Progressive damage analysis of Composite laminates with big cutouts

Pengcheng Chu, Jianlin Chen and Zheng Li

College of Engineering, LTCS， Peking University, Beijing, China

Abstract:

According to the extensive application of fiber reinforced composite laminates in practical engineering, there are many composite laminates with big cutouts to be designed and applied, such as in aircraft structures for the gate on the fuselage, hatch opening, and maintenance cutouts, etc. However, the stress concentration and the complicated failure modes around the cutout are difficult to be studied. The progressive failure process induced by the stress concentration needs to be thoroughly investigated because it is essential for predicting the performance of composite structures and designing reliable and safety structures.

In the case of more complex structures and complicated stress states, most of the failure criteria are not suitable to predict the propagation of failure and the ultimate strength directly. Therefore, an simulation approach is developed in this paper by combining the finite element method and the progressive damage model to analyze the progressive failure process of composite structures.

Keywords: composite laminate, cutout, progressive failure model

Introduction:

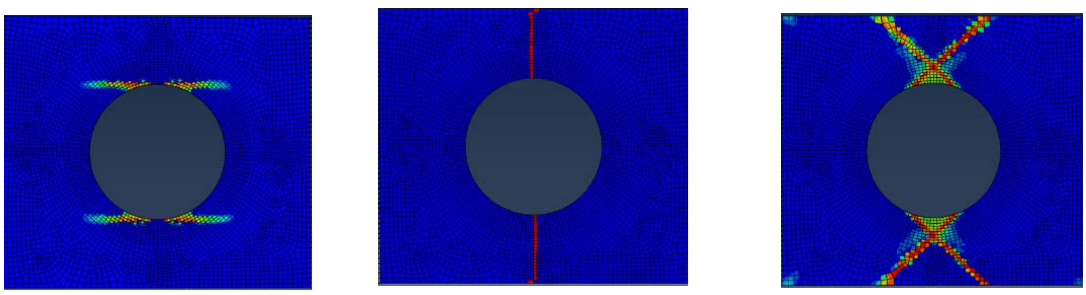
In this study, numerical and experimental studies have been carried out to investigate initial failure and post-failure behaviors of carbon fiber reinforced composite laminates with big circular cutouts under uniaxial tension. The composite laminates with different lay-up and different sizes of big cutouts are considered to figure out the failure behaviors of composite laminates. Here, we only consider the composite laminates with three kinds of lay-up ($[0]_{10}$, $[0°/90°]_{5}$, $[45°/-45°]_{5}$) and the laminates have the size of 240mm in length and 160mm in width. In the center, the diameters of circular cutouts are 60mm, 80mm, and 100mm separately.

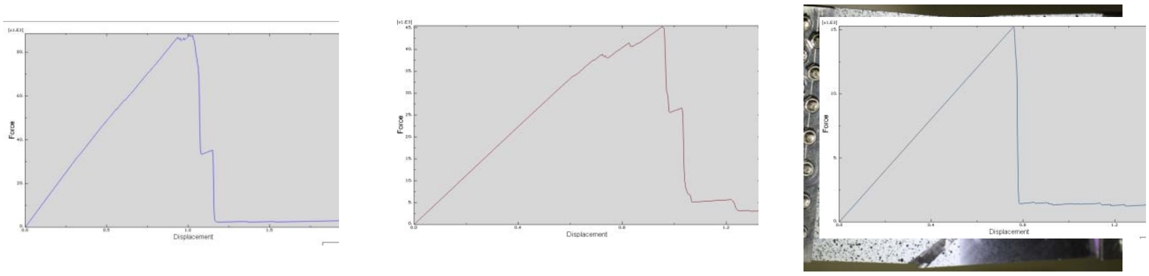
Numerical Analysis

In the numerical analysis, the onset of failure is predicted by Hashin criteria which consists of four different failure modes: fiber tension, fiber compression, matrix tension, and matrix compression. The growth of failure is simulated using a continuum damage model, in which the failure evolution is based on the fracture energy dissipation and the stiffness reduction of matrix is controlled by a set of scalar damage variables. Comparing to the traditional macro-mechanical methods such as the point stress and average stress models, which are semi-empirical and use the calibrated parameters, all the material parameters used in this paper have physical meaning and do not require calibration. The model has been implemented in the finite element programme Abaqus using a UMAT subroutine.

Experiments

All simulation results are compared with experimental tests. The numerical results of ultimate strength correlate well with the experimental data as show in Figure 1. The force-displacement curves in the simulation results exhibit the quasi-brittle failure of the composite laminates as the experiment shows. In contrast with experiments, the simplified model such as the ply discount method can only predict the ultimate strength of composite laminates, but it cannot simulate the quasi-brittle behaviors of laminates accused by the accumulation of damage.





$[0]_{10}$ $[0/90]_5$ $[45/-45]_5$

Figure 1 Failure results of composite laminates with big cutouts

Conclusions

The initial and growth of failure in simulation results show that the proposed model preforms well for predicting the failure behavior of composite laminates with big cutouts. So, the failure mechanism can be explained by the failure process. Furthermore, the finite element based failure model of composite laminates can be used in composite structures with arbitrary configurations under complex stress states to make up for the shortage of analytical failure analysis.