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An Adaptable Semi-Numerical Anisotropic Hyperelastic Model for the Simulation of High Pressure Forming

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Abstract : High-quality surfaces of plastic parts can be achieved in a very cost-effective manner using in-mold processes, where e.g. scratch resistant or high gloss polymer films are pre-formed and subsequently receive their support structure by injection molding. The pre-forming may be done by high-pressure forming. In this process, a polymer sheet is heated and subsequently formed into the mold by pressurized air. Due to the heat transfer to the cooled mold the polymer temperature drops below its glass transition temperature. This ensures that the deformed microstructure is retained after depressurizing, giving the sheet its final formed shape. The development of a forming process relies heavily on the experience of engineers and trial-and-error procedures. Repeated mold design and testing cycles are however both time- and cost-intensive. It is, therefore, desirable to study the process using reliable computer simulations. Through simulations, the construction of the mold and the effect of various process parameters, e.g. temperature levels, non-uniform heating or timing and magnitude of pressure, on the deformation of the polymer sheet can be analyzed. Detailed knowledge of the deformation is particularly important in the forming of polymer films with integrated electro-optical functions. Care must be taken in the placement of devices, sensors and electrical and optical paths, which are far more sensitive to deformation than the polymers. Reliable numerical prediction of the deformation of the polymer sheets requires sophisticated material models. Polymer films are often either transversely isotropic or orthotropic due to molecular orientations induced during manufacturing. The anisotropic behavior affects the resulting strain field in the deformed film. For example, parts of the same shape but different strain fields may be created by varying the orientation of the film with respect to the mold. The numerical simulation of the high-pressure forming of such films thus requires material models that can capture the nonlinear anisotropic mechanical behavior. There are numerous commercial polymer grades for the engineers to choose from when developing a new part. The effort required for comprehensive material characterization may be prohibitive, especially when several materials are candidates for a specific application. We, therefore, propose a class of models for compressible hyperelasticity, which may be determined from basic experimental data and which can capture key features of the mechanical response. Invariant-based hyperelastic models with a reduced number of invariants are formulated in a semi-numerical way, such that the models are determined from a single uniaxial tensile tests for isotropic materials, or two tensile tests in the principal directions for transversely isotropic or orthotropic materials. The simulation of the high pressure forming of an orthotropic polymer film is finally done using an orthotropic formulation of the hyperelastic model.

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