Simulation of thermoforming processes with anisotropic and visco-hyperelastic sheets of laminate

P. G. Gruber[1,a), A. Humer[1,2,b)] and C. Zehetner[1,c)]

[1]Linz Center of Mechatronics GmbH, Altenbergerstraße 69, 4040 Linz, Austria

[2]Institut für Technische Mechanik, Johannes Kepler Universität, Altenbergerstraße 69, 4040 Linz, Austria

[a)]Corresponding and presenting author: peter.gruber@lcm.at

[b)]alexander.humer@jku.at

[c)]christian.zehetner@lcm.at

ABSTRACT

Many of daily life's digital gadgets are thermoformed devices, which are populated with electronic patterns (such as sensors, piezzos, screens, etc.), all of which are connected via an imprinted and dense path of conductors. Typical examples of such devices are game-controllers, parts of a mobile phone, or of a car's cockpit. In order to keep production cost low, and at the same raise the quality of the outcome, one innovative idea is to imprint patches and conductors to the laminated sheet even before it has been subject to the thermoforming process. Regarding the design of such devices it is clearly of essential importance to understand the overall behavior and predict zones of high stretches and strains of the sheet during the forming process. The design of an efficient and stable numerical simulation, which is the topic of this presentation, yields a valuable tool in assisting the real life experiment.

Keywords: Large Deformation Analysis, Finite Element Method, Material Processing, Anisotropy, Visco-Hyperelasticity.

Geometrical Model and Finite Element Discretization

A thin sheet of laminate, undergoes large deformation and a temperature shock when contacting the thermoforming profile, see Fig. 1.

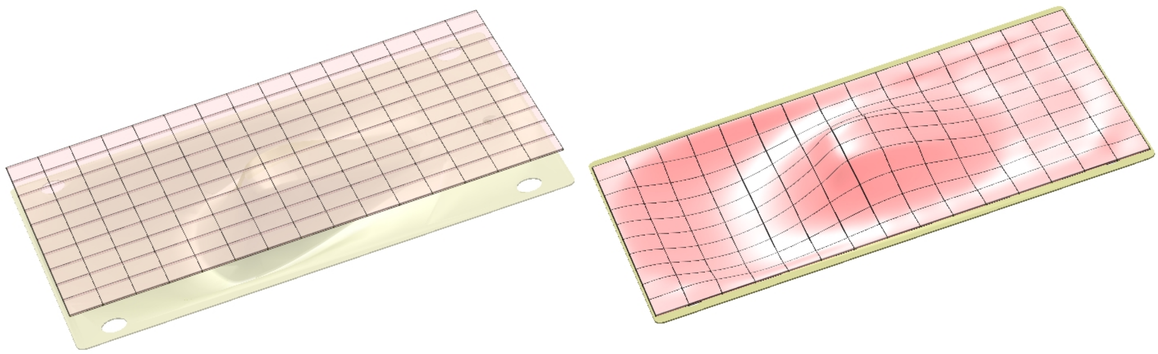

Figure 1. Geometrical outline: Thermoforming profile (green) and foil (transparent grey) are separated in their initial configuration (left). The profile is moved to the foil and air pressure is applied to bring the foil in contact with the profile surface (right).

Spatial discretization is performed by using shell Finite Elements with absolute nodal coordinates, see [2], which due to a time-constant mass matrix perform highly efficient in the dynamic simulation. The elements provide high smoothness (normal flux continuity), and therefore guarantee realistic behavior at sharp edges or rough corners of the thermoforming profile. We present simulation results obtained in the multibody-dynamics simulator HOTINT, a freely available and open source software framework, see [1].

Material Model

The material responds to a viscoelastic constitutive equation

$$\mathbf{S}(t) = \int_0^t G(t-\tau)\frac{\partial \mathbf{S}^e}{\partial \tau}\, d\tau\,, \tag{1}$$

in which $\mathbf{S}$ denotes the second Piola-Kirchhoff stress tensor. The relaxation functional G in Eq. (1) is defined

$$G(t-\tau) = G_\infty + \sum_{i=1}^{n} G_i \exp\left(\frac{\tau - t}{\tau_i}\right)\,, \tag{2}$$

with weights $G_i \in [0,1]$, such that $G_\infty = 1 - \sum_i G_i$ is in $[0,1]$, and with a strictly monotonic sequence of time instances $\tau_{i+1} > \tau_i > 0$. The elastic response $\mathbf{S}^e$ in Eq. (1) obeys an anisotropic hyperelastic law

$$\mathbf{S}^e = 2\,c_1\mathbf{I} + (-2\,c_1 + 2\,d_1 J(J-1))\,\mathbf{C}^{-1} + 2\frac{\partial\Psi}{\partial I_4}\mathbf{a}_0\otimes\mathbf{a}_0 + 2\frac{\partial\Psi}{\partial I_6}\mathbf{b}_0\otimes\mathbf{b}_0 + 2\,k_1(I_8-1)\exp(k_2(I_8-1)^2)\,\mathbf{c}_0\otimes\mathbf{c}_0\,, \tag{3}$$

where $\mathbf{I}$ denotes the identity tensor, $\mathbf{C} = \mathbf{F}^T\mathbf{F}$ the right Cauchy-Green strain tensor, $\mathbf{F}$ the deformation gradient, $J = I_3$ its determinant, I_i all of its other invariants, and finally $\mathbf{a}_0$ and $\mathbf{b}_0$ denote in-plane fiber directions, and $\mathbf{c}_0$ the normal direction, both as seen in reference configuration. The derivatives of the strain energy Ψ with respect to the invariants I_4 and I_6 are defined as strictly monotonous and piecewise linear functions.

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