MODELLING OF TIME AND RATE DEPENDENT BEHAVIOUR OF 3D BRAID COMPOSITES USING CONTINUUM-BASED MULTI-SCALE ANALYSIS

Hyunchul Ahn[a] and Woong-Ryeol Yu[a]*

[a]*Department of Materials Science and Engineering, Seoul National University, 1 Gwanak-ro, Gwanak-gu, Seoul, 151-742, Korea*
** Corresponding author: woongryu@snu.ac.kr*

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Abstract

Time and rate dependent behaviour of textile composites are important design parameters to develop new composite parts that are used in the dynamic loading structure. In this study, a new numerical method is developed that can reflect the microstructural change of the textile structure during time dependent loading and can calculate the stress increments due to the deformation. For calculating the stress increment, first the yarn orientation is calculated and updated using incremental deformation gradient. The tangent stiffness matrix is then computed based on the updated yarn orientation. Here, the viscoelastic properties of the yarns and matrix are considered to include time dependent deformation and the strain rate effect. As for damages, partial damage and propagation are incorporated into the stress calculation using partial failure and ply discount method. The failure conditions are obtained by testing unidirectional composites at various strain rates and then formulated using Puck's criterion. We implemented this new method into a user material subroutine of ABAQUS (commercial finite element analysis software). The mechanical behaviour of 3D braid composites is then simulated using the user subroutine and compared with experimental one to demonstrate the validity of the developed method.

1. Introduction

Fiber reinforced composites have been widely used in such as automobiles, sailboats, and sports goods, because of their high stiffness and strength. Braid composite is a type of three-dimensional (3D) fiber reinforced composite, showing high impact resistance, high failure strength, and long fatigue life. 3D braided structure has no delamination and therefore, recently, has been used for lightweight automobile parts (such as bumper and back-beam) that have to sustain high impact load. The mechanical analysis of braid composites has been well performed using numerical methods developed in many studies [1, 2]. On the other hand, in-plane mechanical properties and damage tolerance and fatigue properties were improved by introducing axial yarns into 3D braid structure, forming so called five-axis braid structure [3, 4]. Even though failure and fatigue properties of braid composite have been studied [5, 6] however, few studies are dedicated to dynamic properties of braid composites.

In this study, we developed a new numerical analysis method to analyze dynamic properties of braid composite. First, we considered the yarn orientation because it is most important factor to determine the mechanical behaviour of 3D braid composite. An update algorithm was developed to reflect the change in the yarn orientation. Using this yarn orientation, the inner structure of the braid composite was defined. The elastic property of the composite was calculated based on the mechanical properties of the unidirectional composites and yarn orientation. Damage propagation was also considered for analyzing the failure behaviour of the braid composite. The failure conditions were obtained by testing unidirectional composites and then used in damage analysis. Partial damage and propagation were incorporated using partial failure and ply discount method for composite damage analysis. The failure condition was formulated using three-dimensional Puck's criterion [7]. The numerical analysis was carried out using ABAQUS, the results of which were compared with experimental results for the validation purpose.

2. Methods

2.1. Numerical approach

In this study, a new numerical method was developed that can reflect the microstructural change of the textile structure during time dependent loading and can calculate the stress increments due to the deformation. The new method consisted of broadly four steps as shown in Figure 1.

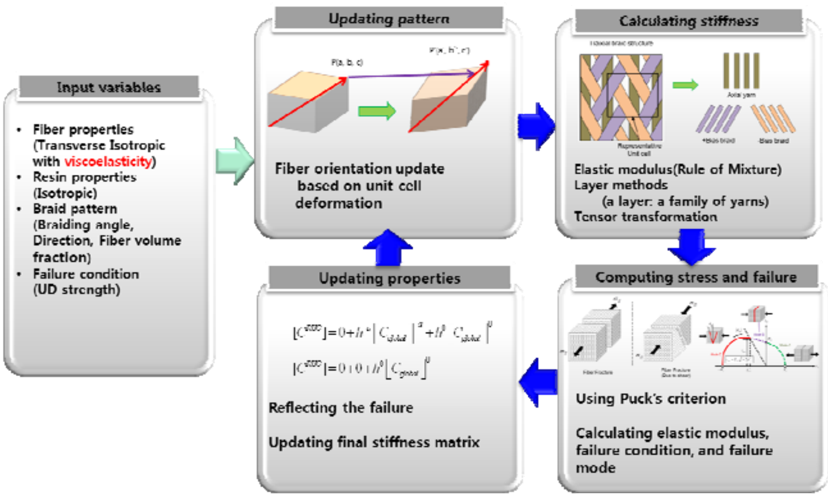


Figure 1. Schematic diagram describing new numerical method to calculate the stress based on strain increment.

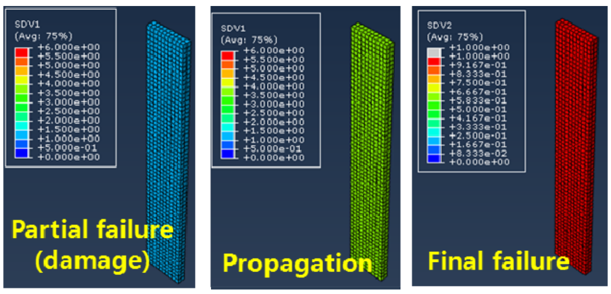
First, the yarn orientation was defined using the direction cosine and changed using incremental deformation gradient. Based on the yarn orientation, the yarn angle was updated each section, followed by the calculation of the stiffness matrix. Then, 3D tangent stiffness matrix of the braid composites was computed for their elastic behaviour considering yarn orientations. The mechanical properties of the unidirectional composite were calculated using mixture rule [8]. The yarn was assumed to be transversely isotropic, while the resin was assumed to be isotropic. Since the braid composite is 3D object, the tensor transform was carried out for calculating the mechanical properties of the composites. Based on the elastic properties, partial damage and propagation were incorporated into the stress calculation using partial damage and failure with ply discount method. The failure condition was obtained by testing unidirectional composites at various strain rates and then formulated using Puck's criterion. Finally, the stiffness matrix was updated including damage propagation for next increment. The algorithm developed above was implemented into ABAQUS for numerical analysis, for which a UMAT subroutine was developed. Based on the static analysis, time and rate dependent analysis of the composite will be carried out. For this, we will consider the viscoelastic properties of fiber and matrix.

2.2. Experimental

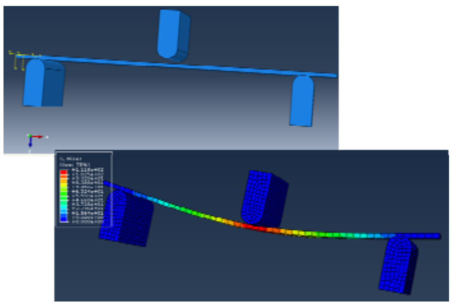
Experimental studies were carried out to characterize the material properties of the unidirectional and 3D braid composites. For the unidirectional composites, tensile tests were carried out to obtain their elastic properties. Glass fiber (GF)/Epoxy unidirectional composites were fabricated using the press molding at 90℃ and 50 MPa. The curing time was 30 minutes. In addition, their time and rate dependent properties of the unidirectional composites will be also characterized at various strain rates. Braid composite samples were also fabricated, tested and compared with the numerical results. Here, 3D braid preforms, which were prepared with a braiding structure of 4 layers and 12 carriers in each layer, were used. The braid angles were fixed to be 30 degree. Vacuum assisted resin transfer molding (VARTM) was used for manufacturing the composite. The tensile and three points banding tests were carried out following ASTM standards.

3. Results and discussion

The failure properties of the unidirectional composites were determined and provided. The numerical analysis of 3D braid composites was then carried out using the new method (see Figure 2). The periodic boundary condition was used for tensile test simulation.



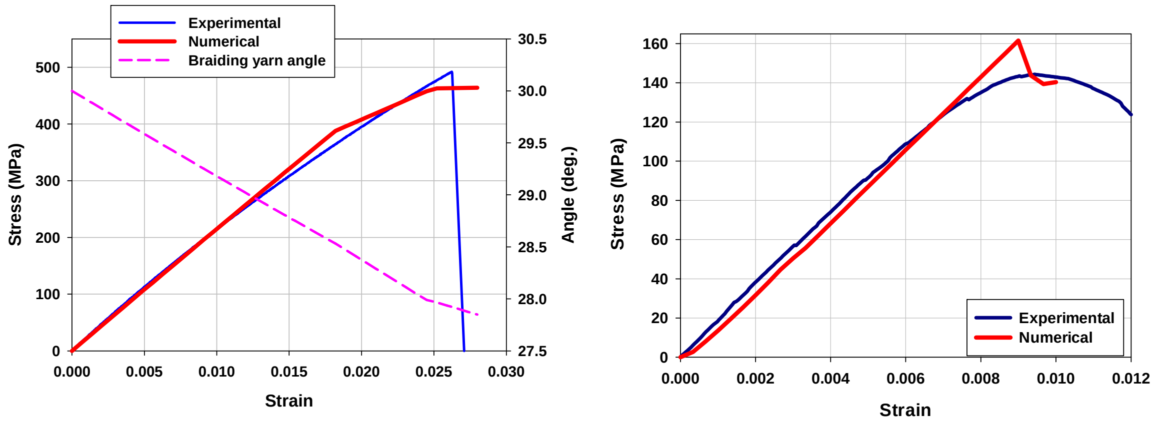
(a)



(b)

Figure 2. Numerical analysis model. Tensile test model (a) and bending test model (b). SDV1 is partial failure variable and SDV2 is final failure variable.

Experimental results (averaged from 5 sample test) were compared with results obtained from the numerical method. Figure 3 (a) shows the tensile test results, demonstrating that the current method can adequately predict the mechanical behaviour of the braid composites including the damage propagation. Note that the braiding angle was also traced. Figure 3 (b) shows the bending test results. The predicted failure stress shows a significant discrepancy (about 15%) between numerical and experimental results. This error seemed to come from the imperfection of the composite specimens. The detailed analysis is under going and will be presented at the Conference.



(a) (b)

Figure 3. Comparisons between numerical and experimental results. (a) tensile and (b) bending tests.

4. Summary

A mechanical model to analyze the mechanical behaviour of the braid composites was developed based on fiber-based continuum mechanics framework. The developed model was able to predict the mechanical properties of the braid composites adequately including their damage deformation. To simulate time and rate dependent behaviour of braid composites, the viscoelastic properties of fiber and matrix will be incorporated into the model. .

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