A computationally efficient model to predict the uniaxial tensile loading response for dry woven fabrics

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A computationally efficient model to predict the uniaxial tensile loading response for dry woven fabrics

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Abstract

Woven structure is an essential component widely used in composite materials, bio-materials and mechanical metamaterials. The mechanical response of the dry woven fabric, which is widely used as reinforcement in composite materials is studied in the present paper. Typically, for the dry woven fabric, the warp and weft yarns are weaved with each other. Each warp or weft yarn also consists of large amounts of small filaments. Because of this multiscale nature, a model that can predict the material response as a function of the underlying structure is important for the design of the dry woven fabric. Hence, a computationally efficient model to simulate the uniaxial tensile loading response for dry woven fabrics is proposed. The proposed model is able to predict the macroscopic loading-deformation response, the effective in-plane Poisson's effect and the deformation of the thickness by taking into account the influence of the filaments, the weaving pattern and the surface contact at the crossover of the yarns. The accuracy of the model is validated by a digital image correlation (DIC) experiment. For the weaved yarns, complex yarn geometries can be easily modelled and different yarn curve assumptions can be conveniently incorporated in the proposed model. The high computational efficiency of the model makes it potentially helpful for designing woven materials with high mechanical performance.

Keywords: Dry woven fabrics, computationally efficient model, uniaxial tensile loading

1. INTRODUCTION

Woven structure is a core building block for many materials, ranging from macroscale product, such as inflatable tents [1], to materials in nanoscale, such as smart textiles for sensors and displays [2]. One advantage of the woven material is that the macroscopic mechanical behavior can be designed by controlling the underlying structure and this advantage makes the woven structure widely used in designing composite materials [3], bio-materials [4], and mechanical metamaterials [5].

A typical dry woven fabric, which is widely used as reinforcement in composite materials, is shown in fig. 1. Orthogonally weaved warp and weft yarns are arranged periodically. Each yarn is also composed of large amounts of small filaments, as shown in fig. 1. The mechanical behavior of the dry woven fabric and also the fabric reinforced composites are related to the weaving pattern, the yarn property and the arrangement of the filaments.

One key issue in designing the dry woven fabric is to understand the relationship between the internal structure in meso/micro-scale (weaving pattern, yarn property and arrangements of the filaments) and the macro-scale material response. Because of the periodicity of the weaving pattern, a common method to deal with this multiscale nature in computational modelling is to use the repeating unit cell (RUC) method and associated periodic boundary conditions, in which the volume averaged meso-scale stress-strain of the RUC can be used to estimate the macroscopic material response [6]. As a result, only one unit cell is needed to be analyzed instead of modelling the whole material, and thus the computational efficiency can be greatly improved. Hivet et al. [7] developed an accurate meshing procedure for the construction of woven fabric unit cells that mimicked yarn interaction under different in-plane loadings. Rahali et al. [8] proposed a finite element model to study

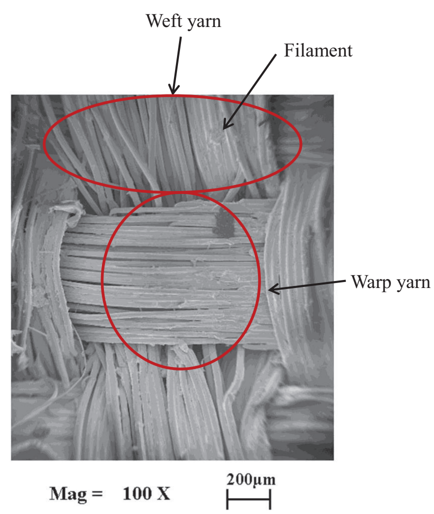

Figure 1: An orthogonal plain weave untwisted fabric

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