ON IMPROVED TOW COMPACTION MODELLING FOR ACCURATE PERMEABILITY PREDICTION OF WOVEN TEXTILES

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Introduction

The permeability of textile reinforcements is a critical input for any mould filling simulation. A permeability prediction chain is under development which encompasses realistic textile modelling, textile compaction simulation, and steady-state flow simulation. The focus has been placed on characterising the plain-weave architecture with future expansion to biaxial braids. Acknowledging the dominant influence of the flow channel geometries to the permeability values, a realistic dry textile compaction simulation is vital. This paper provides insight into the preliminary work completed by the authors in the context of textile compaction simulation, which motivates a shift from adopting a simple linear-elastic material approach towards a more sophisticated hyperelasticity constitutive model. Meso-scale simulation has been adopted where the textile tows are treated as continuums.

Material

The study was based on an 800g/m2 glass fibre plain weave, procured from Aurora Glass Fibre, New Zealand. The average geometric parameters to construct an idealized meso-scale textile model were measured using a combination of microscopy and semi-automated image analysis methods executed in MATLAB. Through observations on how the fibre filaments were arranged within the yarns, each yarn was modelled as a transversely isotropic continuum.

Linear-elastic based textile compaction simulation

The linear-elastic material model is based on the small deformation theory where it is assumed that the stress and strain tensors are related with a constant 4th order elasticity tensor. This elasticity tensor is completely defined through well-known elastic constants: Young's moduli, shear moduli, and Poisson's ratios. The ease of obtaining such constants was the main reason why this constitutive model was adopted for the initial study. The elastic constants used in this study were based on [1], chosen due to similarity to the plain-weave considered in that work.

Single and multi-layer (2,4,8 layers) meso-scale compaction simulations were conducted in ABAQUS/standard. For multi-layer simulations, two extreme configurations were chosen: no nesting and maximum nesting. Periodic boundary conditions were imposed through a mesh-tie constraint approach. The textiles were compacted between two analytically rigid plates to different final fibre volume fractions: 50%, 55%, and 60%. Though easily implemented through the ABAQUS material library, a linear-elastic approach led to unrealistic compacted tow geometries as seen in Figure 1. As can be observed, at a high fibre volume fraction, unrealistic tow buckling phenomena occurred which resulted in unrealistic flow channels that falsely increased the predicted permeabilities.

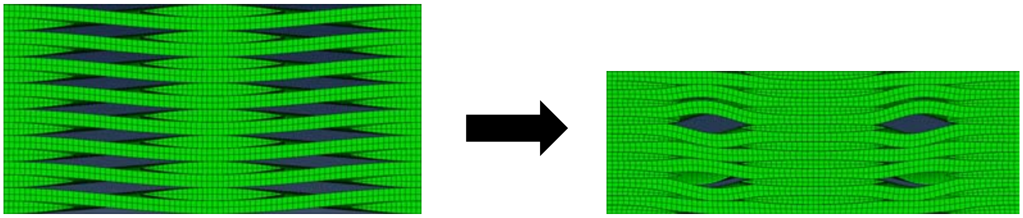

Figure 1: *8-layer no nesting model compacted to 60% fibre volume fraction based on linear elasticity*

Hyperelastic constitutive models

From the previous section, it is clear that a more realistic material model for tow compaction should be implemented. Such a material model needs to eliminate the linear stress-strain relationship assumption from the linear elasticity theory because textiles tows undergo significant deformation when compacted to practical fibre volume fractions in a nonlinear fashion. For this reason, a hyperelastic material models are considered in this work. A hyperelastic material is characterised by the existence of a strain energy function per unit reference volume which describes the strain/potential energy stored at a material point due to deformation. Various stress measures can be derived from the mathematical expression of the strain energy function. When the load is removed, this stored energy is released back to return the continuum to its reference configuration (completely elastic).

Various isotropic and anisotropic hyperelastic models are available in the ABAQUS material library. These models were originally developed to simulate the mechanical behaviours of rubber-like materials and soft biological tissues; thus, they are not completely suitable for the modelling of textile tows. Therefore, there is a clear motivation to construct novel strain energy functions that realistically model the transversely isotropic behaviour of textile tows and which can then be implemented in the form of ABAQUS material subroutines.

A significant step towards achieving this goal was made by Charmetant et al. [2]. They developed a strain energy formulation based on the physically-based strain invariants. The principle behind the transformation of the conventional strain invariants to the physically-based invariants was based on the work by Criscione et al. [3]. Each of the physically-based strain invariants represented different tow deformation modes which, by Charmetant, were assumed to be uncoupled to each other. The proposed form of the strain energy function can be referred to Equation (1):

$$w = w\left(I_{elong}\right) + w\left(I_{comp}\right) + w(I_{dist}) + w(I_{sh}) \tag{1}$$

Note that $w\left(I_{elong}\right)$, $w\left(I_{comp}\right)$, $w(I_{dist})$, and $w(I_{sh})$ represent the strain energy contributions due to elongation, compaction of the cross section, cross fibre pure shear, and along the fibre simple shear. The material parameters associated with each of the deformation modes were obtained through an iterative technique to fit the experimental data obtained from the uniaxial tensile test of a single tow and the biaxial tensile test of fabric.

It is proposed that new strain energy formulations can be developed which incorporate some degree of coupling between different deformation modes, and a transition from compressible to incompressible behaviour once the textile tow has reached a limiting fibre volume fraction. Furthermore, new experimental characterizations will be implemented to provide accurate data with which to determine the required material parameters. Development of new strain energy formulations and experimental characterisation methods is the ongoing focus of this work.

Concluding remarks

A realistic dry textile compaction simulation is important for an accurate permeability prediction. From the preliminary works completed by the present authors, it has been shown that a simple linear elastic model led to unrealistic tow deformation behaviour. This motivates the need to develop and implement a new hyperelastic-based tow model, which remains work in progress.

References

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