STRENGTH ANALYSIS OF 3D AXIAL BRAIDED COMPOSITES

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1 Introduction
There are majority of failure mechanisms for composites. Therefore, it is recognized by many scholars that the failure locus of anisotropic composites can be expressed by an unsmooth function. The failure envelope corresponding to the specific failure mode should be formulated by the independent functions. Hashin [1] has proposed the failure criteria of transversely isotropic material which are controlled by the fiber and matrix failure modes. Rychlewski [2] has extended the Mises criteria to the anisotropic material. I Huber [3] has proposed a limit condition based on the assumption that only a certain part of elastic strain energy is responsible for the limit condition. Kowalczyk-Gajewska [4] has also developed the energy-based limit criteria for anisotropic elastic materials with internal constraints which include the restriction from the elastic region and limit state. Arramon [5] has utilized the Kelvin energy-based mode and complementary maximum stress condition to consider the different tensile and compressive strength of material. It is well known that the fiber reinforced composites have the different stiffness and strength when the different loading conditions are imposed on the different directions. Therefore, in the normal stress space, there are eight loading combinations. In this paper, the strength of 3D braided composites is studied by the micromechanical and macromechanical methods. The progressive damage analysis of the composites is conducted by using the representative volume cell (RVC). The failure stress can be simulated in the constituent scale. In addition, the failure mechanisms of constituent in the composites have been included during the progressive damage computation. Meanwhile, the energy-based limit condition is also utilized in the composites based on the spectral decomposition of elastic tensor. In the limit condition, the different tensile and compressive stiffness is taken into account.

2 Geometry and finite element model
The 3D axial braided composite preforms have four directional reinforcements. Three directional carbon fibers is uniform angular distribution in the meridional plane. And the fine carbon fiber pultruded rigid rod is reinforced in the normal direction of meridional plane, as shown in Fig. 1.

Fig.1 Braid configuration of 3D axial braided composites.

(a) Geometry model (b) finite element model
Fig. 2 Geometry and finite element model of 3D axial braided composites.

A representative volume cell (RVC) of the composites is established by measuring the mesoscopic geometrical sizes. The cross-section of fibers in the meridional plane represents the rectangular. The cross-section of rigid rod
exhibits circle. Then, the finite element model of the composites is establishes as shown in Fig. 2.

3. Kelvin spectral decomposition of elastic tensor

The spectral decomposition of elastic tensor is to calculate the eigenvalue and eigenvector problem, which can be written as

\[ \mathbf{E} \cdot \mathbf{e}^{(i)} = \Lambda^{(i)} \cdot \mathbf{e}^{(i)} \quad i \leq 6 \]

where, \( \Lambda^{(i)} (i \leq 6) \) and \( \mathbf{e}^{(i)} (i \leq 6) \) are eigenvalue and second order symmetry model tensor of the stiffness tensor.

The elastic strain energy of the material can be divided into several Kelvin mode forms, that is

\[ U_e = \sum_{A=1}^{K} U_A = \frac{1}{2} \sum_{A=1}^{K} \frac{1}{\Lambda_{AA}} \sigma_{\alpha}^{(A)} \sigma_{\alpha}^{(A)} \]

The limit tensor and elastic tensor exhibit coaxial for the quasi-brittle composite material. Therefore, the limit conditions of the material can be written as

\[ \left( \frac{T_{12}}{h_{12}} \right)^2 + \left( \frac{T_{13}}{h_{13}} \right)^2 + \left( \frac{\tau_{12}}{S_{12}} \right)^2 + \left( \frac{\tau_{13}}{S_{13}} \right)^2 + \left( \frac{\tau_{23}}{S_{23}} \right)^2 = 1 \]

where, \( T_{12} = A_{i1}\sigma_{11} + A_{i2}\sigma_{22} + A_{i3}\sigma_{33} \), \( T_{13} = A_{i4}\sigma_{11} + A_{i5}\sigma_{22} + A_{i6}\sigma_{33} \), \( h_{ti} (i \leq K) \) is the elastic limit energy corresponding to the specific Kelvin mode.

4. Results and discussion

Fig. 3 is the biaxial compressive curve of the 3D axial braided composites. The biaxial compressive experiment was conducted. The simulation is carried out by the progressive damage analysis of RVC of the composites applied the periodical boundary condition. It can be found that the numerical results are in good agreement with the experimental data. Fig.4 is the failure locus of the composites. After the RVC is applied a different proportion of loading, the numerical results exhibit some rules. The numerical results are very close to the experiment data. Therefore, the failure loci of the braided composites can be fitted by these failure points. The tendency of limit envelope is similar with the numerical and experimental data.

Fig. 3 biaxial compressive stress-strain curve with 1:1 loading

Fig. 4 failure locus of 3D axial braided composites

References


