INVESTIGATION OF THE THREE-DIMENSIONAL MICROMECHANICAL BEHAVIOR OF WOVEN-FABRIC COMPOSITES

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A three-dimensional representative volume-element model is presented to study the micromechanical behavior of woven-fabric composites. The effects of the fiber undulation zone and the fiber braid angle on the elastic modulus of the composites are taken into account in the unit cell. Based on isostrain and isostress assumptions, a standard homogenization procedure is used to calculate the effective elastic properties of woven-fabric composites, and all the final stiffness components are expressed in an explicit form. The results obtained by the model considered agree with published experimental results very well. The relationship between the geometric parameters, such as fiber width, thickness, volume fraction, etc., and the macromechanical behavior of the composites can be obtained by this model.

1. Introduction

In recent years, much attention has been devoted to woven-fabric composite materials. In addition to some common advantages over other composites, such as laminates, filament-wound composites, etc., woven composites offer a potential for increasing the through-thickness strength. However, a disadvantage of woven composites is the difficulty in predicting their elastic properties. In most of the detailed work related to the modeling of the behavior of woven composite materials, the representative volume-element approach is employed. In [1] is developed simplified two-dimensional micromechanics and mesomechanics models in order to predict the elastic behavior of satin woven fabric composites. In [2], the geometric characteristics and elastic constants of a plain-woven fabric composite are examined, and a parametric study is carried out to investigate the effects of various geometric parameters on its elastic properties. In [3] is developed a unit cell with a series of subunit cells, which takes into account the geometric pattern of yarn undulation and the influence of pure resin region on the elastic modulus. Several methods for predicting the elastic properties of woven-fabric composite materials are compared, and a simplified method with a nonlinear stress-strain relation is developed and implemented in ABAQUS as a user subroutine in [4-7]. Based on the theory of thin laminates, an analytical model MESOTEX for predicting the 3D elastic and failure properties of woven fiber composite materials is proposed in [8]. Based on the Timoshenko beam theory, a mathematical model taking into account the out-of-plane fiber waviness is presented in [9]. In [10] is studied the effect of mesh type on the material properties.


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of woven-fabric composites, and is developed a new analytical/numerical model in order to obtain reasonably accurate results with minimum modeling and computational efforts.

Almost all the above-mentioned studies are limited to only one case, where fiber bundles are orthogonal to each other, which they are not in most cases. Therefore, the aim of the present work is to elaborate a computationally efficient three-dimensional micromechanics model for woven composite materials with random-angle interlacing fiber bundles.

2. Micromechanics Model Unit Cell

A general three-dimensional unit-cell model is shown in Fig. 1. The center zone is a fiber bundle, which is surrounded by a matrix material. A detailed simplified model is depicted in Fig. 2a. The unit cell is uniquely characterized by five parameters: $d$, the bundle width; $h$, the bundle thickness; $w$, the spacing between two fiber bundles; $\beta$, the undulation angle; $\theta$, the braid angle.

Some geometric relations with dimension of the unit cell is seen in Fig. 2b, where the center zone shows a fiber bundle. The volume of the fiber bundle and of the whole unit cell can be expressed as follows:

$$
Volume_f = \frac{dh(d + 2w)}{2\sin 2\theta \cos \beta} \quad Volume_{cell} = \frac{(d + w)^2 [(d + w) \sin \beta + h \sin 2\theta]}{2 \sin^2 2\theta \cos \beta}
$$

wherefrom for the fiber volume fraction $V_f$, we have

$$
V_f = \frac{dh(d + 2w) \sin 2\theta}{(d + w)^2 [(d + w) \sin \beta + h \sin 2\theta]}
$$

The fiber volume fraction $V_f$ in relation to the braid angle $\theta$ is shown in Fig. 3a. It is seen that $V_f$ is a monotonically increasing function of $\theta$. The fiber volume fraction $V_f$ as a function of $w/d$ is shown in Fig. 3b.

3. Homogenization of One Fourth of the Unit Cell

Assuming that the matrix is isotropic and a perfect interfacial contact exists, we homogenize one fourth of the unit cell in the local coordinate system $123$ and then transform the constitutive matrix obtained to the global coordinate system $xyz$. Mixed boundary conditions — isostrain and isostress assumptions — are adopted at each level of homogenization for the representative volume element.