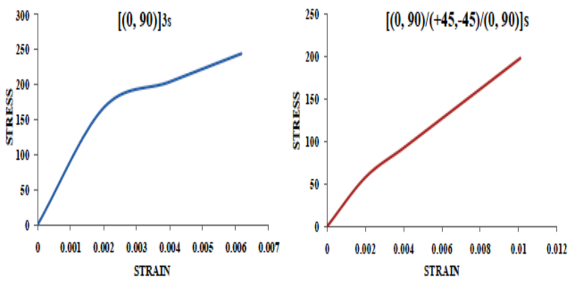


Fig.6Stress strain curve of the laminates

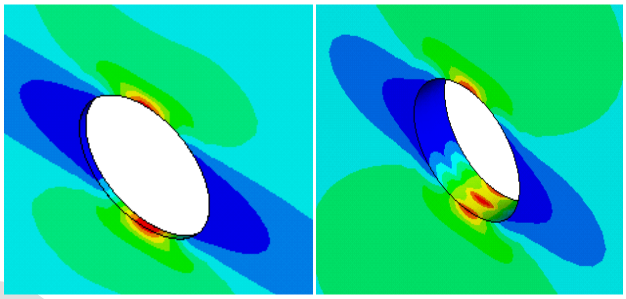
TABLE III
ULTIMATE TENSILE STRENGTH OF THE LAMINATES

Laminate	Ultimate tensile strength (UTS) in MPa
[(0,90)]3s	241.12
[(0,90)/(+45,-45)/(0,90)]s	204.833

Theoretical calculation and finite element analysis was carried out to find the stress concentration in these laminates. Table-4 shows the theoretical and finite element result of the two laminates and there comparison.

TABLE IV
THEORETICAL AND FEA RESULTS FOR STRESS CONCENTRATION FACTOR

Laminate	Stress concentration factor	
	Theoretical	FEA
[(0,90)]3s	4.054	3.6
[(0,90)/(+45,-45)/(0,90)]s	3.34	3.38



[(0,90)]3s[(0,90)/(+45,-45)/(0,90)]s

Fig.7Stress contour of the laminates

From table 3 and 4 we can say that [(0,90)/(+45,-45)/(0,90)]s laminate has a slightly less ultimate strength compared to the [(0,90)]3s laminate but the [(0,90)/(+45,-45)/(0,90)]s laminate exhibit less stress concentration factor.Fig.7 shows the stress contours of the two laminates. It can be seen that, in fig.5 both the 0° lamina and 45° lamina have their stress concentration region perpendicular to loading direction at the hole periphery, but the 45° lamina has a lesser value. Hence looking into the stress contour of [(0,90)/(+45,-45)/(0,90)]s laminate we can say that the red spots at the hole periphery is the (0,90) layer and the yellow spots are the (+45,-45) layer. Even though the load carrying capacity is slightly less for the [(0,90)/(+45,-45)/(0,90)]s laminate , the stress concentration value is reduced. Hence we can conclude that stress concentration factor can be reduced in a composite laminate by altering the stacking sequence based on the load carrying capacity required.

V. CONCLUSION

This study was conducted to investigate the effect of fibre orientation on the stress concentration factor of the composite lamina. Theoretical calculations were compared with finite element results. From the results we can conclude that,

1. For all lamina with a hole the maximum stress region is found at the periphery of the hole.
2. As the fibre angle increases from 0° to 45° the stress concentration factor reduces but further increase in fibre angle from 45° to 90° the stress concentration factor increases.
3. A 45° lamina will have the least stress concentration factor

4. It can observed that,as the fibre angle increases from 0º to 45º the stress concentration region at the hole periphery will be approximately perpendicular to the specified fibre angle with respect to the loading direction and for the fibre angle from 45º to 90º, the stress concentration region will be approximately parallel to the specified fibre angle with respect to the loading direction.
5. Hence we can conclude that stress concentration factor can be reduced in a composite laminate by altering the stacking sequence based on the load carrying capacity required.

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