MINIMIZATION OF STRESS CONCENTRATION IN A RECTANGULAR ALUMINIUM COMPOSITE PLATE WITH A HOLE

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ABSTRACT

Holes, notches, cutouts etc. are common in various machine members. But such irregularities often lead to stress concentration near the irregularity due to which the stress near the irregularity is higher than the average stress in the whole member. This stress concentration can be reduced by the use of suitable composites. In this study, a rectangular composite plate with circular hole at center is analyzed by using three dimensional finite element analysis (ANSYS APDL). The plate is made up of carbon/epoxy reinforced aluminium composite. The plate is subjected to tensile loading and the equivalent stresses are studied. Further stress mitigation is carried out by introduction of auxiliary holes in the plate. The results indicate that the composite materials exhibit improved physical and mechanical properties, such as, high ultimate tensile strength, minimal stress concentration and effective stress distribution. Being extremely lighter than the isotropic Aluminium plate, the aluminium composites efficiently used for applications in the automobile industry, for instance, in making car disc brake rotors.

Keyword: - *Aluminium composite panel, Stress Concentration, Tensile Strength, Auxiliary Holes*

1. INTRODUCTION

Though, composite materials are not new to us, its sophisticated engineering applications and significant research works have been started a long way back, 1940. Emergence of strong and stiff reinforcements like carbon fiber along with advances in polymer research to produce high performance resins as matrix materials have helped meet the challenges posed by the complex designs of modern manufacturers. The large scale use of advanced composites in current programmes of development of military fighter aircraft, small and big civil transport aircraft, sports equipment, sportscars etc. all around the world is perhaps the most glowing example of the utilization of potential of such composite materials [2].
In the last few decades there has been an extensive usage of aluminium composite panels in the fields of automotive, aerospace and architectural industries. A sandwich panel is a structure made of three layers: low density core inserted in between two relatively thin skin layers. This sandwich setup allows to achieve excellent mechanical performance at minimal weight. The very high rigidity of a sandwich panel is achieved thanks to interaction of its components under flexural load applied to the panel: core takes the shear loads and creates a distance between the skins which take the in-plane stresses, one skin in tension, the other in compression [12]. Aluminium Composite Panels (ACP) are mainly light-weight composite material consisting of two pre-finished aluminium cover sheets

heat-bonded (laminated) to a core made of polyethylene plastic material, available in 3mm, 4mm, and 6mm thicknesses after finishing and can be curved and bent to form corners [14]. These panels are used widely as exterior covering of commercial buildings and corporate houses. While adding to aesthetic beauty of the structure, they are also resistant to acid, alkali salt spray, pollution and provide good thermal as well as sound insulation. Saksham Dhanjal, Richa Arora [4] analyzed the stress concentrations in a rectangular block of aluminium with a hole in the center, under influence of uniaxial tensile loading and found out the maximum equivalent stress on the plate. The dimensions and the boundary conditions are kept the same for every model used in this analysis. Even after using composites, further stress mitigation can be done by the introduction of auxiliary holes in the rectangular plate [8]. Positioning of auxiliary holes in different locations can lead to varying stress distributions in the plate and also assist material reduction [13]. The optimum distance of the auxiliary holes and their respective radius was experimentally carried out by Kambale et al [10]. In the research work done in [4], the stress distribution and the maximum equivalent stress in the plate is evaluated. The plate is made up of Aluminium (isotropic material) [4]. Further in [5] and [7], auxiliary holes and cutouts have been used for stress mitigation in the isotropic plates. R.K. Lou [3] has studied the impact damage in a composite plate made up of unidirectional carbon fibers.

2. SCOPE

As we have seen in the introduction regarding the research done, there is still no study on how fiber orientation of the composite can affect the stress distribution in a rectangular plate with a central hole, when subjected to uniform tensile loading. So in this study we have applied the same geometry and boundary conditions as considered by Dhanjal et al [4], on an aluminium composite plate and the results have been studied. Different fiber orientations and the different positioning of the auxiliary holes has been done to determine how it can assist to stress reduction.

3. OBJECTIVES OF THE PRESENT RESEARCH

Analysis of Sandwich Aluminium Composite with Carbon/Epoxy fibers subject to static loading

3.1. Evaluation of maximum stresses on a rectangular plate with a hole

3.2. Minimization of maximum stress concentrations using different fiber orientation

3.3. Analyses of stress concentrations in holes or cutouts (auxiliary holes)

3.4. Stress mitigation in the plate by positioning auxiliary holes in different orientations

4. PROBLEM DESCRIPTION

In this research work, a rectangular aluminium composite consisting of three layers (aluminium-carbon/epoxy-aluminium) and having a hole in the center is considered, as shown in Fig. 1. Each layer has a thickness of (10/3) mm. It is then subjected to a uniform tensile load of 8MPa on one end and the other end is kept fixed. It is done for different fiber orientations of carbon/epoxy (i.e. 0^0,30^0,60^0,90^0) .The stress distribution in each case is studied and is compared to an isotropic aluminium plate with a hole. The material properties of Aluminium (Al 7075) and carbon/epoxy are taken from Table 1 and Table 2. Further stress mitigation is done by introduction of 2 auxiliary holes in the composite plate and placing them in various orientations as shown in Fig 2.

Young's Modulus	
E_x	72000 MPa
Poisson's Ratio	
v_x	0.3

Table 1: Mechanical properties of Aluminium [4]

Young's Modulus	
E_x	145000 MPa
E_y	9200 MPa
E_z	9200 MPa
Poisson's Ratio	
v_x	0.3
v_y	0.3
v_z	0.3
Rigidity Modulus	
G_{xy}	4600 MPa
G_{yz}	3000 MPa
G_{xz}	5200 MPa

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Table 2: Mechanical properties of Carbon/Epoxy [3]

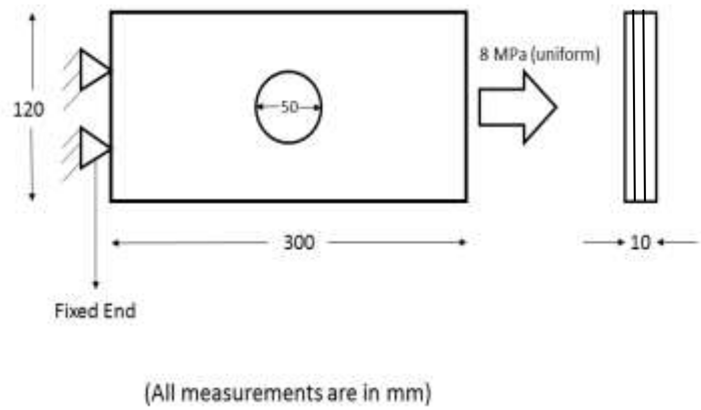


Fig 1: Plate geometry

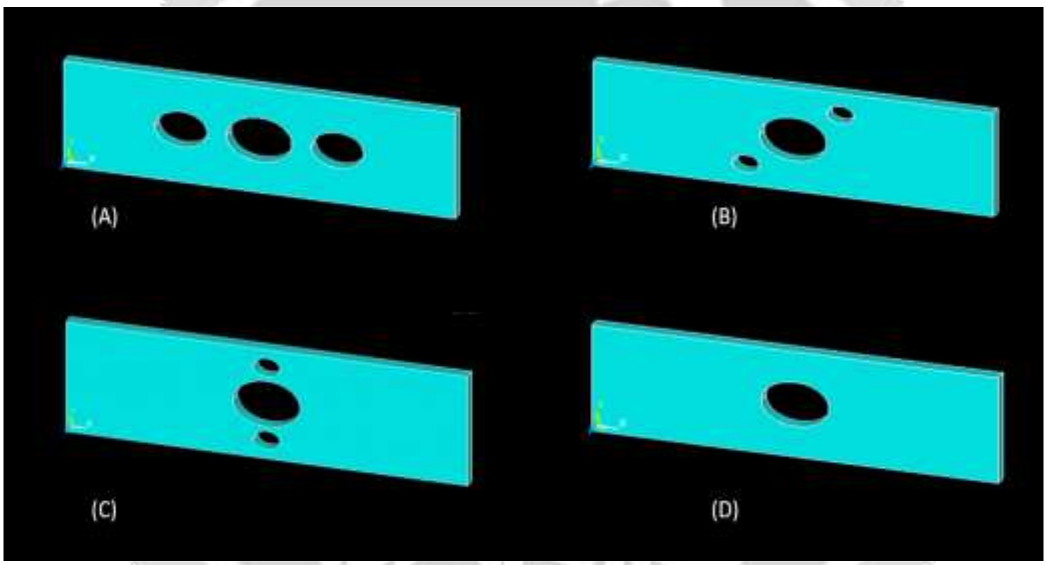


Fig. 2: Auxiliary Holes (A, B, C) and their positioning

5. FINITE ELEMENT ANALYSIS

Finite element analysis of the problem is performed in popular FEA package ANSYS 15. Model of the geometry is generated and analyzed in ANSYS. The plate is fixed at one end and a tensile load of 8 MPa is applied on the other end of the plate. The model of the isotropic aluminium plate is meshed with SOLID186 element. This element has 20 nodes per element and 20 degrees of freedom at each of the node. This element has the capabilities like plasticity, creep, stress stiffening, large deflections etc. It is also suitable for modeling irregular meshes [11]. The mesh is refined near the hole. The FE model of the plate are shown in the Fig.3. The element used for designing orthotropic carbon/epoxy layer in SOLID186. This element has 8 nodes per element and 8 degrees of freedom at each of the node. It is a lower ordered element of SOLID185. It is used mainly to reduce the mesh generation time.

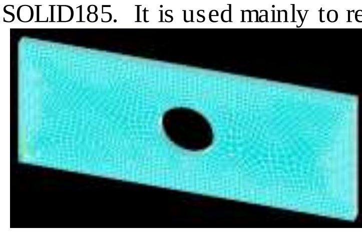


Fig. 3: 3D Finite Element model after meshing

6. RESULTS AND DISCUSSION

6.1 Evaluation of stress in an isotropic (Aluminium) plate with a hole

A uniform tensile load of 8 MPa is applied on an isotropic rectangular plate having geometry as shown in Fig 1. The maximum equivalent stress is evaluated for the plate and the stress distribution is shown in Fig 4 and the value of maximum equivalent stress on the plate is computed and compared with Dhanjal et al [3] as shown in Table 3. From Table 3 it is observed that the value of maximum equivalent stress shows good agreement with Dhanjal et al [3].

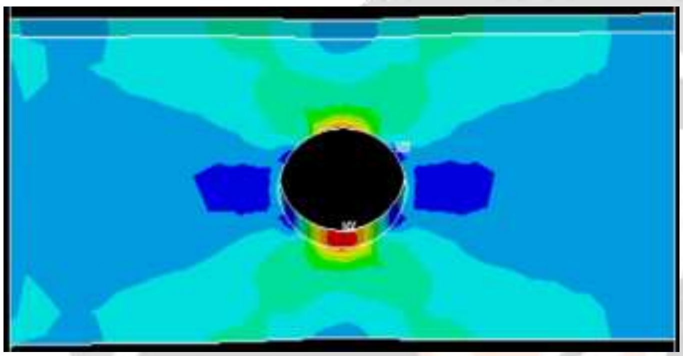


Fig 4: Stress distribution in isotropic plate

Max Equivalent Stress in [3]	**Max Equivalent Stress in present analysis**
30.88 MPa	30.99 MPa

Table 3: Maximum equivalent stress comparison with [3]

6.2 Stress distribution in rectangular composite plate with a hole having different positions of auxiliary holes (fiber orientation at 0^0).

When the fiber orientation is at 0^0 to the applied tensile load i.e. as shown in Fig. 5, the stress in calculated across the main hole (shown by a red line in Fig. 5) and then a graph is plotted as shown in Graph 1, comparing different positions of auxiliary holes.

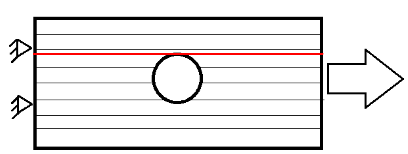
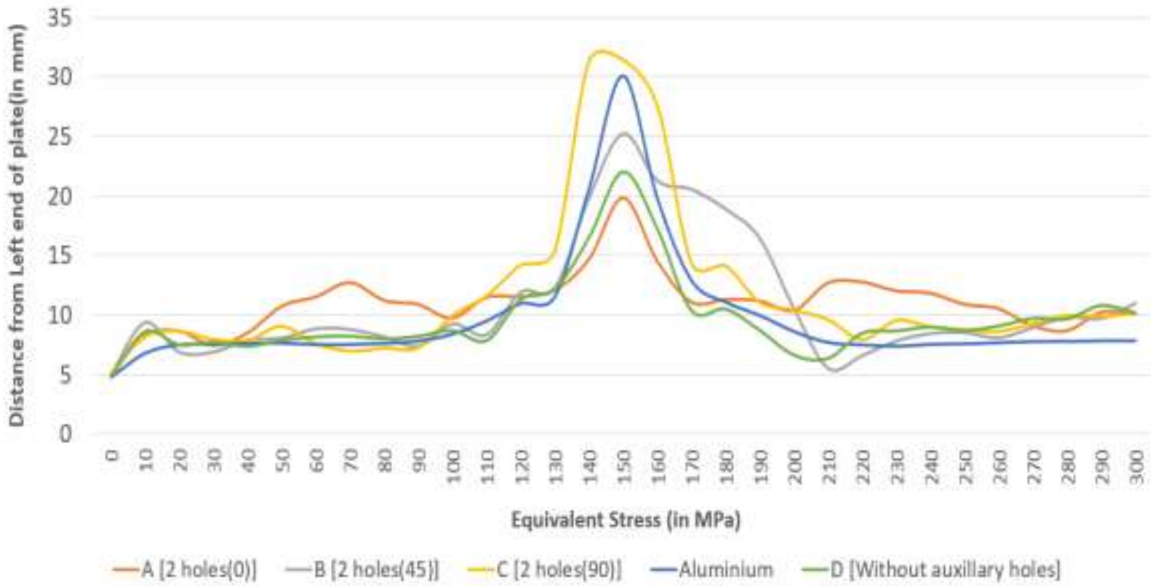


Fig. 5: Fiber orientation at 0^0



Graph 1: Distance from left end of plate v/s equivalent stress

The stress distribution in the plate in the cases mentioned in Graph 1 are shown below in Fig. 6, Fig. 7, Fig. 8 and Fig. 9 respectively. The areas where maximum stress concentration occurs can be seen in red and the values of the maximum equivalent stress in the plate are mentioned in Table 4.

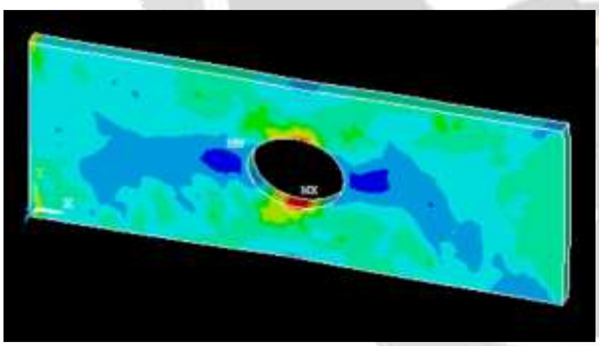


Fig. 6: Composite plate without auxiliary holes

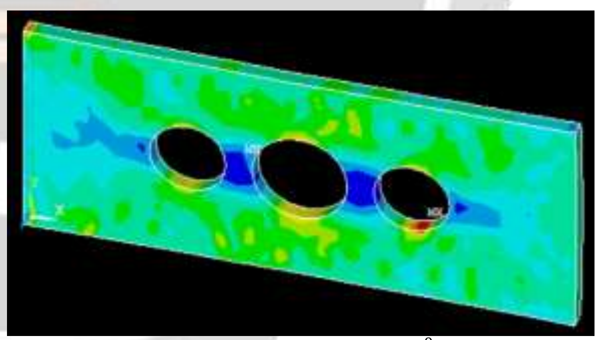


Fig 7: 2 Auxiliary holes at 0^0

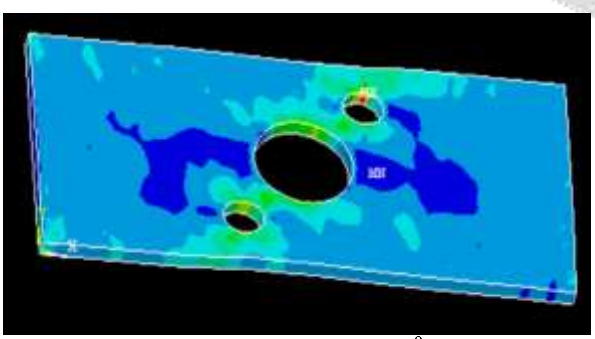


Fig 8: 2 Auxiliary holes at 45^0

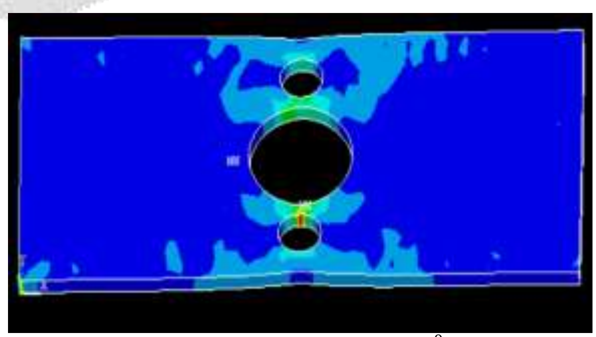


Fig 9: 2 Auxiliary holes at 90^0

S. No	Position of auxiliary holes	Maximum Equivalent Stress on the plate
1	Without auxiliary holes	24.54 MPa
2	2 auxiliary holes at 0^0	24.85 MPa
3	2 auxiliary holes at 45^0	45.56 MPa
4	2 auxiliary holes at 90^0	90.9 MPa

Table 4: Maximum Equivalent Stress for different positioning of auxiliary holes for fiber orientation $0^0/0^0/0^0$

There is an abnormal increase in the stress concentration in the auxiliary hole when the holes are positioned at 90^0, as the stress curves get constricted in the very thin area between main hole and the auxiliary hole. Due to increase in the density of stress curves in the region, so there is a high value of stress in the auxiliary hole. Among all the cases considered, when the holes are at 0^0 the stress reduction is maximum and there is also an efficient material reduction in the plate.

6.3 Stress distribution in rectangular composite plate with a hole having different positions of auxiliary holes (fiber orientation at 30^0).

Using the same geometry, now when the fiber orientation is at 30^0 to the applied tensile load i.e. as shown in Fig. 10, the stress in calculated across the main hole (shown by a red line in Fig. 10) and then a graph is plotted as shown in Graph 2, comparing different positions of auxiliary holes.

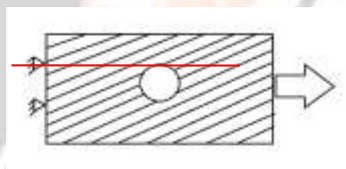
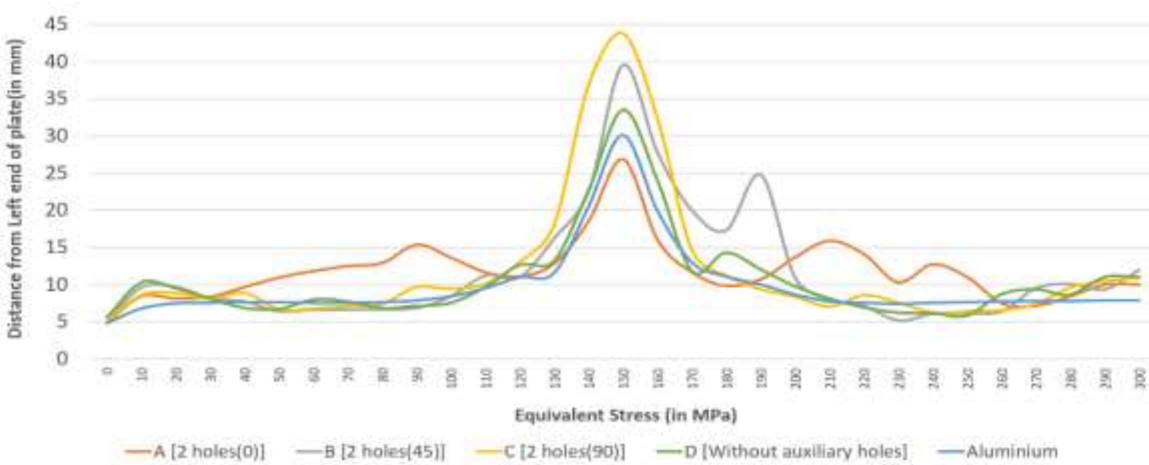


Fig. 10: Fiber orientation at 30^0



Graph 2: Distance from left end of plate v/s equivalent stress

The stress distribution in the plate in the cases mentioned in Graph 2 are shown below in Fig. 11, Fig. 12, Fig. 13 and Fig. 14 respectively. The areas where maximum stress concentration occurs can be seen in red and the values of the maximum equivalent stress in the plate are mentioned in Table 5.

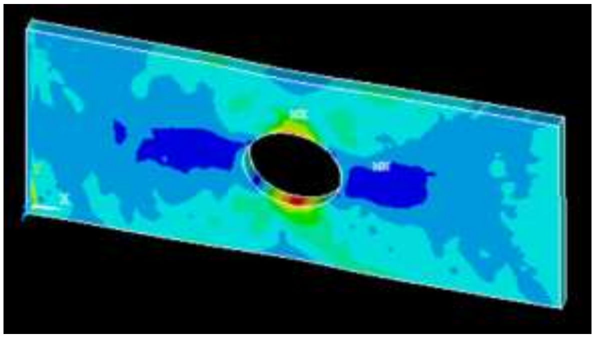


Fig. 11: Composite plate without auxiliary holes

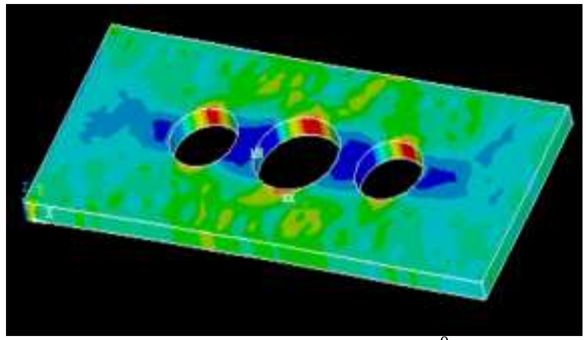


Fig 12: 2 Auxiliary holes at 0^0

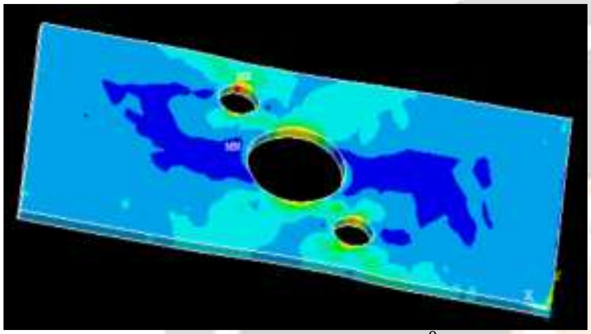


Fig 13: 2 Auxiliary holes at 45^0

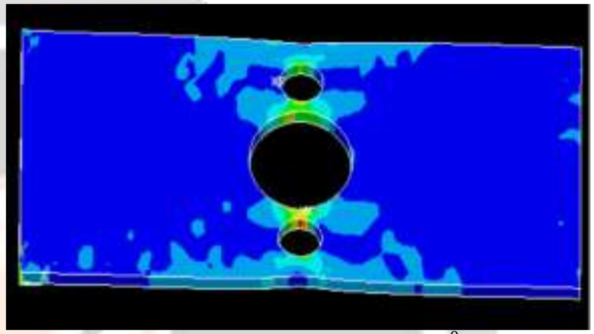


Fig 14: 2 Auxiliary holes at 90^0

S. No	Position of auxiliary holes	Maximum Equivalent Stress on the plate
1	Without auxiliary holes	37.01 MPa
2	2 auxiliary holes at 0^0	27.15 MPa
3	2 auxiliary holes at 45^0	50.25 MPa
4	2 auxiliary holes at 90^0	90.15 MPa

Table 5: Maximum Equivalent Stress for different positioning of auxiliary holes for fiber orientation $0^0/30^0/0^0$

There is an abnormal increase in the stress concentration in the auxiliary hole when the holes are positioned at 90^0, as the stress curves get constricted in the very thin area between main hole and the auxiliary hole. Due to increase in the density of stress curves in the region, so there is a high value of stress in the auxiliary hole. Among all the cases considered, when the holes are at 0^0 the stress reduction is maximum and there is also an efficient material reduction in the plate. As the load applied is purely tensile and there isn't any shear force or twisting, fiber orientation doesn't play an important role in the stress reduction.

6.4 Stress distribution in rectangular composite plate with a hole having different positions of auxiliary holes (fiber orientation at 60^0).

When the fiber orientation is at 60^0 to the applied tensile load i.e. as shown in Fig. 15, the stress in calculated across the main hole (shown by a red line in Fig. 15) and then a graph is plotted as shown in Graph 3, comparing different positions of auxiliary holes.

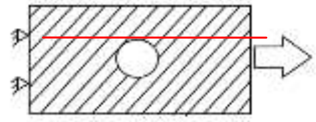
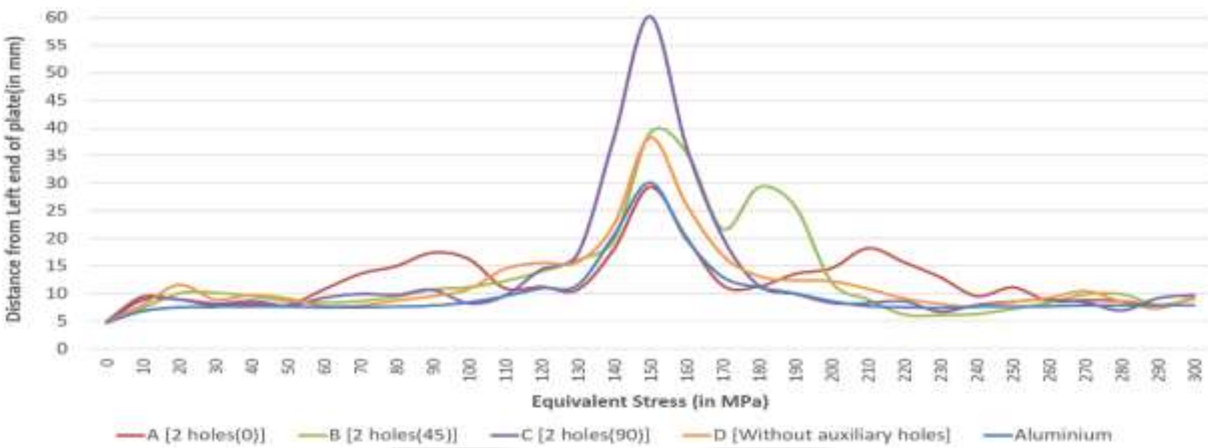


Fig. 15: Fiber orientation at 60^0



Graph 3: Distance from left end of plate v/s equivalent stress

The stress distribution in the plate in the cases mentioned in Graph 3 are shown below in Fig. 16, Fig. 17, Fig. 18 and Fig. 19 respectively. The areas where maximum stress concentration occurs can be seen in red and the values of the maximum equivalent stress in the plate are mentioned in Table 6.

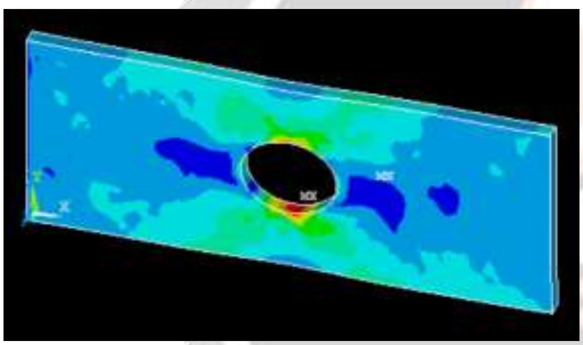


Fig. 16: Composite plate without auxiliary holes

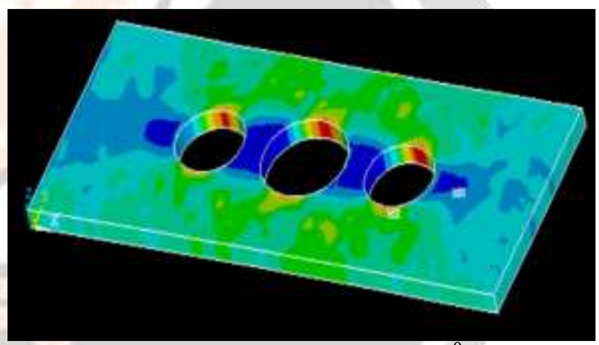


Fig 17: 2 Auxiliary holes at 0^0

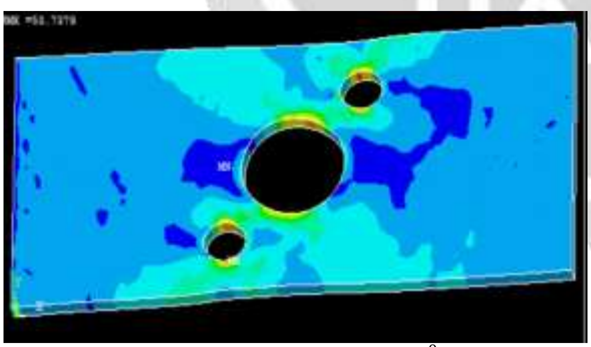


Fig 18: 2 Auxiliary holes at 45^0

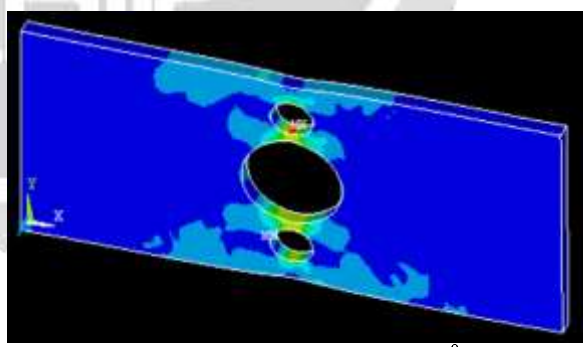


Fig 19: 2 Auxiliary holes at 90^0

S. No	Position of auxiliary holes	Maximum Equivalent Stress on the plate
1	Without auxiliary holes	40.01 MPa
2	2 auxiliary holes at 0^0	30.31 MPa
3	2 auxiliary holes at 45^0	53.73 MPa
4	2 auxiliary holes at 90^0	98.03 MPa

Table 6: Maximum Equivalent Stress for different positioning of auxiliary holes for fiber orientation $0^0/60^0/0^0$

6.5 Stress distribution in rectangular composite plate with a hole having different positions of auxiliary holes (fiber orientation at 90^0).

When the fiber orientation is at 90^0 to the applied tensile load i.e. as shown in Fig. 20, the stress in calculated across the main hole (shown by a red line in Fig. 20) and then a graph is plotted as shown in Graph 4, comparing different positions of auxiliary holes.

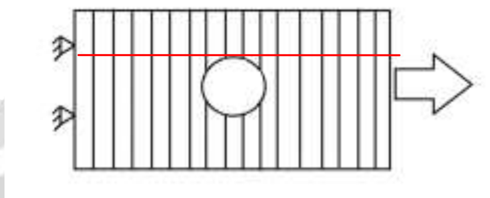
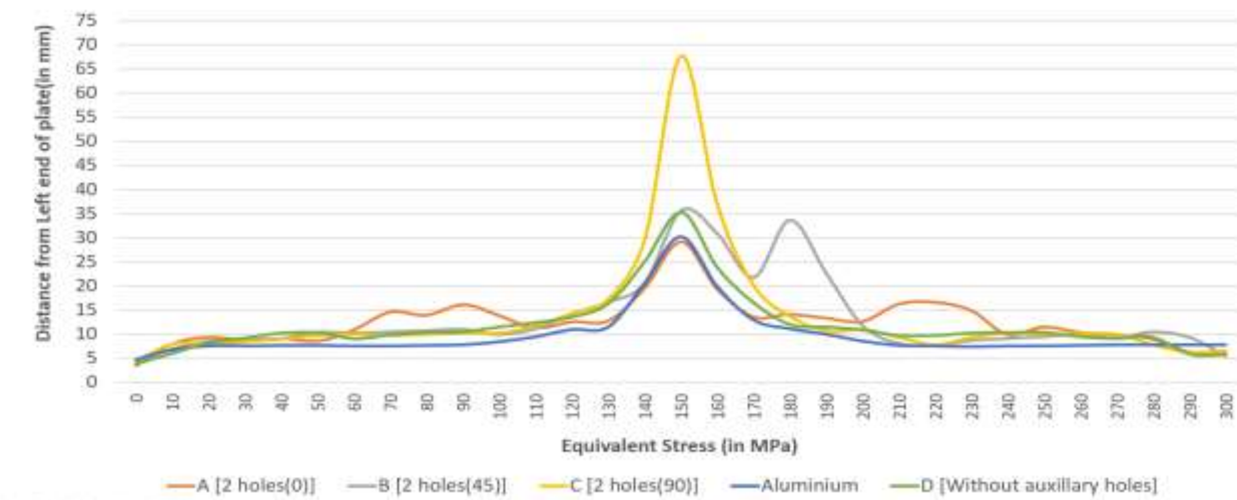


Fig. 20: Fiber orientation at 90^0



Graph 4: Distance from left end of plate v/s equivalent stress

The stress distribution in the plate in the cases mentioned in Graph 4 are shown below in Fig. 21, Fig. 22, Fig. 23 and Fig. 24 respectively. The areas where maximum stress concentration occurs can be seen in red and the values of the maximum equivalent stress in the plate are mentioned in Table 7.

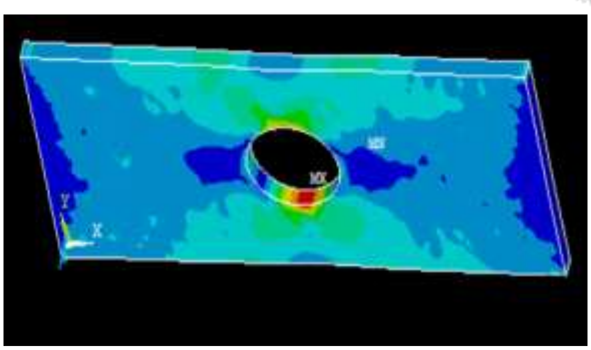


Fig. 21: Composite plate without auxiliary holes

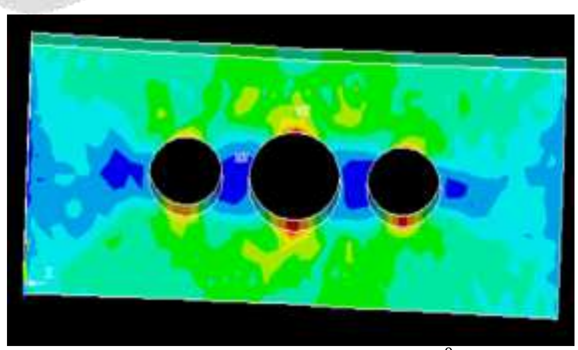


Fig 22: 2 Auxiliary holes at 0^0

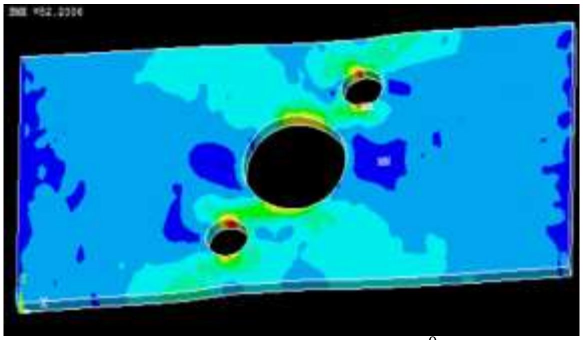


Fig 23: 2 Auxiliary holes at 45^0

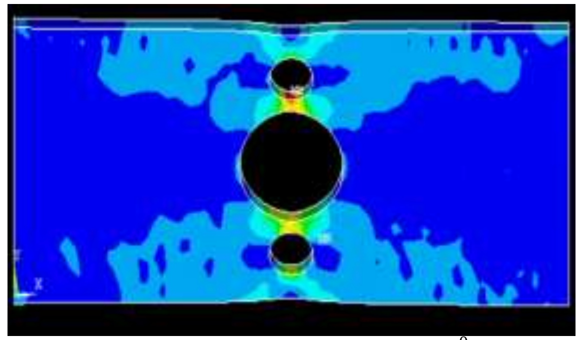


Fig 24: 2 Auxiliary holes at 90^0

S. No	Position of auxiliary holes	Maximum Equivalent Stress on the plate
1	Without auxiliary holes	39.41 MPa
2	2 auxiliary holes at 0^0	29.16 MPa
3	2 auxiliary holes at 45^0	52.20 MPa
4	2 auxiliary holes at 90^0	81.84 MPa

Table 7: Maximum Equivalent Stress for different positioning of auxiliary holes for fiber orientation $0^0/90^0/0^0$

There is an increase in the stress concentration in the auxiliary hole when the holes are positioned at 90^0, as the stress curves get constricted in the very thin area between main hole and the auxiliary hole. Due to increase in the density of stress curves in the region, so there is a high value of stress in the auxiliary hole. Among all the cases considered, when the holes are at 0^0 the stress reduction is maximum and there is also an efficient material reduction in the plate. As the load applied is purely tensile and there isn't any shear force or twisting, fiber orientation doesn't play an important role in the stress reduction. When the fiber orientation is 90^0 the stress reduction isn't substantial because the carbon/epoxy used is an orthotropic material. It has higher Young's modulus in the direction of fibers as we can see in Table 2. So, stress reduction occurs the most when the fibers are parallel to the direction of tensile load.

7. CONCLUSIONS

In this study a rectangular aluminium composite plate with a hole in the center subjected to a uniform tensile load is studied using FEA. Different fiber orientations and different positioning of auxiliary holes have been used so as to study stress distribution and mitigate stress concentration respectively. Following conclusions can be drawn from the study:-

- The maximum stresses of an isotropic plate and a composite plate are evaluated and it is concluded that there is reduction of stress concentration near the hole, in composite plate.
- Among the different fiber orientations, it is observed that in case of $0^0/0^0/0^0$ composites, the stress reduction is the maximum.
- When 2 auxiliary holes are made at 0^0 with the main hole, there is a minimal stress concentration in the auxiliary holes. In all other positions of auxiliary holes there is an increased stress concentration.
- In case of $0^0/0^0/0^0$ fiber orientation, the rectangular composite plate having 2 auxiliary holes at 0^0 to the main hole had the minimal stress concentration and there was efficient material reduction. Hence, it has been observed to be the most efficient form of composite plate having central hole.

8. FUTURE SCOPE

- Analysis of sandwich panel composites under influence of twisting and bending
- Efficient measures for material reduction in the plates when subject to tensile loading
- The other properties of composites such as moisture absorption, fatigue and tribological behaviour may be determined using extensive experimentation.
- Evaluation of properties by varying the thickness of the Aluminum plates.

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