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A hyperelasticity approach for modelling of woven composites

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Structural woven composites made with high strength fibres are now widely used in automotive and aeronauticengineering due to their high strength/weight ratio as compared with metals. During the forming process, though the extension of the woven composite fabrics is usually small, the shear deformation (i.e., the angle change between weft and warp yarns) can be significant. Because of the anisotropy and the finite relative rotation between weft and warp yarns, it is usually difficult to model the macroscopic behaviour of the woven composites and several phenomenological nonorthogonal constitutive models have been developed in the literature (for example, (Peng and Cao, 2005)).

In this paper, a phenomenological hyperelastic model is attempted to simulate the forming process of the woven composites. Here the weft yarns are assumed to be orthogonal to the warp yarns in the undeformed configuration for simplification. Although energy dissipation is unavoidable during the deformation of the woven composite, in our phenomenological hyperelastic approach, however, the energy required to deform the woven composite is treated as the strain energy of the corresponding deformation state. This assumption is fine as long as the unloading process is not considered and similar treatment is implied in other hypoelastic models.

In a hyperelastic framework, the mechanical response of a material can be determined by its strain energy density function. For a woven composite, any general deformation state of a (macroscale) material point can be fully characterised by three invariants (Aimene *et al.*, 2008): the stretch ratios of the warp (λ_1) and the weft yarn (λ_2), and the angle between the (local) warp and weft yarn (θ). In our model, the strain energy density is then defined as a function of three invariants λ_1^2, λ_2^2, and $\cos\theta$.

Because the shear stress is usually assumed to be independent of the yarn stretch (Peng and Cao, 2005), the strain energy required for the shear deformation can be represented as a function of the relative rotation angle between the weft and warp yarns. This shear strain energy function can be directly determined by the load-displacement curve of a picture frame test (Harrison *et al.*, 2008). A co-extruded self-reinforced polypropylene (SRPP) plain woven fabric has been tested. The side length of the picture frame rig is 170 mm and the fabric thickness is 0.15 mm. The load-displacement curve can be fitted by a cubic polynomial (Figure 1). The strain energy density function (per unit volume in the undeformed configuration) *Ws* can then be computed by a simple integration procedure. Figure 2 shows that *W* can in turn be fitted by a simple polynomial function of $\cos\theta$. The original and fitted curves are undistinguishable (Figure 2).

The tensile strain energy resulting from stretch of

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