MICROSTRUCTURAL MODELING OF WOVEN FIBER COMPOSITES

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INTRODUCTION

Three-dimensional woven composites have the potential to be superior to laminates in many areas, including out of plane mechanical properties, damage resistance, and cost-effectiveness in manufacturing. However, the practical use of these materials has been limited by the lack of appropriate tools to predict stress and failure behavior of woven composite components accurately.

In this work, we present a multi-scale modeling strategy in which the unit cell geometry is used to both quantify average macroscopic material properties as well as to estimate local stresses within composite components.

METHODS

The overall goal of this work is to develop a model for estimating the local stress distribution within woven composite components (i.e., fiber vs. matrix stress) in an accurate and efficient manner. In general, the model consists of two steps (1) estimation of effective material properties and (2) multi-scale modeling of local stress distribution.

Effective Material Properties

Finite element modeling is used to estimate the effective material properties of the composite. A geometric model and finite element mesh of the unit cell is generated and subjected to numerical tension and shear tests. Results of these simulations were used to deduce effective orthotropic material coefficients. In the results presented here, a five-harness satin architecture was used.

Multi-scale Modeling

For this work, an angle bracket was used as the component to be modeled. This was chosen as a relatively simple geometry that would still lead to a non-trivial stress distribution. Once the average properties were determined, a finite element mesh of the component was generated (Figure 1; below). Note that a 2-dimensional view is shown for simplicity.

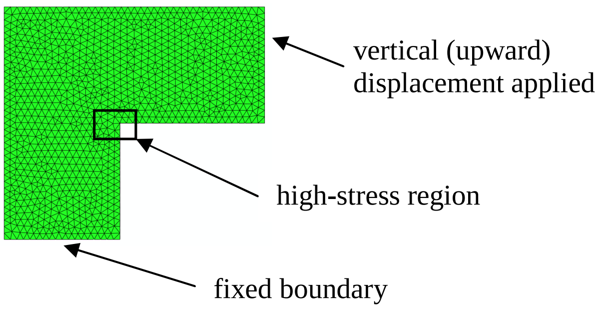

Figure 1: Geometry used for component simulation.

This mesh for this component is coarse when compared to the unit cell model, but of sufficient resolution to accurately capture component-level geometric features. The effective material properties were assigned based on the average properties previously determined. The boundary conditions indicated in Figure 1 were then applied to this model to simulate the average stress distribution, where average refers to the stress distribution computed assuming a homogeneous the material.

High stress regions, such as indicated in Figure 1 (above) are identified for further study. In these regions, the coarse mesh is replaced with a fully discretized model of several unit cells of the material, as shown in Figure 2 (next page – gray indicates averaged properties and white indicates resolved microstructure). A few unit cells away from the area of interest, the model transitions back to the average properties.

As a basis of comparison, a model was generated in which the entire angle bracket was modeled with fully resolved fiber and matrix components. This model is referred to as the Direct Numerical Simulation (DNS).

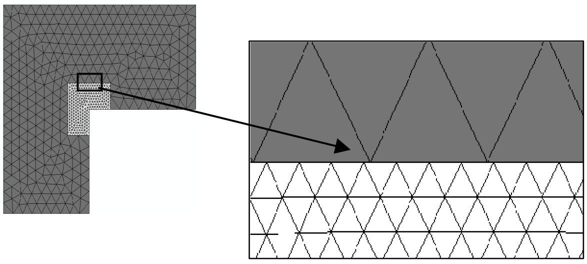

Figure 2: Averaged component mesh (gray) with embedded unit cell models (white).

RESULTS

The multi-scale modeling technique showed qualitative agreement with the DNS for regions away from the interface, both inside and outside the resolved region (Figure 3). Note that whereas the stress distribution is smooth in the homogenized region, it is irregular in the DNS and resolved regions of the multi-scale model. This irregularity is due to the fact that the material properties are rapidly varying in space moving between fiber and matrix and is expected for the DNS model.

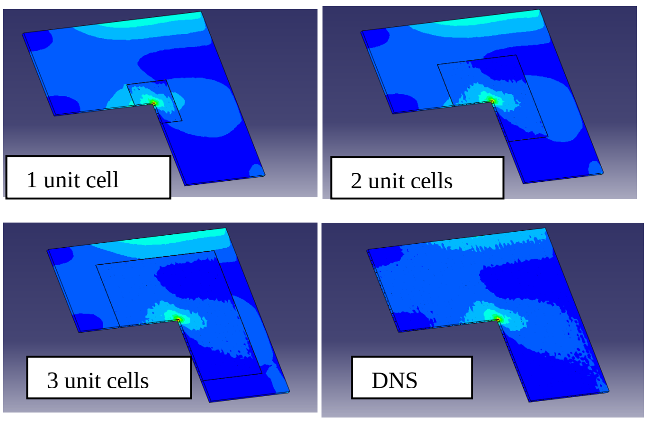

Figure 3: Results of three-dimensional simulation for multi-scale modeling method and DNS.

For ease of visualization, fiber and matrix stress distributions were plotted separately (Figures 4 and 5, respectively). Note for both cases the similarity between all multi-scale models and the DNS model.

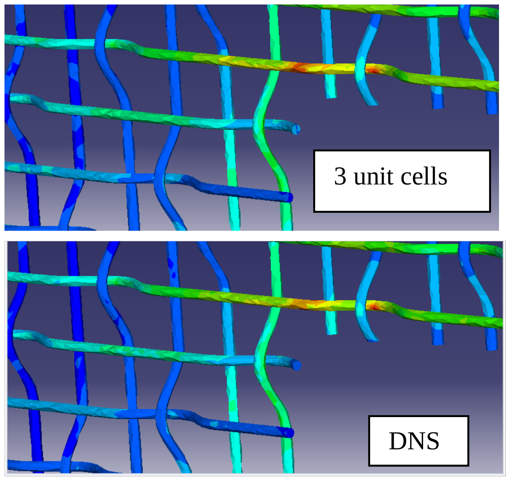

Figure 4: von-Mises stress within fiber for multi-scale model versus DNS.

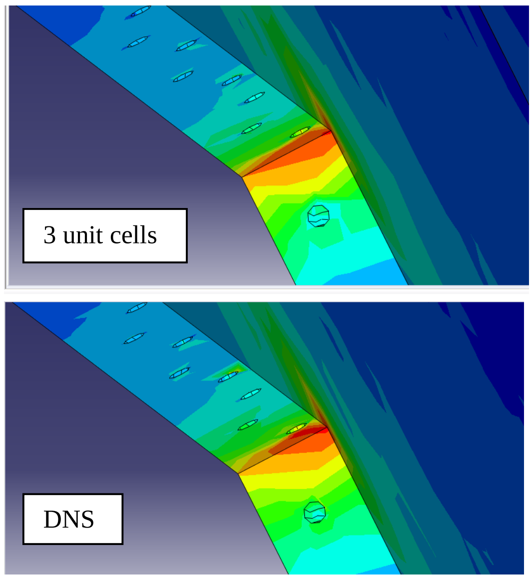

Figure 5: von-Mises stress within matrix for multi-scale model versus DNS.

CONCLUSION

The proposed method is a promising approach for computationally efficient and accurate prediction of local stress distributions within woven fiber composite materials.