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ISOGEOMETRIC HOMOGENIZATION ANALYSIS FOR DRY WOVEN FABRICS

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We propose a method of in-plane homogenization analysis to evaluate the macroscopic material behavior of dry woven fabric which largely depends on frictional contact between fiber bundles. Our proposed method is formulated within the micro-macro decoupled multiscale framework based on the evaluation of the macroscopic response obtained by the Numerical Plate Testing (NPT) [1] for an in-plane periodic unit structure (in-plane unit cell). In NPT, the generalized macroscopic deformation gradients such as elongation and bending deformation defined in classical plate bending theory are imposed on the in-plane unit cell with in-plane periodic boundary conditions. In addition, to consider large deformation and rotation of fiber bundles in a micro-scale, the method of NPT that was originally formulated within small strain framework is re-formulated within the framework of finite strain theory. For the robust treatment of frictional contact, the method of isogeometric analysis (IGA) [2] is employed for NPT. In this method, higher order spline functions such as NURBS can be utilized for bases of finite element approximations. This guarantees that the geometry of the numerical model for NPT can be exactly the same as the corresponding CAD model and higher-order of continuity can be achieved on any contact surfaces, which realizes high convergence performance in solving frictional contact problems involving large slip. Frictional-contact problem is solved by the penalty method and the mortar-based knot-to-surface method [3] which relaxes over-constraining due to high penalty parameter is employed for evaluation of frictional contact-related variables.

We employ the in-plane sub-unit cell instead of the standard definition of in-plane unit cell as shown in figure 1 in order to realize the reduction of computational costs. To realize in-plane periodic motion of actual unit cell, anti-symmetry of plane weave fabrics is imposed on the boundary of in-plane sub-unit cell. Its initial state is obtained via weaving process, which enables us to obtain natural geometry and initial stress distributions caused by bending of fiber bundles. In order to show the validity of proposed method, we

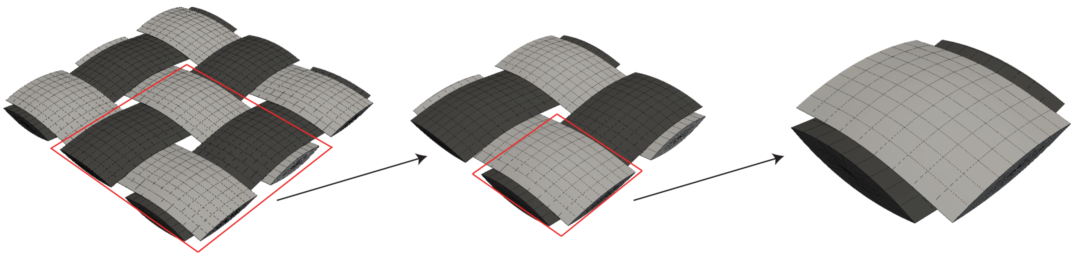

Figure 1: Definition of in-plane unit cell and in-plane sub-unit cell

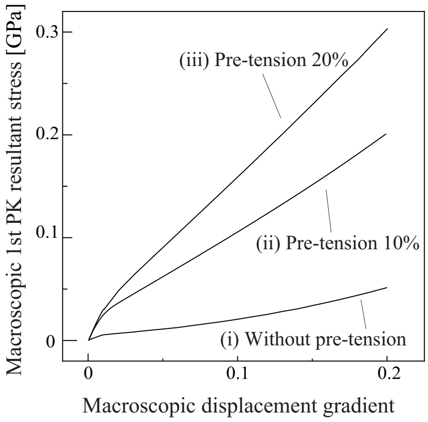

Figure 2: Relationships between macroscopic generalized resultant stresses and displacement gradients in response to macroscopically in-plane shear loading after three different cases of pre-tensile loading

present some numerical examples, in which some macroscopic in-plane and out-of-plane characteristics of dry woven fabrics are appeared. Among them, some in-plane shear characteristics are shown in Figure 2; (i) without pre-tension, (ii) with 10% pre-tension and (iii) with 20% pre-tension. These results indicate that the macroscopic in-plane resultant stress increases in response to the amount of pre-tension, which is also observed by the actual experiment [4].

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