NUMERICAL SIMULATION OF TRIAXIAL WOVEN CFRP UNDER TENSILE LOADING

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Abstract

This paper discusses strain localization in triaxial woven CFRP under a tensile loading. Numerical result calculated by periodic unit cell simulation is compared with experimental result evaluated using digital image correlation (DIC) technique. In the numerical simulation, a straight-type fiber bundle composite is first modeled and is cut into appropriate shape to compose the unit cell. A contact analysis is then executed to make woven and the contacted area is attached each other following cohesive behavior. Uniaxial global tensile strain is applied to the unit cell at last. For the experiment, black and white random pattern is attached on the surface of triaxial woven CFRP and a full field strain measurement is carried out by DIC method. For the evaluation of full-field displacement and strain, a mesh DIC and shape-function strain calculation are employed, respectively. The strain distribution obtained by this method is hence slightly broader than the actual one but comparable enough to the analytical result. Whereas the analysis is very simple and done by only ABAQUS, the experimental and analytical results show good agreement. It is clarified that intersection point of 30° and -30° fiber bundle has the most significant tensile-directional local strain.

1. Introduction

Triaxial woven CFRP has been widely used in this dicade due to its unique characteristics such as thin, light, flexible and behaving like membrane [1]. In the aerospace field, the triaxial woven CFRP is about to be used for a material of extensible antenna in satellite [2]. However, mechanical properties of triaxial woven CFRP has not been understood because of several reasons, e.g. stress-strain (load-displacement) relationship is complicated because this is affected by hardening involving “scissoring effect”. Mesoscopic strain localization is also a key factor for discussing material strength [1]. Numerical modeling for this material is indispensable for future spreading applications.

The purpose of this study is to model numerically the triaxial woven CFRP. RVE (relative volume element) modeling is effective for such a material having periodic structure [3]. The present study prepare at first fiber bundle composite model and assemble them to make periodic unit cell by contact analysis using finite element analysis (ABAQUS 6.14). In order to make adhesive between the fiber bundles, cohesive behavior is defined there. For a periodic boundary condition, displacements of

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corresponding nodes are related by displacement of dummy node. A global strain is controlled by the displacement of dummy node. The analytical results are compared with experimental results [1] in terms of strain distribution.

2. Analytical Procedure

2.1. Unit cell modeling

Figure 1 illustrates how to make the triaxial woven CFRP model from a fiber bundle model. We made two types of fiber bundle models and assemble them as shown in Fig. 1 which also indicates geometry and dimensions of the fiber bundle models. The six fiber bundles are placed on the same plane and contact analysis is done in order to make triaxial woven CFRP. Table 1 shows mechanical proeprties for the bundle composite. In order to bond fiber bundles each other, cohesive behavior [3] is introduced for the contact region. In the present study, the bonding is assumed to be strong enough in terms of both of strength and toughness so that inter-bundle debonding does not occur. It should be noted that stresses and straines occurred by the contact analysis are removed, i.e. as stress and strain free condition, before appling tensile loading.

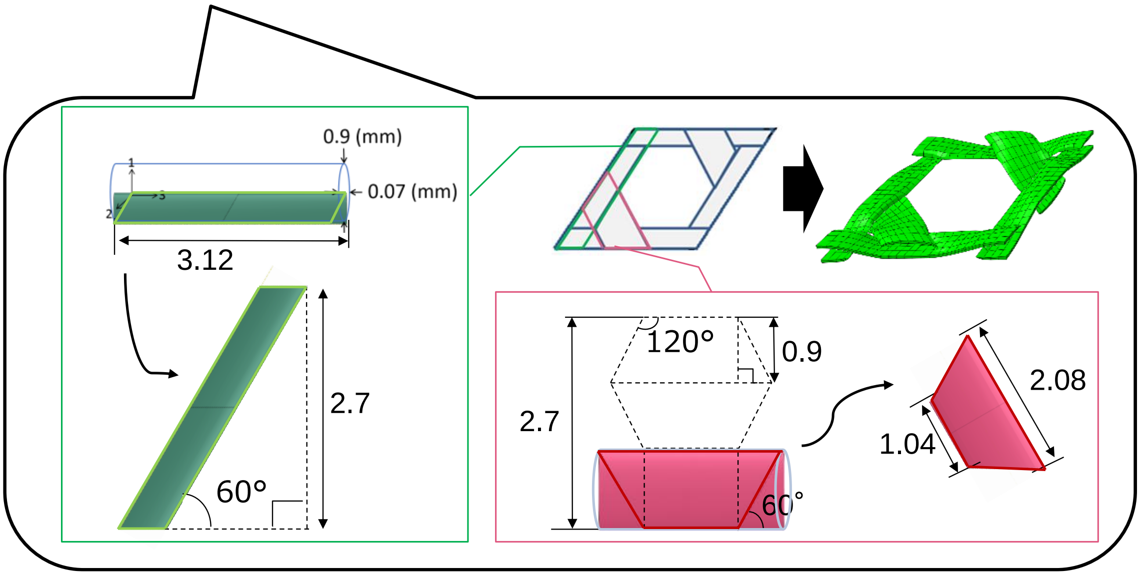

Fig. 1 Making procedure of triaxial woven CFRP from fiber bundle model

Table.1 Mechanical properties

E_1 (MPa)	115000
E_2 (MPa)	9000
E_3 (MPa)	9000
G_{12} (MPa)	4000
G_{13} (MPa)	4000
G_{23} (MPa)	3000
ν_{12}	0.3
ν_{13}	0.3
ν_{23}	0.4

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2.2 Boundary Conditions

In this section, a way used in the present study for boundary condtion is described. This method is reffered as dummy node method here. As shown in Fig. 2, let us assume node A and corresponding pair node B for periodic boundary condition and dummy node C.

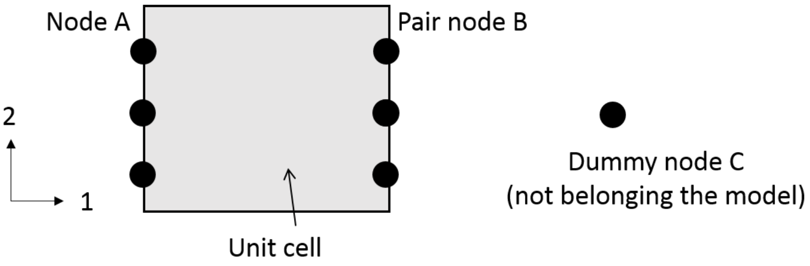

Fig. 2 Dummy node method

Following constraint equation is applied to displacement for the three nodes.

$$\mathbf{u}_A - \mathbf{u}_B + \mathbf{u}_C = \mathbf{0} \qquad (1)$$

Here, **u** is displacement vector. This equation is applied to each node pair for periodically so that the global strain of *x* direction can be determined by the displacement of $\mathbf{u}_{cx}$. As shown in Fig. 3, there are two periodic pairs so that it is neccesarry two dummy node: one is intended for 1-1 edge and 1-2 edge, another is intended for 2-1 edge and 2-2 dege. The displacements of dummy nodes are difined as $\mathbf{u}_{d1}$ and $\mathbf{u}_{d2}$ in this study.

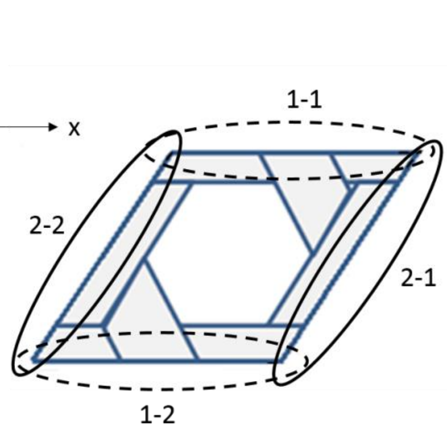

Fig. 3 Pair of periodic boundary conditions for unit cell

This study gives following displacement for dummy nodes.

$$\mathbf{u}_{d1} = \begin{pmatrix} free \\ 0.027 \\ 0 \end{pmatrix} \qquad (2)$$

$$\mathbf{u}_{d2} = \begin{pmatrix} free \\ free \\ 0 \end{pmatrix} \qquad (3)$$

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The number of 0.027 in the equation (2) can make the global strain 1% for the comparison with experimental condition. “free” in equation (2) means this unit cell is allowed to have global shear deformation. Also by equation (3), the unit cell can have transverse global strain with the condition that transverse nodal force is totally balanced, which means natural Poisson’s contruction, and another global shear deformation can be allowed, also. Thus, pure uniaxial tensile loading has been simulated.

3. Results and Conclusion

Figure 4 compares strain 11 distributions obtained experimentally and numerically. As shown in this comparison, the numerical result is very similar to experimental result. This study concludes here the numerical modeling for triaxial woven CFRP is accomplished well.

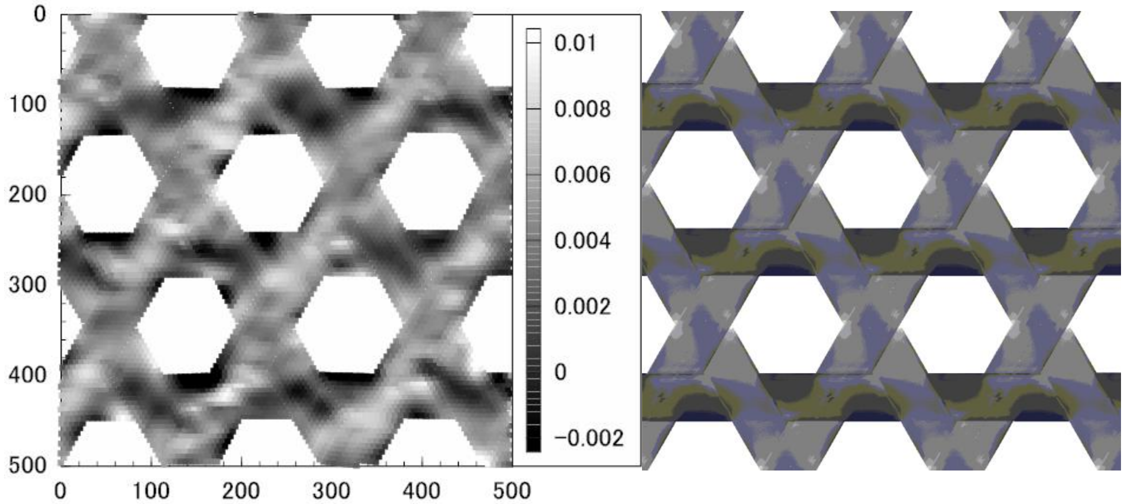

Fig. 4 Comparison of experimental result (left) and numerical result (right) in strain 11 distribution.

Acknowledgments

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