International Journal of Solids and Structures 48 (2011) 2920–2930

Contents lists available at ScienceDirect

International Journal of Solids and Structures

journal homepage: www.elsevier.com/locate/ijsolstr

Equivalent properties of monolayer fabric from mesoscopic modelling strategies

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ARTICLE INFO

Article history:
Received 17 September 2010
Received in revised form 18 April 2011
Available online 14 June 2011

Keywords:
Mesoscopic models
Woven structures
Potential energy
Yarn–yarn interactions
Genetic algorithms
Equilibrium shape
Twill
Poisson's ratio

ABSTRACT

A general and systematic approach for the development of mesostructurally-based continuum model of woven fabrics has been elaborated, relating the fabric behavior at the macroscopic continuum scale to the response and geometry of the fabric's mesostructure (geometrical configuration of the weave and the yarn properties). Mesoscopic discrete models of dry fabric have been developed based on a discretization of the yarn geometry, accounting for the yarn–yarn interactions at the yarns crossing points. The yarns are modeled within a unit cell consisting of the repetitive fabric pattern as curved planar beams submitted to the reaction forces of the transverse yarns at discrete crossover points. Those reaction forces are expressed in semi-analytical form versus the yarn geometry and mechanical properties for general armour from beam theory. The equilibrium shape of the woven fabric is obtained by minimizing its total potential energy, accounting for the work of the reaction forces due to the transverse yarns. The absolute minimum of the structure's total potential energy is achieved by a classical genetic algorithm. Simulation results show that plain weave presents a nonlinear response in the early deformation stage due to the crimp change, whereas twill shows a quasi linear response due to yarn extension being the dominant deformation mechanism. Plain weave fabric overall exhibits an orthotropic constitutive law, as biaxial simulations show. The transverse behavior of plain weave fabric is presently evaluated in terms of Poisson's ratio, based on virtual simulations at the mesoscopic scale of analysis. Simulation results show that Poisson's ratio first increases towards a maximum due to the rapid shrinkage of the sample in the transverse direction, and decreases thereafter when the crimp changes become limited by the reaction forces of the transverse yarns. The influence of the mechanical properties of both warp and weft on Poisson's coefficient is assessed. The predictions of the mesoscopic models regarding the impact of yarn geometry and mechanical properties on the overall behavior provide a guideline for the design of woven fabrics.

1. Introduction

The analysis of the deformations and shape forming of textiles has become an important scientific and technological topic nowadays, due to the wide range of applications of these structures in many domains, as exemplified by the use of composites with a woven reinforcement in aerospace industry. The analysis of the motion and behaviour of the dry fabric (before being impregnated with a resin as in the RTM process) is very peculiar, due to the relative ease of motion of the yarns. This motion, in turn, determines the shape forming of the woven structure, thus calling for a separate analysis (Gasser et al., 2000; Kawabata et al., 1973; Kawabata, 1989).

There is accordingly a need for reliable simulation tools for predicting the overall mechanical behavior of textile composites, accounting for informations relative to the fiber orientations and fibre density, which strongly determines how the composite part will behave, especially with regards to stiffness, damage, fatigue, rupture (Potluri et al., 2006; Liu et al., 2007; Mattsson et al., 2007). The mechanical behavior of textile is clearly a multiscale problem, and the macroscopic behavior strongly depends on the mechanical behavior of the fibres or yarns at the microscopic scale, the interactions between yarns at both the microscopic (interactions between the fibers constituting the yarns) and the mesoscopic scale (scale of the woven unit cell). Despite the great amount of existing works and modelling strategies, no unitary model exists in the literature, as mentioned in Hamila and Boisse (2008); the existing families of models can be summarized as follows.

The mechanical behavior of the mesostructure can be homogenized assuming the fabric to behave as an anisotropic continuum (Dong et al., 2001; Peng and Cao, 2005; Boisse et al., 2005; Akkerman and Lamers, 2007). Those models can next be incorporated into large strain finite element analysis using shell or membrane elements. The drawbacks of this first class of models

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doi:10.1016/j.ijsolstr.2011.06.010