A PROPOSAL OF FE MODELING FOR OFF-AXIS WOVEN FABRIC LAMINATE

Y. FUJITA¹, Y. WATANABE¹, T. KURASHIKI², M. ZAKO²
1. Graduate Student of Osaka University, 565-0861, Suita, Japan
2. Department of Management of Industry and Technology, Osaka University, 565-0861, Suita, Japan
y-fujita@mit.eng.osaka-u.ac.jp

SUMMARY

Numerical analysis for off-axis woven fabric laminate has been carried out based on M³ method, which is one of the mesh superposition methods. The mechanical behaviors for the laminate plate with arbitrary laminate angle can be carried out. As an example, the numerical result of FE analysis of [0/45] laminate has been described.

Keywords: off-axis, mesh superposition method, woven fabric composite

1. INTRODUCTION

Finite element method has been widely used to estimate the mechanical behaviors of woven fabric composites [1]. As the finite element modeling for a complicated three dimensional structures has been difficult, the FE modeling software such as MeshTex has been developed [2]. Fig.1 (a) shows the woven fabric composites generated by MeshTex.

FE analyses of woven fabric composites with on-axis lamination have been conducted [3]. In the studies, unit cells with periodic boundary conditions have been used to simulate the micro or meso behaviors on the macroscopic loading. However, the effect of the mismatch of layup in woven fabric laminates on the mechanical behaviors had not been considered completely. Most of the woven fabric composites used for structures has the mismatch of periodic woven architecture when they are laid up. It is important to characterize the effect of the mismatch of layup on the initial damage stresses of woven fabric composite, stresses between the fiber bundles and those of among fiber bundles. And if we could estimate them, it is enable to design woven fabric laminate with most appropriate lay-up considering the micro behaviors. In this paper,
woven fabric laminates with a mismatch of rotation of layup such as shown in Fig.1(b) are called as off-axis woven fabric composites. The aim of this study is to develop the procedure of the FE analysis for off-axis woven fabric composites and characterize the mechanical behaviors based on the mesh superposition method.

2. PROPOSED METHOD

The mesh generation of off-axis woven fabric composites has been very difficult because of the mismatch of nodal points between laminates. Even if the model could have been generated, it is very difficult to apply proper boundary conditions because the model doesn’t have periodic structure. To avoid those problems, the mesh superposition method has been applied.

Fig.2 Superimposed FE model of off-axis woven laminate [0/45]

The mesh superposition method has been developed [4], which is one of the multi scale analytical methods. It is also applied to the mesh superposition with two model in same scale such as FE model of NCF composites [5]. The M³ method [6], which is the
mesh superposition method with three scale model, meso-macro-micro or
global-meso-local has also proposed. Fig.3 shows the concept of M$^3$ method. As shown
in Fig.2, we have generated FE models with a homogenized off-axis woven fabric laminate as the global model, only matrix part as meso model and the fiber bundle as local model. The boundary conditions have applied to the global model. The meso model and local model have same scale, and fiber bundles in resin matrix can be simulated.

3. VERIFICATION

3.1 Procedure for verification and FE models

Before the proposed method has been applied for off-axis woven fabric composites, it is important to verify the accuracy of the proposed method because the results of analysis may have error caused by boundary conditions and mesh size in mesh superposition method. In order to verify the proposed method, numerical result by M$^3$ method has been compared with one by full model with periodic boundary conditions (Fig.4(a)) and with one by the mesh superposition method using homogenous model as global model and woven fabric model as local model (Fig.4(b)). The mesh superposition method using global model and local model is expressed as ‘GL method’ for short. Fig.4(c) and 4(d) show FE mesh of M$^3$, the position of superimpose of local mesh to global mesh, and boundary condition, respectively. The numerical results of FE analysis by full model is compared with the experimental results in previous study [2]. It has been demonstrated that full model has a good agreement with experiment.

Fig.4 FE models of [0$_2$] laminate and boundary conditions for verification
The GL method is employed for verification of boundary conditions. M³ method is also employed for the verification of the strain distribution in fiber bundles. Table 1 shows the mechanical properties used for numerical analysis.

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Value</th>
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<tbody>
<tr>
<td>Modulus of elasticity</td>
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<td>Shear modulus</td>
<td>$G$</td>
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<td>Poisson's ratio</td>
<td>$\nu$</td>
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<tr>
<td>Tensile strength</td>
<td>$F$</td>
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<tr>
<td>Compressive strength</td>
<td>$F_c$</td>
<td>120[MPa]</td>
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(a)Polyester resin

(b)Fiber bundle (Volume fraction of fiber=60%)

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<td>Tensile strength</td>
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<td>Compressive strength</td>
<td>$F_{CL}$</td>
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(c)Homogenized woven fabric composite ([0])

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<td>Poisson's ratio</td>
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</table>

3.2 Verification of [0°2] model

Fig.5 shows the numerical result of strain distributions of x direction and F value when applied strain is 0.1%. F value is calculated by Hoffman’s criterion [2]. If F value is larger than 1, the element will be damaged. Fig.6 shows the strain distribution of x direction and F value in a fiber bundle.
It is recognized from Fig.6 that the numerical results of GL method is closer to ones of full model and the difference between M$^3$ method and full model is a little. It means that the superposition method can apply to both the model with different scale and same scale. The differences of strain and F value distribution are no less than 3%.

4. NUMERICAL RESULT OF OFF-AXIS LAMINATE

As an application of M$^3$ method, it has been applied for FE analyses of [45$_2$] and [0/45] woven fabric laminates.

4.1 [45$_2$] model

M$^3$ method and GL method are employed to analyze the mechanical behavior of [45$_2$] woven laminate under off-axis loading. Fig.7 shows the FE models and boundary conditions for the analysis.
Fig. 7 FE models of [45_2] laminate and boundary conditions

Fig. 8 shows the strain distributions of x direction and F value when the applied strain is 0.1%. Fig. 9 shows the strain distribution of x direction and F value in a fiber bundle.

Fig. 8 Distributions of x strain and F value
From these results it reveals that GL method and $M^3$ method give almost same result. The difference will occur because the mesh shape of meso resin model in $M^3$ method is not rectangle. In order to check the global evaluation, the average strains are calculated by Eq.(1)

$$\bar{\varepsilon} = \frac{\sum \varepsilon_i V_e}{\sum V_e} \tag{1}$$

where, $\varepsilon_i$ is strain of each element and $V_e$ is volume of the element. The average strain of local model on GL method is 0.1%, the ones of fiber bundles on GL method is 0.096% and fiber bundles (micro model) of $M^3$ method is 0.097%. The difference of strain between global model and local model is no more than 3%. From the result, the initial crack will occur at the edges of fiber bundle in case of off-axis loading condition.

4.2 [0/45] model

The employed model is shown in Fig.2. The numerical results of the strain distribution and F value are shown in Fig.10. In the figures, 0 layer and 45 layer are separately shown.
From Fig. 10, it is shown that the fiber bundles in transverse direction to loading in [0] layer will be damaged earlier than any other parts. In this method, the element size of meso model is very important to evaluate z strain or z stress considering the each behavior of fiber bundles. In the mesh superposition method, element in the local model must be smaller than that in meso model. In this paper, we can recommend that the mesh size of z axis of meso models is about double the local ones (shown in Fig. 11 represented by [0\_2] model).
5. CONCLUSIONS

1) We proposed M$^3$ method to characterize the micro behavior in the off-axis woven fabric composite.
2) The accuracy of the method is investigated and it is found that there are about 3% between the method and full model analysis.
3) Optimization of mesh size and mesh shape will contribute to improve the accuracy.

References