

Finite Element Analysis of Compression Behavior of Composite Egg-Box Panel with Non-Orthogonal Constitutive Model

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ABSTRACT

In the current study, thermoforming and compression analysis were carried out for the woven composite egg-box panel with the non-orthogonal constitutive material model, which is proposed by Xue et al (Composites: Part A 34 (2003) 183-193). The material model is implemented in commercial engineering software, LS-DYNA, with user subroutine. Xue et al obtained the nonlinear Young's modulus and shear modulus from the experiment test, but the constant Young's modulus and shear modulus for fiber are used in this woven composite egg-panel compression analysis for the convenience. Directional properties in non-orthogonal coordinates are detected using the deformation gradient tensor and the material modulus matrix in local coordinate is updated at each time step.

After the implemented non-orthogonal constitutive model was verified by performing bias extension test, the egg-box panel simulation was performed. The egg-box panel simulation is divided into two categories: thermoforming (draping) and crushing. For thermoforming process, the only die compression effect is considered and the temperature effect is ignored in this study. The finite

element model for compression test can be obtained using the displacement result of thermoforming process. Isotropic transverse shear modulus is assumed for the compression simulation. The results from simulation are compared with the experimental tests and also compared with the result using the isotropic material model in order to help understanding the directional property.

INTRODUCTION

The crashworthy characteristic of a structure becomes crucial in automobile as well as civil industries. Nowadays, composite egg-box panel as well as foam employed sandwich structure is focused on due to its remarkable improvement of impact resistance and energy absorption. Several researches [22][23] associated with experimental study of egg-box panel were carried out concerning mechanical behavior, analytical modeling, application and fabrication. However its numerical simulation was rarely tried due to its non-orthogonal directional property between weft and warp yarn, which affects the mechanical behavior after thermoforming.

The numerical model for woven fabric composite can be divided into two categories: one is the geometric model and the other is material constitutive model for finite element method. The pin-jointed-net method [2][3][9] is one of the popular geometric numerical methods to represent the directional property of the woven fabric type composite. In this method, truss structure is used to describe the woven fabric composite of yarns and translational spring is added to describe its stiffness for tension and shear behavior, but it is not easy to use and hard to consider the complicated condition. Nowadays the development of the constitutive material model of the woven fabric type composite for finite element model becomes more important because of the convenience to simulate forming process or impact test with commercial engineering software. Mostly the unit cell technique, which specifies local material property in unit cell (one element) and assumes homogeneous characteristic, is used.

Most of numerical model in woven fabric composite is started from the research of shear characteristics of woven material through bias extension and picture frame test [1][4-7][11][18-19]. Then numerical shell element and three dimensional material model for woven fabric composite is developed and compared with those tests [8][10][12][14][20-21]. However, there are still problem to use by other users. Xue and Peng [15-17] developed very efficient numerical material model for woven fabric composite and proved it by various examples. In this research, this non-orthogonal material model is used for egg-panel simulation [13] with simple assumption for transverse shear modulus.

In this paper, first, non-orthogonal material model is introduced briefly and then numerical simulation for bias extension test is discussed. Then, manufacturing process of the egg-panel is described. Finally, numerical examples for draping and compression tests of egg-panel are provided and compared with experimental result.

NON-ORTHOGONAL MATERIAL MODEL

In this study, non-orthogonal material model, which is developed by Peng et al [15], is used. Non-orthogonal material model can be traced the rotation of fiber yarns in woven composite as shown in Fig. 1.

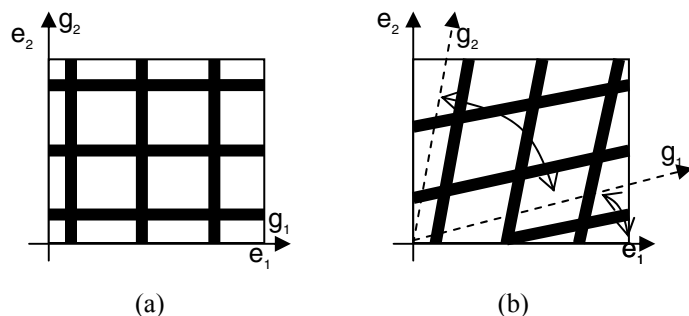


Fig. 1. Fiber coordinates during shear deformation in woven material. (a) before deformation, (b) after deformation

During deformation, material coordinates of fiber g_1 and g_2 are rotated having rotation angles of α and β measured from local coordinate vector e_1 and e_2 . With two rotation angles, the following relationship between material coordinate and local coordinate can be constructed.

$$\begin{Bmatrix} g_1 \\ g_2 \end{Bmatrix} = \begin{bmatrix} \cos(\alpha) & \sin(\alpha) \\ \cos(\alpha + \beta) & \sin(\alpha + \beta) \end{bmatrix} \begin{Bmatrix} e_1 \\ e_2 \end{Bmatrix} = \mathbf{P} \begin{Bmatrix} e_1 \\ e_2 \end{Bmatrix} \quad (1)$$

Reminding of continuum mechanics, the above relationship is the same as that of the contravariant coordinate and Cartesian coordinate [15]. With the above relationship the following transformation can be made for strain in both coordinates.

$$\epsilon'_{ij} = P_i^m P_j^n \epsilon_{mn} \quad (2)$$

where

ϵ'_{ij} : strain component in contravariant coordinate (g_i)

ϵ_{ij} : strain component in cartesian coordinate (e_i)

And each step the contravariant coordinate is updated using the deformation gradient tensor F as the following.

$$g^n = F \cdot g^{n-1} \quad (3)$$

where n is current step and $n-1$ is last step.

Then, in-plane stress components can be derived using the above equations as the following. The detail derivation can be found in the reference [15].

$$\begin{Bmatrix} \sigma_{11} \\ \sigma_{22} \\ \sigma_{12} \end{Bmatrix} = \begin{bmatrix} \cos^2 \alpha & \cos^2(\alpha + \beta) & 2 \cos \alpha \sin(\alpha + \beta) \\ \sin^2 \alpha & \sin^2(\alpha + \beta) & 2 \sin \alpha \cos(\alpha + \beta) \\ \sin \alpha \cos \alpha & \sin(\alpha + \beta) \cos(\alpha + \beta) & \sin(2\alpha + \beta) \end{bmatrix} \begin{Bmatrix} \sigma'_{11} \\ \sigma'_{22} \\ \sigma'_{12} \end{Bmatrix}$$

$$\Leftrightarrow \sigma = \mathbf{T}^T \sigma' \quad (4)$$

$$\therefore \sigma = \mathbf{D} \epsilon = \mathbf{T}^T \mathbf{D}' \mathbf{T} \epsilon \quad (5)$$

In this research, LS-DYNA is used for the implementation of non-orthogonal material model with user subroutine, urmat41.