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INFLUENCE OF THE PROPERTY OF HOLE ON STRESS CONCENTRATION FACTOR FOR ISOTROPIC PLATES

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Summary: In this paper, the stress concentration factors (SCFs) are predicted by the ANSYS finite element models for the isotropic plates with different holes. The influences of geometric and material parameters of the hole on SCFs are discussed. The geometric shape of holes includes circle, rectangular, elliptic, rhombus and combined-section. The changes of materials properties are discussed by taking the hole as a special inclusion with high elastic modulus. The results show that the isotropic plates reinforced with the inclusions with high elastic modulus is effective to resist on stress concentration, and the hole with smooth shape is reasonable to decrease stress concentration factor. In order to improve the ability to resist on stress concentration, the distribution methods of holes are also discussed in this paper. The results show that two holes in the plate are effective to improve the stress distribution, and to decrease the stress concentration factor. It is significant to improve the mechanical properties of isotropic plates by adjusting the properties of holes. The present study may provide designers an efficient way to estimate the strength of the plate structures with holes.

1 INTRODUCTION

The abrupt changes of stress around holes in structure have important significance for practice because they are often the origin of cracks nucleating and growing in a zone of stress concentration, and they are normally the cause of failure. Wu and Mu[1] proposed a simple computation method based on the scale factors (SFs) to estimate the stress concentration factors (SCFs) of finite-width isotropic/orthotropic plates/cylinders with a circular cutout under uniaxial or biaxial tension. The influence of Poisson's ratio on the thickness-dependent stress concentration factors (SCFs) along the root of elliptic holes in elastic plates subjected to far end uniform tension loading have been systematically investigated by use of the 3D finite element (FE) method[2]. Ukadgaonker and Kakhandki[3] analyzed the stresses in an orthotropic plate with an irregular shaped hole under different in-plane loading conditions and had well matching with the FEM solutions. Much research has been performed to discuss the influence of circle or elliptic hole on the stress concentration factor for different plates [4-7], and majority of the studies performed for the SCF have treated the hole properties. However,

it is available to improve the stress concentration for the structures with hole by adjusting the properties of the hole in the structures. In this paper, taking the hole as the special inclusion, the stress concentration factors (SCFs) are predicted by the ANSYS finite element models for the isotropic plates with different inclusions. The influences of geometric and material parameters of the inclusions on SCFs are discussed. The changes of materials properties are discussed by selecting different elastic modulus for the inclusions. The results show that it is effective to improve the stress concentration by adjusting the geometric and materials properties of the holes for the isotropic plates with holes.

2 FINITE ELEMENT MEDOLS

Typical geometric models are used in this paper are shown in Fig.1.

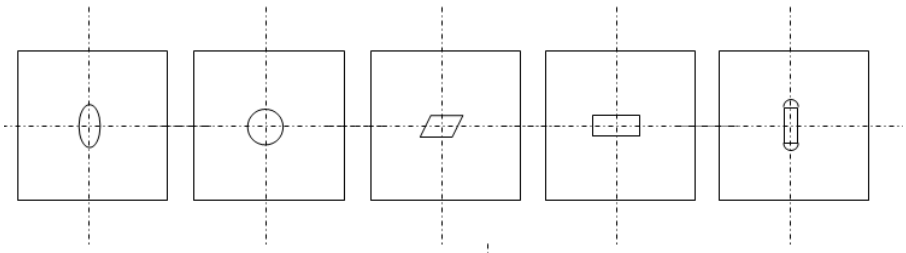

Fig.1 Different shapes of hole for a square plate

Fig. 1 shows a square plate containing a hole with different shapes and subjects different loadings action at the boundary x=±L/2 (here, L is the side length of the square) along x-axis, and Cartesian coordinate system is used with origin locating at the center of the hole in the plate. The typical stress distribution of the cross-section of the square plate with an elliptic hole at the center is shown in Fig.2. The maximum stress σ_{max} takes place at points A and C. The stress concentration factor is defined as the ratio of the maximum stress σ_{max} to the mean tensile stress σ_0 produced from the axis displacement, which is shown in Eq. (1).

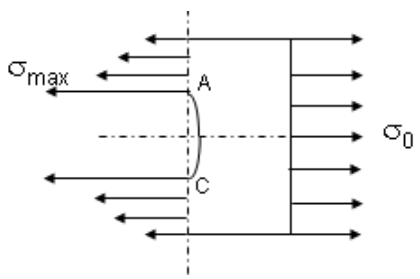

Fig.2 Stress distribution for a square plate with an elliptic hole in the center

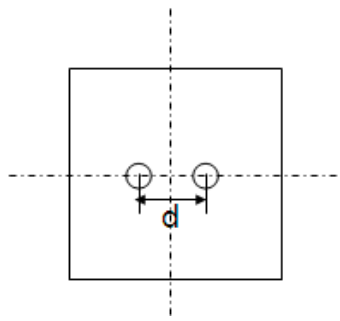

Fig.3 Stress distribution for a square plate with two holes

$$K = \frac{\sigma_{max}}{\sigma_0} \tag{1}$$

The elastic properties of the plate materials are: E = 402 GPa, ν= 0.34, the hole is taken as the inclusion with elastic modulus is zero. For the convenience of comparing, the hole is also taken as the inclusion with high elastic modulus: E = 700 GPa, ν = 0.23.

The plate is modeled in two dimensions using isoparametric quadrilateral Plane 183 elements, which have eight nodes: four vertex nodes and four midside nodes. To improve

veracity of the solution, the mesh was refined around the hole. The plate is analyzed for uniaxial loading by applying a uniform tensile displacement along x-axis direction ($u_x=\pm L/2$ at $x=\pm L/2$), and the boundary conditions are imposed by constraining the y-displacement ($u_y=0$) at $y=\pm L/2$. The average stress σ_0 is calculated for the plate without hole at the same boundary conditions and uniaxial loadings. For the convenience of comparing, the stress concentration is also analyzed by applying shear loadings to the plate, in which $u_y=\pm L/4$ is applied at the side length of $x=\pm L/2$, and $u_x=\pm L/4$ is applied at the side length of $y=\pm L/2$.

3 RESULTS AND DISCUSSION

At first, the mesh sensitivity is verified by using the isotropic plate with elliptic hole. The results are shown in Fig.4 and Fig.5. It is observed that the results are sensitive on the division of grid, and they are random and unstable for free mesh, but they are smooth and stable for the model with mapped mesh. The more fine the mapped mesh, the higher the stress concentration factor. In order to assure the consistence of the results, the mapped mesh with middle size is selected for the calculation in this paper.

The influence of the hole's shape on stress concentration factor is shown in Fig.6. It can be observed that the stress concentration factor is the largest for plate with rhombus hole, which shows that the stress is sensitive on the sharp corners of the hole. When the hole is replaced by the inclusion with a higher elastic modulus than that of the plate, the stress concentration factor decreases rapidly as shown in Fig.7, and the largest stress concentration factor for plate with rhombus inclusion is only 0.34 times of that plate with the rhombus hole. Moreover, the stress concentration factor increases with the increase of the hole's radius, but it keeps nearly unchanged after the radius of inclusion is higher than 0.02mm. It shows that the stress concentration factor is not so sensitive on the size of the inclusion, and it is effective to improve the stress concentration by substituting the inclusion with high modulus to the hole.

The influences of shear loading on stress concentration factor are shown in Fig.8 and Fig.9. Three kinds of typical holes and inclusions are shown in the figures. The largest stress concentration factor is the plate with rhombus hole, and the second is the rectangular hole, and the smallest stress concentration factor is the plate with circle hole. The results show that the shape of the hole with sharp angles is weak to stand up to the stress concentration. Different from the results in Fig.8, when the hole is replaced by the inclusion with the same shape, the stress concentration factor is not so sensitive on the shape of the inclusion. From Fig.9 we can find that not only the stress concentration factor decreases greatly, and the largest SCF is only 0.588 times of that in Fig.8, but also the SCFs keep nearly unchanged with the changes of the radius of inclusion for the same shape, and it has nothing to do with the size of the inclusion.

The double holes are designed to decrease the stress concentration in this paper. The results are shown in Fig.10. Comparing to the plate with single hole, the stress concentration factor decreases for the plate with double holes, and the lower stress concentration factor is obtained for the shorter holes spacing. It is efficient to improve the stress concentration by increasing a hole near the original hole, and the method can be used to crack arrest in fracture mechanics. The same way is used for plate with two inclusions as shown in Fig.11. It is not the same with the above result, the single inclusion is better to cut down stress concentration compared to the plate with two inclusions.

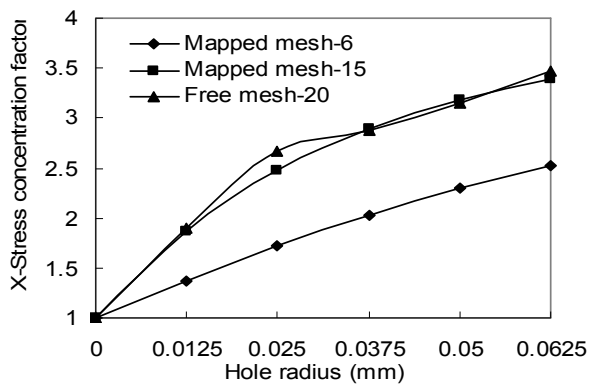

Fig.4 Mesh sensitivity for plate with hole

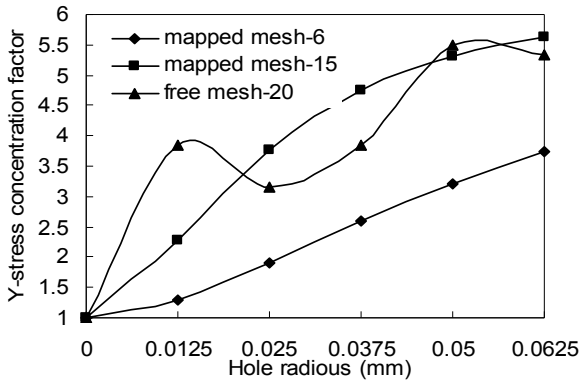

Fig.5 Mesh sensitivity for plate with hole

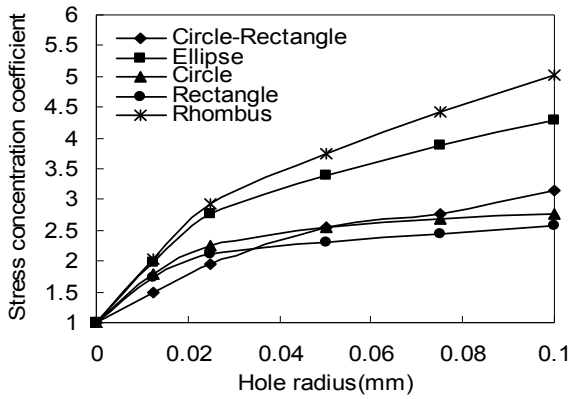

Fig.6 Influence of hole's shape on SCF

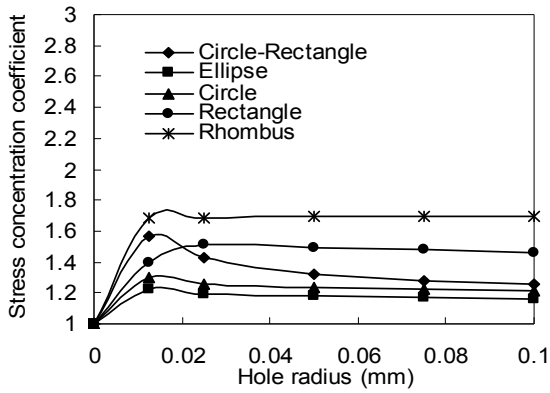

Fig.7 Influence of inclusion's shape on SCF

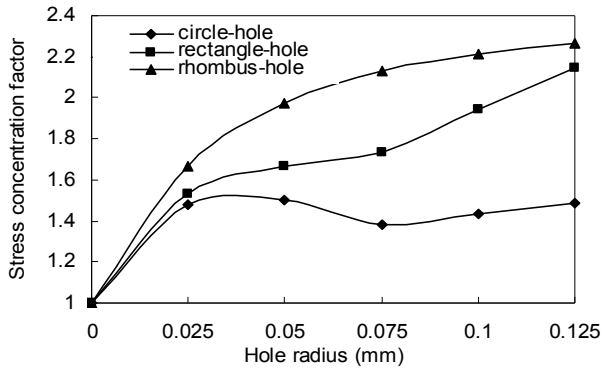

Fig.8 Influence of shear loading on SCF

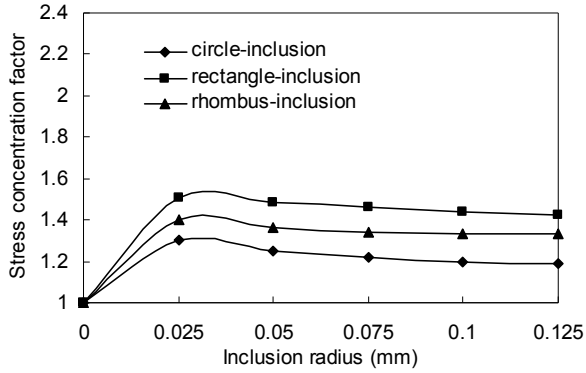

Fig.9 Influence of shear loading on SCF

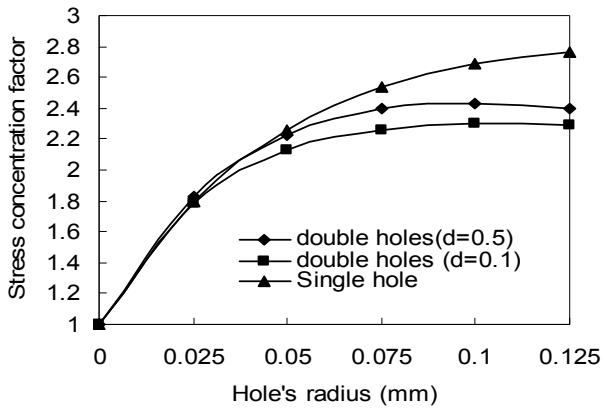

Fig.10 Influence of hole's numbers on SCF

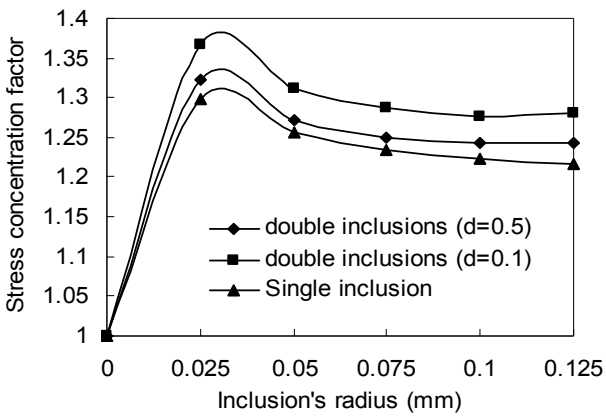

Fig.11 Influence of inclusion's numbers on SCF

4 CONCLUSIONS

Stress concentration factor (SCF) for the plate with holes and inclusions subjected to different loadings action is obtained by using finite element analysis. The reliability of the results on the grid precision is well verified, and some conclusions are obtained as followings:

(1) The stress is sensitive on the shape of the hole in the plate, and stress concentration factor is high for the plate with sharp corners of the hole, and the SCF is low for the plate with circle hole.

(2) It is effective to improve the stress concentration by substituting the inclusions with high elastic modulus to the hole, and the SCF is not sensitive on the inclusion with high elastic modulus in the plate.

(3) The SCF is sensitive on loading method, and it is higher for uniaxial loading than that for shear loading.

(4) Two holes is effective to improve the stress concentration than the case of single hole, and the SCF is affected by the hole spacing. Since the SCF is not sensitive on inclusion with high elastic modulus, the single inclusion seems better to get a lower SCF.

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