MODELING OF COMPRESSIVE STRENGTH OF Z-PINNED FIBER COMPOSITES WITH THE DISTORTED FIBER ARCTECTURE

Junqian Zhang [*,**,a)], Shunli Xie [*]
[*] *Department of Mechanics, College of Science, Shanghai University, Shanghai, 200444, China*
[**] *Shanghai Key Laboratory of Mechanics in Energy Engineering, Shanghai University, Shanghai, 200072, China*

Summary In-plane compressive strength of z-pinned unidirectional composites is predicted by using the theoretical model based on variational principle and the finite element model. The fiber waviness and the fiber volume content concentration, which are distributed inhomogeneously, as well as the resin-rich pocket, are taken into account. The predicted results are in good agreement with the test data. The nonlinear shear property of matrix has significant influence on the compressive strength of the examined unidirectional z-pinned laminate.

INTRODUCTION

Z-pinning as a cost-effective method has received recognition for the remarkable improvement in the through-thickness mechanical properties of the composite laminates [1-2]. However the z-pinning not only causes the distortion and heterogeneous distribution of fibers which stimulate buckling or kinking of fiber, but also forms a resin-rich zone around pins [3-4]. These conditions have adverse effects on in-plane properties, especially on compressive strength. Therefore, an important issue is how to appropriately evaluate the loss of compressive strength caused by insertion of z-pins. In this work, the compressive strength of z-pinned composites will be analyzed by using the theoretical model and the finite element model in which the fibers and matrix are treated as discrete layers.

MODELS

The pattern of pins is supposed to be in periodic arrangement such that one unit cell with periodic boundary condition can be chosen as a representative volume element, Fig.1. The length of cell is equal to the horizontal pin-spacing L and the width of cell the vertical pin-spacing H. Because of the symmetry of unit cell, only a half of cell shown in figure 1 is

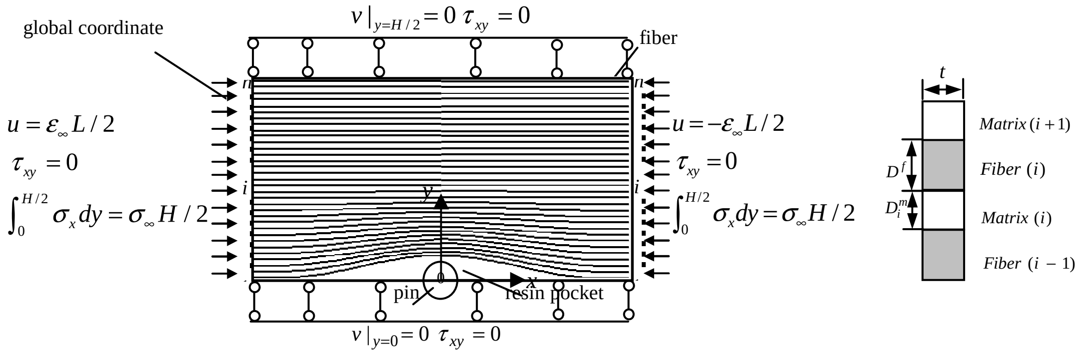

Fig.1. The half-unit cell of z-pinned composite

analyzed, which includes n fibers and n resin regions (where n is decided by the diameter and volume fraction of fibers and the vertical pin-spacing). For simplicity we assume elastic properties of pins are the same as those of resin. The resin-rich zone including a pin is defined as No.1 matrix region. The numbering of fibers and matrix were shown in figure 1. The fiber orientation and fiber content in z-pinned composite laminates will vary from point to point in the distortion region. The fiber distortion model (FDM) developed in [4] is used to quantitatively evaluate the in-plane fiber misalignment angle and fiber volume fraction at an arbitrary point in the z-pinned unidirectional composite ply. The initial path of the i-th fiber is represented by a cosine function $f_i^0(x)=a_i\cos(\pi x/\lambda)+b_i$, where the shape parameters a_i and b_i.

Because there exists initial fiber waviness caused by pin insertion, fibers under axial compressive stress are the most likely to produce deformation shown in Figure 2. So, we could assume shape function of fibers after deformation as $f_i(x)=A_i\cos(\pi x/\lambda)+b_i$ for the i-th fiber. For the matrix layers between fibers, the main deformation in matrix is

a) Corresponding author. Email: jqzhang2@shu.edu.cn.

assumed to be in shear and the strain energy is calculated according to the shear mode, and the energy associated with axial deformation is ignored. The total potential energy in the unit cell can be given by $\Pi = \Delta U_f + \Delta U_m - \Delta W$, where the mechanical work done under axial compressive stress ΔW, the total strain energy in fibers ΔU_f and the total strain energy in matrix ΔU_m can be evaluated according to the beam theory. By using the variational principle, the expression for the fiber stress σ_f involving coefficient A_i can be solved. The maximum shear stress in matrix is taken

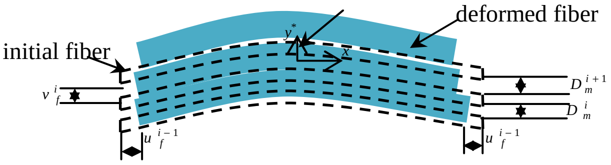

Fig 2. Deformation of fibers

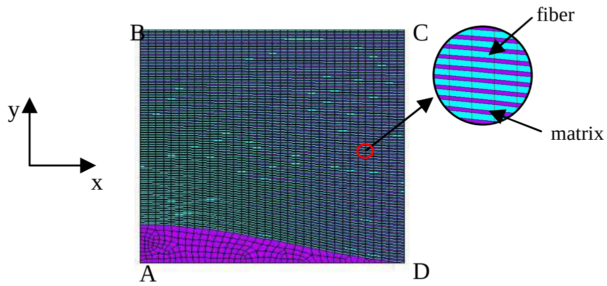

Fig 3. FE mesh of the unit cell (quarter)

as the failure criterion i.e. $\tau_m^{\max} = \tau_Y$.

The finite element model is established for the same Z-pin composite analyzed by the theoretical model, Figure 3. The matrix is simulated as a nonlinear isotropic material for which the constitutive relationship is taken as a J2 incremental theory of plasticity. Using the Arc-length method supplied by ANSYS the reaction force at left edge can be computed for each increment of displacement. The $\sigma - \varepsilon$ curve can be obtained, showing that the response of Z-pinned composite is an unstable “snap back” after the maximum stress that is taken as the compressive strength.

RESULTS

The T300/914C unidirectional composite laminate with z-pins, which has been tested in [3], is taken as an example to verify the present models. The table shows the compressive strength values of the z-pinned composite, which are predicted by present theoretical models with the linear matrix and the nonlinear matrix and the FEM model with the nonlinear matrix of J_2-plasticity, along with the experimental data and FLASH model prediction. It can be seen that the agreement between predicted value from the present model and test value is acceptable. From the predicted values calculated by different constitutive relationships of matrix we can see shear properties of matrix has a considerable effect on compressive strength. The results indicate clearly that the results with nonlinear shear constitutive relationship of matrix have a better accuracy.

Table: Comparison of test data and predicted values of the z-pinned composite

	Test value [3]	Predicted value			
		Linear matrix	Nonlinear matrix	FEM with nonlinear matrix	FLASH model [3]
T300/914C Compressive strength/MPa	894	992	878	870	887

CONCLUSIONS

A model for prediction of the in-plane compressive strength of z-pinned unidirectional composites has been developed which takes into account the influence of micro-structural changes caused by z-pinning. Predicted results have a good agreement with test data.

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