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# Mechanical analysis of 3D braided and woven composites using fiber-based continuum analysis

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ABSTRACT

A numerical method was developed to reflect the microstructural changes of 3D textile composites and to predict their mechanical behavior based on continuum mechanics framework. The first step of the new method is to define the yarn orientation at every point of 3D textile composites and to update the yarn orientation using the deformation gradient. 3D textile composites are assumed as a combination of several uni-directional layers, each of which represents continuous distribution of fibers in the yarn direction. The tangent stiffness of each layer is then computed considering the yarn undulation, followed by calculation of the stress increment. Damage initiation is then evaluated using Puck's criterion and its propagation is implemented using modified ply discount method. The proposed numerical method was incorporated into commercial finite element software through a user material subroutine. The mechanical behavior of 3D braided and 3D woven composites was then predicted and compared with experimental to demonstrate the validity of the developed method.



## 1. Introduction

Due to their high stiffness and strength, three-dimensional (3D) textile composites based on 3D woven and braided preforms have been widely used in various engineering fields. The woven composite, now a conventional structure, has been researched for several decades. Some of the earliest analytical studies were performed by Ishikawa and Chou, who developed linear and nonlinear models for the stiffness and strength of woven composites [1,2]. Chang and Chang proposed a progressive failure model for laminated and woven composites [3]. Failure analysis method of woven composite laminate is also developed [4]. In addition, the mechanical properties of woven composites have been examined using 3D modeling [5–7]. Moreover, damage mechanisms of woven composites and modeling study such as homogenization are also researched [8,9]. Recently, there has been much interest in 3D woven structures [10,11], promoting various studies on the numerical analysis of 3D woven composites [12–14]. The first part of the numerical analysis of 3D textiles was their geometric modeling [12]. Since tow modeling had significant effects on the unit cell properties of 3D woven textile, various tow models were developed for 3D unit cell modeling [15,16]. The mechanical properties of 3D composites including elastic modulus and failure strength were predicted using unit cell approach [17,18]. Recently, the impact behavior of 3D woven composites has attracted researchers' attention due to their high performance [19,20]. Many researches of 3D woven textile and composites were based on 3D unit cell modeling, confining to researches into the prediction of the basic mechanical properties of the unit cell comprising of 3D woven textile and composites.

On the other hand, 3D braided composites exhibit high failure strength, a long fatigue life, and minimal delamination. Various numerical models have been proposed for the mechanical analysis of 3D braided composites. Despite the 3D structure of 3D braided composites, initial models were proposed in a two-dimensional form [21], which provided computational efficiency and feasible accuracy [22–25]. Unit cell modeling has been used to numerically predict the elastic properties of 3D braided composites [26,27]. As for efficient structure, axial yarns were introduced to provide better in-plane mechanical properties and thus performance enhancement [28]. Failure mechanism and strength have been investigated using unit cell modeling [29–31]. Despite advancements in the mechanical analysis of 3D textile composites, it is still challenging to predict or simulate their mechanical behavior, in particular at product level, considering the microstructure such as fiber orientation and volume fractions.

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In this study, we developed a new numerical model to analyze the mechanical properties of 3D textile composites based on continuum mechanics framework. It is assumed that fiber structure including yarn orientation can be defined at every point of 3D textile composites (continuum assumption of the 3D textiles). Tracking the yarn orientation of 3D textile composites, their elastic properties and failure initiation and propagation are evaluated using a layer method, Puck's criterion, and modified ply discount method. Since this method is based on continuum mechanics framework, it can be implemented into commercial finite element software through user material subroutine, enabling the mechanical analysis of 3D textile composites to be readily performed considering their fiber architecture. The input parameters necessary for this numerical method are clearly defined and numerical simulations are compared with the experimental results for validation as follows.

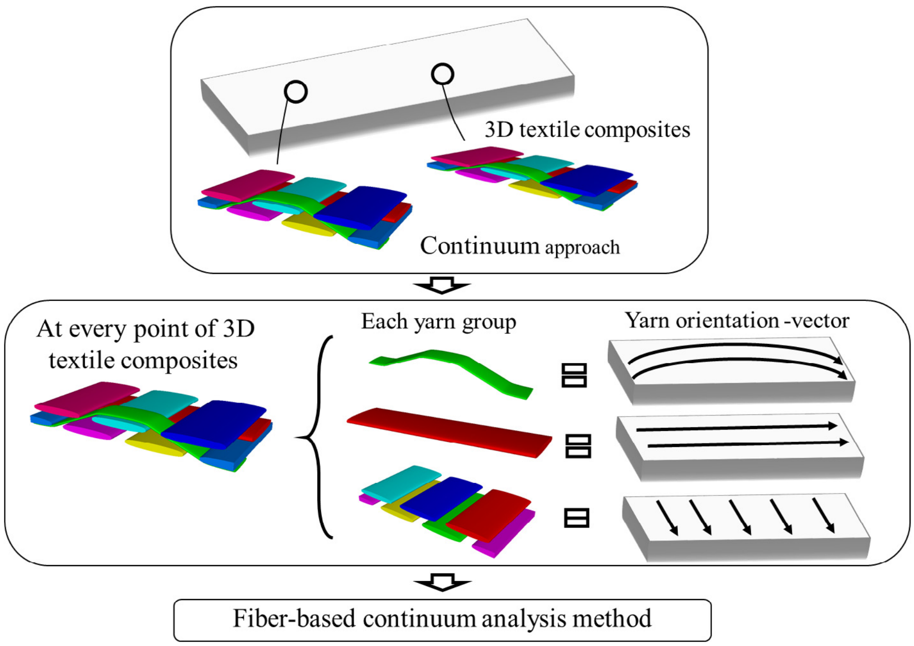


**Fig. 1.** Schematic diagram of fiber-based continuum analysis model.

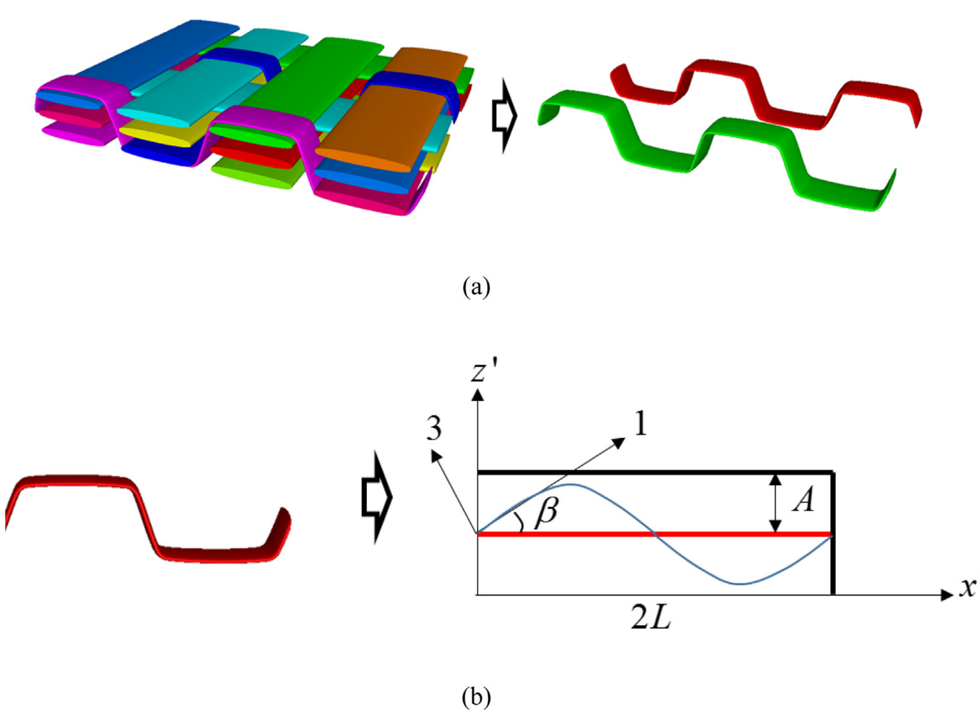


**Fig. 2.** Yarn undulation model. (a) Yarn undulation example of 3D orthogonal woven textile composite and (b) calculation model.