MULTI-SCALE MODELING AND ESTIMATION OF DAMAGE DEVELOPMENT FOR TEXTILE COMPOSITES CONSIDERING MESO/MICRO SCALE STRUCTURES

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Abstract

For an evaluation of mechanical property of textile composites with several design parameters, FEM is one of effective methods in order to reduce the development times and the costs. In this study, an individual modeling method for meso-scale structure of textile composites has been developed. The mechanical behaviors of textile composites have been estimated with the mesh superposition method which is one of the multi-scale analytical methods of FEM. In the individual modeling, two types of numerical models composed of a global model and local model were generated. In the case of woven composites, the global model means the matrix parts, and the local model is the fabric parts. The proposed method applied to 3D woven composites, and the damage development under static on-axis loading has been investigated.

1. Introduction

3D Textile composites have been studied for many years in replacement of laminate structures in composite materials. Especially, a stitched textile composite and woven composites are remarkable materials because they have some advantages. Woven fabric composites have been also used in many industrial applications because they have advantages such as easy handling and high lateral strength. The previous research about mechanical characterization of woven fabric composites established theoretical and experimental investigations, which were based on mechanical behavior at macro scale which means "composite part scale" [1-3]. In order to evaluate fiber cracking, resin failure, delamination which relate to meso and micro scale structures, the recent studies have tried to generate more detailed FE models based on meso scale which means "fiber geometric scale" and micro scale which means "filament scale" [4].

However, woven composites have many design parameters such as volume fraction of fiber, architecture of reinforced fibers, matrix properties, etc. Furthermore, it is very difficult to evaluate the mechanical behaviors because of the complicated geometrical shape.

For an evaluation of mechanical property of textile composites with several parameters, FEM is one of effective methods in order to reduce the development times and the costs. Therefore, the purpose of this study is to establish an estimation procedure of mechanical characterization for woven composites based on multi-scale analysis.

In this study, individual modeling method for meso-scale structure of textile composites has been developed. Furthermore, the mechanical behaviors of textile composites have been estimated with the mesh superposition method which is one of the multi-scale analytical methods of FEM. In the individual modeling, two types of numerical models composed of a global model and local model were generated. In the case of woven composites, the global model means the matrix parts, and the local model is the fabric parts. The proposed method applied to woven composites, and the damage development under static on-axis loading has been investigated.

2. Numerical modeling

2.1. Conventional mesh superposition method

Figure 1 shows the scheme of the structure analysis of woven composites by the proposed method. The geometrical data of NCF is generated by WiseTex software, which has been developed by Lomov S. V. et. al.
Since the geometry of woven composites is complex, it is not easy to generate FE models integrally. Therefore, woven parts and resin parts are modeled individually. In order to consider the interaction of each part, the mesh superposition method is applied to the FE analysis.
In the mesh superposition method, woven model is defined as local mesh, and resin model is treated as the global mesh. Analytical area is divided into global area ($\Omega^G = \Omega \backslash \Omega^L$) and local area ($\Omega^L$) as shown in Fig.1. Ω^G is the area where only global mesh exists, and Ω^L is the area determined both global mesh and local mesh. The boundary between two meshes is defined as Γ^{GL}, and surface forces affect not Γ^{GL} but only the external boundary (Γ^S), because Ω^L is perfectly inside Ω^G. On those assumptions, the stiffness equation is represented as shown in Eq.(1).

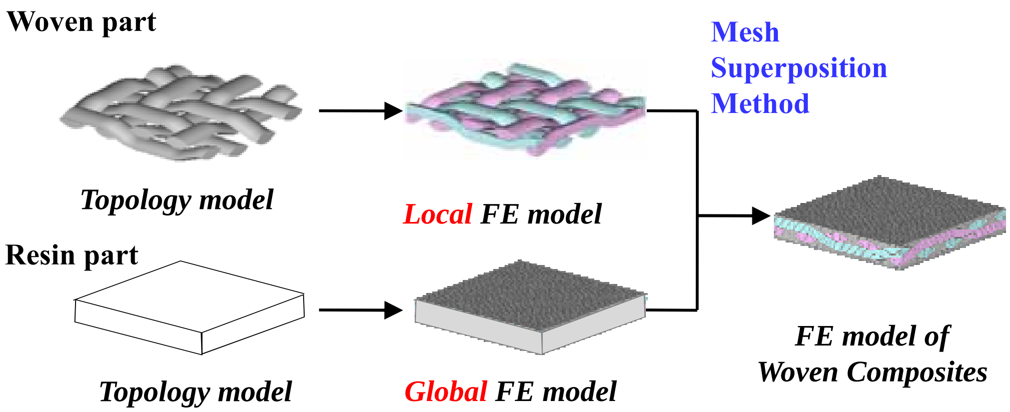

Figure 1. Scheme of numerical modeling for NCF composites.

$$\begin{bmatrix} [K^G] & [K^{GL}] \\ [K^{LG}] & [K^L] \end{bmatrix} \begin{Bmatrix} \{d^G\} \\ \{d^L\} \end{Bmatrix} = \begin{Bmatrix} \{F^S\} \\ \{0\} \end{Bmatrix}. \tag{1}$$

Each argument in Eq.(1) is indicated with the following equations.

$$\left.\begin{aligned}
&[K^G] = \int_{\Omega^G} [B^G]^T [D^G][B^G] d\Omega \\
&\qquad + \int_{\Omega^L} [B^G]^T [D^L][B^G] d\Omega \\
&[K^L] = \int_{\Omega^L} [B^L]^T [D^L][B^L] d\Omega \\
&[K^{GL}] = \int_{\Omega^L} [B^G]^T [D^L][B^L] d\Omega \\
&[K^{LG}] = \int_{\Omega^L} [B^L]^T [D^L][B^G] d\Omega = [K^{GL}]^T \\
&[F^S] = \int_{\Gamma^S} [N^G]^T \{t\} d\Gamma.
\end{aligned}\right\} \tag{2}$$

Where, [N] and {d} have been shape function matrix and displacement respectively, and suffix G and L have represented the domain of global and local. [B] is strain-displacement matrix, and [D] is stress-strain matrix.
This method has some advantages. The local-mesh can be superimposed on a macro-mesh without considering the matching of boundary for each mesh.

2.2 Individual modeling of meso-scale structure

In order to estimate the mechanical behaviors of 3D woven composites, an individual modeling method of fiber bundles is proposed, and the conventional mesh superposition method is improved based on the proposed individual method.
Figure 2 shows the scheme of individual modeling for 3D woven composites. The yarn parts are separated into 2 models. One is woven fabric as local model (1), and the other is Z-yarn as local model (2). The global model is resin part. The local model (1) and (2) can be superimposed on a global model without considering the matching of boundary for each mesh.

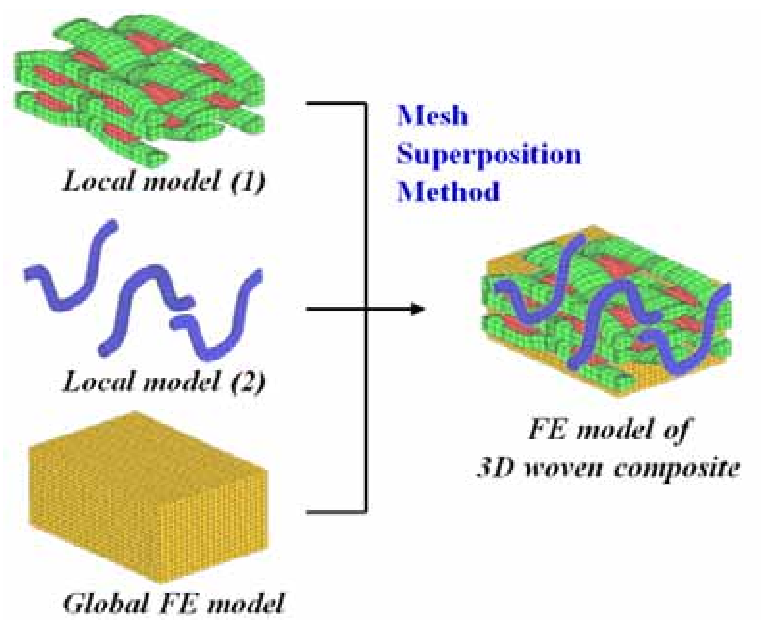

Figure 2. Scheme of numerical modeling for 3D woven composites.

The stiffness equation is improved as shown in Eq.(3) in order to consider the interaction of local model (1) / global model, and local model (2) / global model.

$$\begin{bmatrix} [K^{G}] & [K^{GL1}] & [K^{GL2}] & \cdots & [K^{GLn}] \\ [K^{L1G}] & [K^{L1}] & [0] & \cdots & \vdots \\ [K^{L2G}] & [0] & [K^{L2}] & \cdots & \vdots \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ [K^{LnG}] & \cdots & \cdots & \cdots & [K^{Ln}] \end{bmatrix} \begin{Bmatrix} \{d^{G}\} \\ \{d^{L1}\} \\ \{d^{L2}\} \\ \vdots \\ \{d^{Ln}\} \end{Bmatrix} = \begin{Bmatrix} \{F^{G}\} \\ \{0\} \\ \{0\} \\ \vdots \\ \{0\} \end{Bmatrix} \tag{3}$$

2.3 Numerical example

In order to investigate the accuracy of mechanical characteristics based on the proposed individual modeling, the simplified models are generated as shown in Figure 3. In the individual model, the local models is independently divided into warp yarn and weft yarn. The global model means the resin parts. The models are generated with hexahedral elements. As the comparison, the conventional model without super position method is also prepared as the name of 'continuous model'. The kind of material is E-glass fiber / vinylester composites. Figure 4 shows the numerical results of strain (x direction) with individual model and continuous model. As the results, the proposed individual method has same tendency with the conventional continuous model.

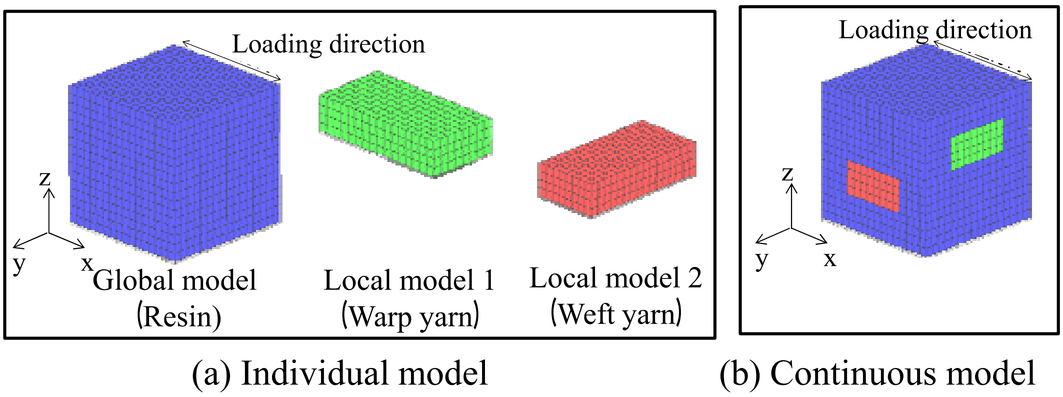

Figure 3. Simplified model of fiber and resin.

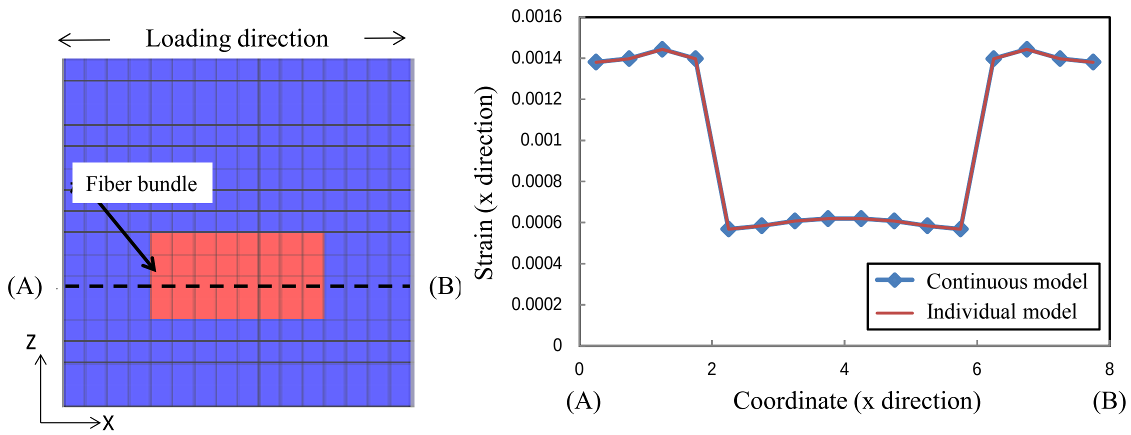

Figure 4. Numerical result of strain (x-direction).

3. Numerical results of 3D woven composites

3.1. Numerical model

Figure 5 shows numerical models of 3D woven composites. In the individual model, the local models is independently divided into woven fabric parts and Z yarn. The global model means the resin parts. As the comparison, the continuous model without super position method is also prepared. The kind of material is E-glass fiber / vinylester composites.
In the simulation, the modeling of damage is very important. woven composites are treated as heterogeneous bodies with anisotropy for fiber bundles and with isotropy for matrix, respectively. The isotropic damage model is applied for matrix, and anisotropic damage model is applied for the fiber bundle, respectively [5]. The occurrence of damage can be predicted by Hoffman's criterion.

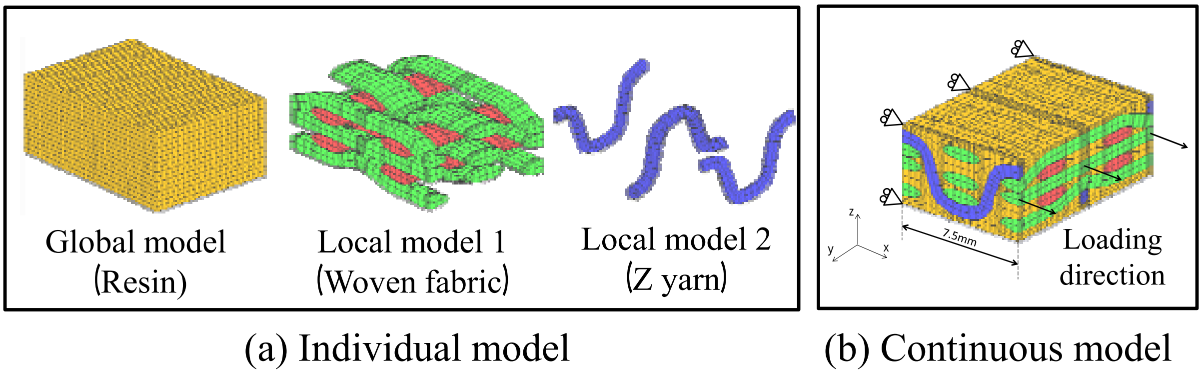

Figure 5. Numerical model of 3D woven composite.

3.2. Numerical results

Figure 6 shows the numerical results of stress in the fabric parts perpendicular to the fiber direction. In order to make the stress distribution clarify, the only fabric parts are illustrated. The stress distribution of z-yarn are shown in Figure 7. The stress along to fiber direction is illustrated. As the results, there are good agreement of stress distribution with the proposed individual model and the continuous model.

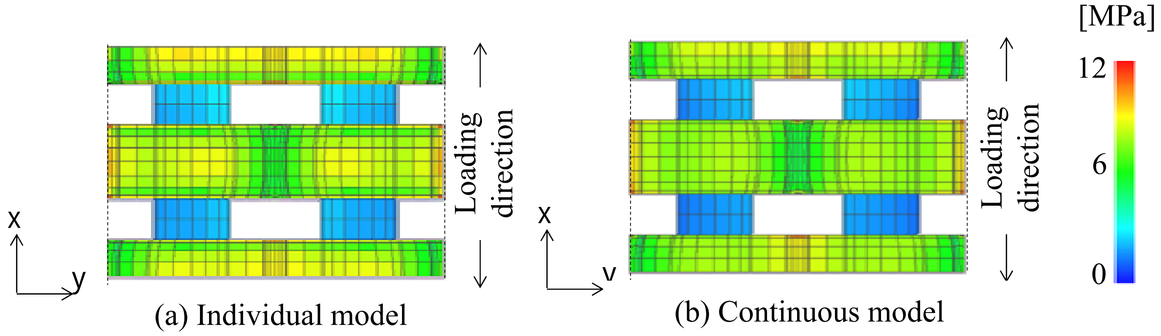

Figure 6. Stress distribution of woven parts.

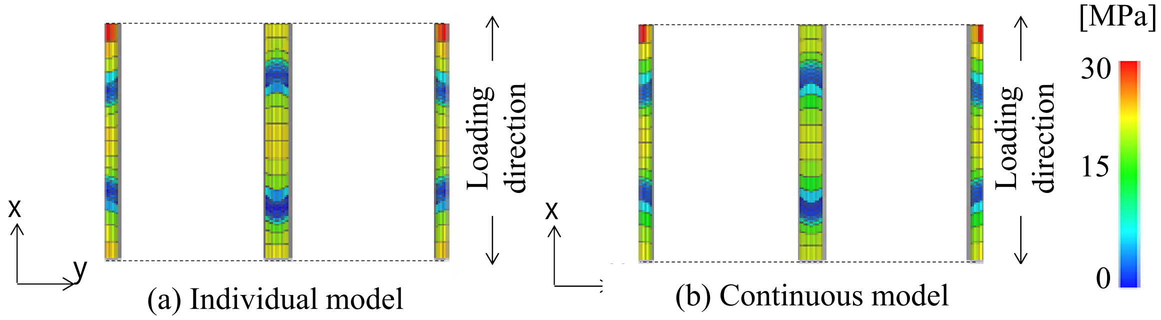

Figure 7. Stress distribution of z-yarn parts.

Figure 8 shows the numerical results of damage state ($\varepsilon = 1.0\%$). The initial damage appears in weft yarn as transverse cracks. The black element means the damage judged by the Hoffman's criterion.
As the comparison with individual model and continuous model, the damages developed in the edge region of weft yarn. From these results, the tendency of damage development is almost same with the individual model and continuous model.

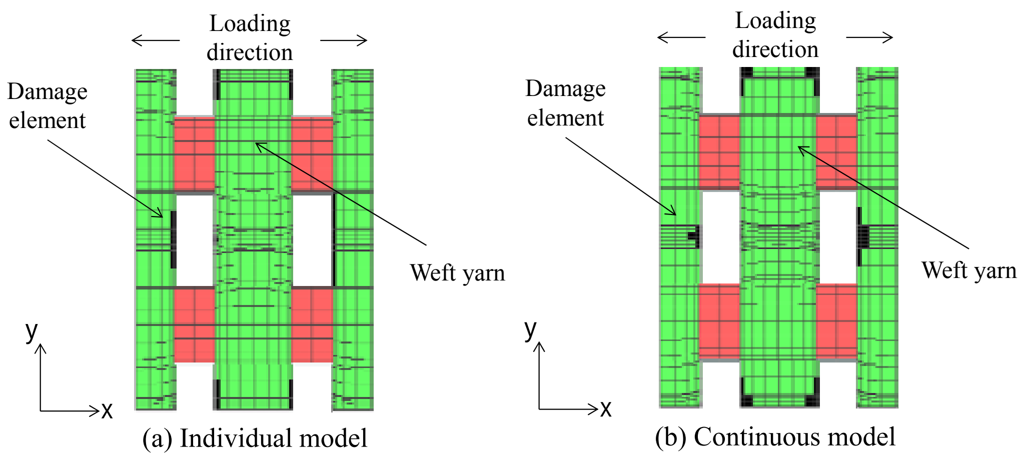

Figure 8. Initial damage of weft yarn parts.

4. Summary

For evaluation of mechanical properties of textile composites, FE modeling method based on mesh superposition method has been developed. The geometrical data are determined by WiseTex, and FE models were generated by the individual modeling method. As the individual modeling method of fiber bundles, the conventional mesh superposition method is improved in order to estimate the mechanical behaviors of 3D woven composites.
In the case of simplified numerical model, the proposed individual method has same tendency with the conventional continuous model.
Furthermore the proposed method was applied to the 3D woven composites. As the results, the stress distribution of fabric parts and z-yarn parts have same tendency with the proposed model and conventional model. The tendency of damage development is almost same with the both models.
It is recognized that the proposed mesh superposition method is very convenient for the estimation of mechanical behaviors of textile composites.

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