3D FINITE ELEMENT ANALYSIS OF PLAIN WOVEN SINGLE-PLY E-GLASS/EPOXY

Ömer Soykasap and Şükrü Karakaya

Afyon Kocatepe University, Faculty of Technical Education, Afyonkarahisar, 03200, Turkey

Introduction

Woven composites of symmetric and balanced material with few layers are frequently used in aerospace structures. Determining the material characteristics of these structures is of importance for safe and functional designs. In order to determine material characteristics, several micromechanical models have been developed so far [1-3]. According to the experiments on carbon fiber and polymer-matrix woven composites [4], bending stiffness and strain values calculated by classical lamination theory (CLT) show great differences. The reason for that is CLT assumes that fibers and matrix are uniformly distributed within the layer and uses these characteristics in the calculation of macro-mechanical characteristics.

In this paper, finite element (FE) method is used to analyze the tensile and bending properties of prepreg E-glass/epoxy. Transverse and longitudinal fibers of the plain woven composite are modeled by three-dimensional (3D) FE. Elastic modulus, Poisson's ratio, bending stiffness, and critical bending radius are obtained, and compared with 1D FE results.

3D Finite Element Modeling

In plain-woven composites, transverse and longitudinal fibers are woven by passing over and under each other (see Fig. 1). For micromechanical model, the section form, thickness and sinusoidal waveform of the fibers are determined from micrographs of woven E-glass/epoxy. The fibers have a period of L=1.70 mm, a total thickness of the ply is t=0.2 mm, and amplitude of the fibers is $h=t/4$.

Resin infiltrated warp and weft fibers (yarn) are modeled in Abaqus [5] by using a sine curve as $y = h\sin\left(2\pi x / L\right)$, where x and y longitudinal and thickness directions, respectively, measured from the mid plane of the yarn. The cross section of the yarns has a lenticular section formed by the sine curve. Then 3D yarns are generated by sweeping the cross section along the sine curve. Material properties of the yarns are based on the typical properties of the fiber, resin and fiber volume fraction; and calculated using the equations in ref. [4] as follows: E_1^y = 39.25 GPa, E_2^y=14.23 GPa, G_{12}^y=4.2 GPa, ν_{12}^y=0.3, ν_{21}^y=0.108.

The warp and weft yarns are tied to each other where they pass over each other using surface-to-surface tie constraint. The relative motion of the yarns with respect to each other is prevented via constraints; hence connecting task of the resin is realized by providing load transfer with this tie (see Fig. 2).

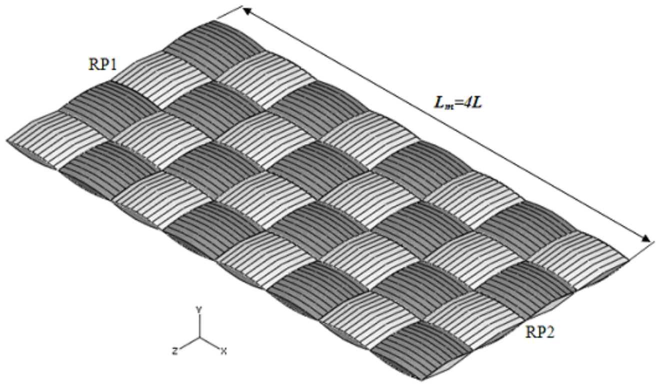

Fig.1 3D FE model of single-ply woven composite (4×8 units)

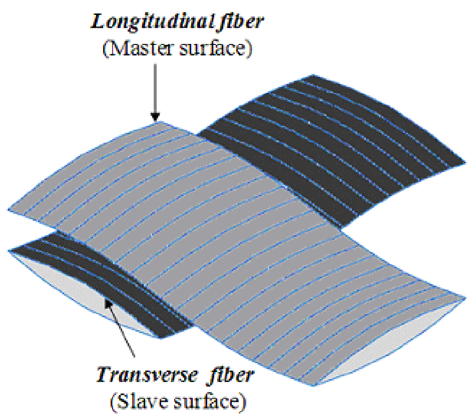

Fig.2 Surface to surface tie constraint.

The model is meshed using tetrahedral elements, C3D4, with an element size of 0.1 mm. Stiffnesses of the ply are obtained by considering the macro behavior of the material through elongations and rotations, which are applied at the ends of the model. For this purpose, both ends of the model are tied to reference points RN1 and RN2, which are defined in the middle of the layer by using multi-point constraints (see Fig. 1). Displacements and rotations are applied to these reference points, hence a nonlinear static analysis is carried out.. To determine the in-plain characteristics, one end of the model is fixed and the other end is subject to prescribed in-plane displacements. Taking into account the reactions to occur on the reference points, the elastic modulus of the model is obtained from the slope of the stress-strain curve. In bending analyses, the reference points are applied equal rotations in opposite directions. The response of the model is used to find bending stiffness. In bending analysis, an average curvature is obtained by analyzing the deformation of the structure at each step. Moments corresponding to these curvatures are found from the reference points.

Results and Discussion

The results are obtained for the 3D model and compared with 1D model that uses beam elements for the yarns [4]. Stress-strain curve of the material is given in Fig. 3 along with 1D FE results. Elastic moduli of 1D and 3D models (4×8 units) are 17.2 GPa and 19.1 GPa, respectively. Next, the effect of model size on the elastic modulus is also analyzed. The slopes of the graphs with 4×4 and 4×8 models are approximately the same. For Poisson's ratio, the longitudinal and transverse strains are considered for the section at $L_m/2$. Poisson's ratios of 3D models with 4×4 and 4×8 units are 0.156 and 0.168, respectively. It is observed that 1D model has a greater Poisson's ratio of 0.279 than that of 3D model. Experiments yield an elastic modulus of 18.2 GPa, and a Poisson's ratio of 0.18; which are in agreement with 3D FE results.

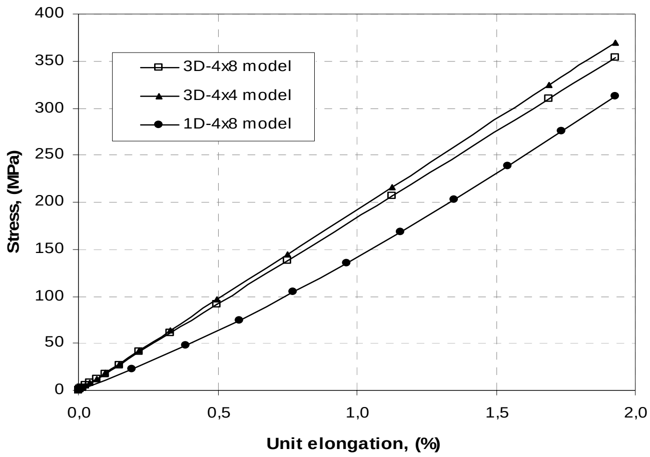

Fig.3 Stress-strain curve of 3D and 1D FE models.

For bending analysis, moment per unit width M_x versus curvature is obtained as given in Fig.4, in which bending stiffness D_{11} is obtained from the slope. It is observed that bending stiffness of the 3D model is approximately 50% larger than that of 1D model. The critical bend radius R_{min} at failure is also obtained from the longitudinal strain-curvature curve. Taking ultimate strain of 1.93% obtained from tensile test, R_{min} of 1D and 3D models is attained as 3.25 mm, and 2.33, respectively. It is observed that R_{min} value of 3D model is less than that of 1D model, but it is closer to test data R_{min} =2.43 mm.

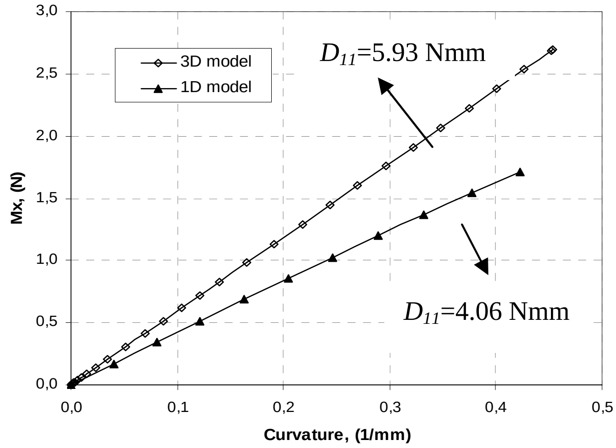

Fig.4 Comparison of bending stiffness values of 3D and 1D models with 4×8 units.

Conclusion

Single-ply woven material is analyzed by 3D finite element analyses. The elastic modulus, Poisson's ratio, bending stiffness and bend radius at failure are obtained by the models. The results are compared with 1D model and test data. The results of 3D finite element model are more consistent with the test data. The function of the resin is not fully represented in the 1D finite element model. However, the warp and weft fibers are tied to each other in 3D finite element model and their relative motions with respect to each other are limited by surface-to-surface tie constraints. Hence the results of 3D finite element model are superior.

Acknowledgement

The research reported herein is supported by Scientific and Technological Research Council of Turkey under grant 109M421; and Scientific Research Fund of Afyon Kocatepe University under grant 08TEF07.

References

1. Naik. R.A. Analysis of Woven and Braided Fabric Reinforced Composites. NASA CR 194930 (1994).
2. Fujita A., Hamda H. and Maekawa Z. Tensile Properties of Triaxial Woven Fabric Composites. *J Compos Mater*, **27** (1992) 1428 - 1442.
3. Page B.H.L., Guild F.J., Ogin S.L. Smith P.A. Finite Element Simulation of Woven Fabric Composites. *Compos Part A-Appl S*, **35** (2004) 861 - 872
4. Soykasap O. Micromechanical Models for bending Behavior of Woven Composites, *J Spacecraft and Rockets*, **43** (2006) 1093-1100.
5. "*ABAQUS/Standard User's Manual*", Version 6.7, ABAQUS Inc., RI, (2007).