Material Effect on Stress Behavioural Characteristics of Composite Rectangular Plate

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Abstract: A numerical study has been carried out to examine the effects of the material on stress behavioural characteristics of a rectangular plate with and without cutout for a conventional and composite material plate subjected to pressure loads using finite element method. Further, this paper addresses the effect of various boundary conditions applied to the plate. A comparison has been made between the conventional and composite material with and without the cutout. It is observed that the application of pressure loads and boundary conditions have a substantial influence on stress behavioural characteristics of a rectangular plate with and without cutout on both the materials. The results obtained from numerical simulation are compared and found that simulation results are in good agreement with the previous studies.

Keywords: Boundary conditions, Composite plate, Finite element analysis, Pressure, Quasi-isotropic rectangular cutout, symmetrically laminated plates.

1. Introduction:
An immense literature survey has been done on the stress analysis of a plate with considering stress concentration as a major parameter by varying position of holes, materials, applied load and boundary conditions. Since the analytical solutions for the determination of three-dimensional stress distribution around a stress concentration for an isotropic plate with arbitrary thickness have been studied by various researchers which are based on generalized plane stress theory. The application of rectangular plate in engineering and technology is universal which becomes predominant to determine the strength of the component in terms of its stress distribution around holes and analyze its load-bearing capacity for these structures. The plates are the structural elements with very small thickness when compared to other dimensions. The thickness to width ratio is less than 0.1. Holes is made in plates to obtain desired results and relieve highly localized stresses. Configuring the structures with cutouts is one of the most important factors in constructing primary structural elements in Aerospace, Mechanical, Civil engineering and Marine structures.

To study the static behaviour of plate Sieme [1] used Kirchhoff plate theory using a finite element method as the basis. A computer programme in FORTRAN has been developed to carry out the simulation using triangular element formulation. An exact solution for the deflection determination of a
clamped rectangular plate was given by Imrak [2] et al. He applied uniform load distribution on the plate for which each term of the series is expressed as trigonometric and hyperbolic functions satisfying the boundary conditions for all the four edges. This paper also investigates the bending behaviour of a rectangular plate with various loading conditions using Matlab code and simulating software Ansys. Stress concentration for different geometries with irregularities and subjected to various types of loadings are given by Peterson[3] et.al.Troyani et.al[4] used finite element method to study the theoretical stress concentration factors for short rectangular plates with a central hole of circular shapes subjected to uniform tension.

Mekalke [5] studied the effect of an initial stretching of a rectangular plate with a cylindrical hole on the stress and displacement distributions around the hole, which are caused by the additional loading, using the finite element method.Tamer Ozben[6] developed computer program using FORTRAN 90 to analyze the elasto-plastic stresses using the finite element method. He also predicted the expansion of the plastic zone and residual stresses in layers of fiber-reinforced, thermoplastic laminated composite plates with a rectangular hole in their studies.SharabanandShahidul[7] used investigations of Heywood, Peterson, and Pilkey for various isotropic shapes with a wide range of holes. They determined the stress concentration factor through finite element analysis using PATRAN pre-processor and NASTRAN solver combination.Pravin Pawar[8] did analyze the same plate for Magnesium alloy and Polyethylene material and he observed that deformation decreases with increase in thickness to depth ratio (T/D ratio) and it resulted in a decrease in vonMises stress.Babulal and Vimal Kannan[9] studied the stretching of an Isotropic rectangular plate with a central hole under uniform tensile load using FEM and found out that SCF is sensitive to ratio and the simulation shows that higher the value of the ratio, higher the maximum stress. Dhiraj Kumar and Somkuwar[10] conducted experiments on Aluminum alloy Al2O3, Boron carbide using ANSYS, FEM and stress concentration analysis is performed for analyzing the change in the behaviour of three materials in terms of stress and found that stress value is same for all three materials. Abdul Siddique and Meera Mirzana[11] concluded that 30° fiber is optimum fiber while considering composite for a rectangular plate with central holes. Jalil and Jaferi[12] investigated flat composite plates with quasi-square central cutouts. From the results, it may be concluded that the maximum normalized stress of perforated composite plates can be significantly changed by using proper material properties, loading angle, cutout bluntness and orientation.Zheng Yang[13] used 3D finite element method to examine the elastic stresses and strain fields of a finite thickness large plate containing a hole which is subjected to uniaxial tension. In his work, Praveen and Mayank[14] to achieve desired material properties variation plate is decomposed into a number of rings. They stated that stress concentration can be reduced if Young’s Modulus increases radially away from the hole.

In the present work stress concentrations of holes in rectangular plates are carried out for different materials which are necessary to know as they have a wide range of applications in the design of aircraft, propellers, and many locomotives, both theoretical and numerical analysis has been carried out with and without cutouts, for two different materials, one being MS and other is composite by applying different boundary conditions to the plates. These results may find good application in relevant research fields and mechanical applications where there is need to reduce the stress considerably for desired characteristics.

2. Methodology of the Present Work

2.1. Dimensions of the Plate
Figure 1. Figure showing the dimensions of the plate

| Parameter   | Value   |
|-------------|---------|
| Length      | 500 mm  |
| Thickness   | 25 mm   |
| Width       | 300 mm  |

Table 1. Dimensions of Rectangular Plate.

2.2. Material Properties of the Plate

Table 2. Properties of MS Rectangular Plate.

| Properties   | Values                |
|--------------|-----------------------|
| Elastic modulus (E) | 205 GPa               |
| Shear modulus (G)  | 80 GPa                |
| Density (ρ)       | 0.32                  |
| Poisson’s ratio (υ) | 7850 Kg/m³           |

Table 3. Properties of Composite Rectangular Plate.

| Properties                          | E-glass-epoxy |
|-------------------------------------|---------------|
| Density (Kg/m³)                     | 2100          |
| Longitudinal modulus Eₓ (GPa)       | 39            |
| Transverse modulus Eᵧ (GPa)         | 8.6           |
| In plane shear modulus Gₓᵧ (GPa)    | 3.8           |
| Major Poisson’s ratio υᵧ₁₂           | 0.28          |
| Major Poisson’s ratio υᵧ₁₁           | 0.06          |

3. Results and Discussions

The stress behavioural characteristics of the composite and conventional material rectangular plate are evaluated using finite element method as the base method. Two sets of different materials with varied boundary conditions are taken into consideration. For stress analysis, a comparison between metallic and composite plates is carried out. The loading uncertainties and material properties influence have been quantified for overall safety and reliability. In addition to above uncertainties related, effects of the cutout for both materials are taken into consideration. Taking these parameters into consideration stepwise calculations are carried out for both these materials. The stress analysis has been carried out using numerical software Ansys, the deflections and various stresses are calculated and its corresponding graphs are plotted Figures 2-5. Based on the results obtained following conclusions are drawn.
For a conventional rectangular plate with a central hole, the effect of von Mises stress for different d/D ratios are determined and plotted in figure 2. From the comparison with the literature, it may be noted that by increasing the d/D ratio the maximum stress tends to increase.

- By varying the clamped free boundary conditions for an isotropic plate without cutout the boundary condition C-C-F-F has attained higher deflection and von Mises stress Table No 5.
- The inclusion of cutout for isotropic material resulted in substantial decrease in deformation for all the boundary conditions. For the case of von Mises stress except for boundary condition C-F-F-F all the boundary conditions resulted in lesser stress value of von Mises stress.
- The replacement of material from conventional to composite and with the presence of cutout resulted in a decrease of deformation for all the boundary conditions.
- The presence of cutout increased the value of x-component for all the clamped free conditions except for C-C-F-C boundary condition. In case of y-component an incremental increase for C-F-F-F, F-C-F-F has been observed.
- The incremental increase for I and II principal stresses with C-F-F-F, F-C-F-F boundary conditions are observed.

**Table 4. Validation of result with previous studies for various d/D ratios.**

| d/D ratio | Maximum stress (von Mises Stress) | Results of Present Study (MPa) | Reference[15] (MPa) | Theoretical results[15] (MPa) |
|-----------|----------------------------------|-------------------------------|---------------------|-------------------------------|
| 0.2       | 303.65                           | 298.31                        | 313.25              |
| 0.4       | 394.85                           | 383.21                        | 372.17              |
| 0.6       | 576.914                          | 551.24                        | 526.50              |

**Figure 2.** Comparison for Effect of Central hole on von Mises stress for various d/D ratios.
Table 5. Isotropic Rectangular plate without hole and constraints.

| Parameter       | C-C-F-F | C-F-F-F | F-C-F-C | F-C-F-F | C-C-F-C |
|-----------------|---------|---------|---------|---------|---------|
| Deformation     | 0.6772  | 0.68572 | 0.2046  | 0.4477  | 0.2349  |
| X-component stres| 404.941 | 404.364 | 239.027 | 404.748 | 446.261 |
| Y-component stres| 52.0301 | 67.283  | 152.417 | 59.347  | 184.901 |
| VonMises Stress | 546.231 | 421.646 | 406.57  | 499.798 | 454.573 |
| First Principal stress| 408.88 | 408.373 | 239.027 | 408.711 | 446.828 |
| Second Principal Stress | 37.389 | 67.283  | 152.417 | 48.514  | 184.901 |

Table 6. Composite Rectangular plate without hole and constraints.

| Parameter       | C-C-F-F | C-F-F-F | F-C-F-C | F-C-F-F | C-C-F-C |
|-----------------|---------|---------|---------|---------|---------|
| Deformation     | 7.3421  | 7.493   | 2.2314  | 4.8825  | 2.562   |
| X-component stress| 347.363 | 347.233 | 239.55  | 347.333 | 354.228 |
| Y-component stress| 146.488 | 150.891 | 210.356 | 170.17  | 233.065 |
| vonMises Stress | 566.807 | 427.167 | 612.802 | 741.833 | 671.57  |
| First Principal stress| 466.598 | 441.529 | 466.618 | 447.423 | 624.103 |
| Second Principal Stress | 39.844 | 55.275  | 79.028  | 52.764  | 87.463  |

Table 7. Isotropic Rectangular plate with hole and constraints.

| Parameter       | C-C-F-F | C-F-F-F | F-C-F-C | F-C-F-F | C-C-F-C |
|-----------------|---------|---------|---------|---------|---------|
| Deformation     | 0.5364  | 0.5696  | 0.2215  | 0.36176 | 0.17341 |
| X-component stress| 324.651 | 505.926 | 339.744 | 472.361 | 179.403 |
| Y-component stress| 108.614 | 69.437  | 73.508  | 73.990  | 132.293 |
| vonMises Stress | 525.595 | 488.915 | 384.633 | 456.512 | 334.809 |
| First Principal stress| 328.287 | 505.931 | 339.748 | 472.482 | 182.902 |
| Second Principal Stress | 41.6051 | 69.4335 | 71.271  | 71.7048 | 132.291 |
Table 8. Composite Rectangular plate with hole and constraints.

| Parameter            | C-C-F-F | C-F-F-F | F-C-F-C | F-C-F-F | C-C-F-C |
|----------------------|---------|---------|---------|---------|---------|
| Deformation          | 5.8437  | 6.248   | 2.5873  | 3.9466  | 1.88248 |
| X-component stress   | 362.981 | 651.47  | 438.304 | 576.098 | 215.864 |
| Y-component stress   | 98.353  | 178.9   | 118.552 | 177.219 | 163.557 |
| vonMises Stress      | 522.683 | 652.144 | 549.572 | 577.036 | 404.303 |
| First Principal stress| 363.434 | 674.057 | 453.731 | 596.3   | 376.304 |
| Second Principal Stress| 66.975  | 79.020  | 50.932  | 70.3552 | 64.3992 |

Figure 3. Deflection comparison for Isotropic and Composite Material.

Figure 4. Vonmises Stress comparison for Isotropic Material.
4. Conclusions

The analysis results of a rectangular plate with central hole subjected to various combinations of clamped free boundary conditions are predicted by using simulation software Ansys 18.0. The parameters of deflection, von Mises stress, XYZ component stress, and principal stresses are calculated for the same boundary conditions. The three-dimensional and finite element model is generated using Hypermesh-13.0 version and exported to Ansys 18.0 for further analysis. The effects of material on rectangular plate in terms of stress behavioural characteristics are predicted and corresponding graphs are plotted. Finally, a comparison has been made between isotropic and composite taking into consideration with and without the effect of the cut-out. Finally, from the results, it can be predicted that the obtained stresses, deflections can be further enhanced by experimenting with various materials, particularly with composites they can be varied by using proper ply sequence, number of layers and ply angles.

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