Modeling of anisotropic suede-like materials during thermoforming

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An extraordinary material

Alcantara® is an innovative material used to cover surfaces and shapes, not falling under any existing category. In fact, any classification would be wrong or limiting.

Alcantara® itself represents a new category of which it is the unique product, though many imitations have been attempted.

Aesthetic properties

- look
- writing effect
- softness
- colour

Functional properties

- mechanical resistance
- breathing ability
- enduring life
- simple maintenance
- colour fastness
- resistance to wrinkling

Workability

- low scrap
- consistency
- technological versatility

Technology

The incredible appeal of Alcantara® stems from an outstanding technological breakthrough, an invention dating back to 1970.

From a technical standpoint, Alcantara® can be defined as a *composite material in which the reinforcement is a non-woven structure of PET ultra-microfiber in a porous PU matrix.*

Alcantara® is the result of a unique, patented technology, still unequalled, which enables the product to maintain its cutting edge characteristics over a long period of time.

The world of Alcantara®

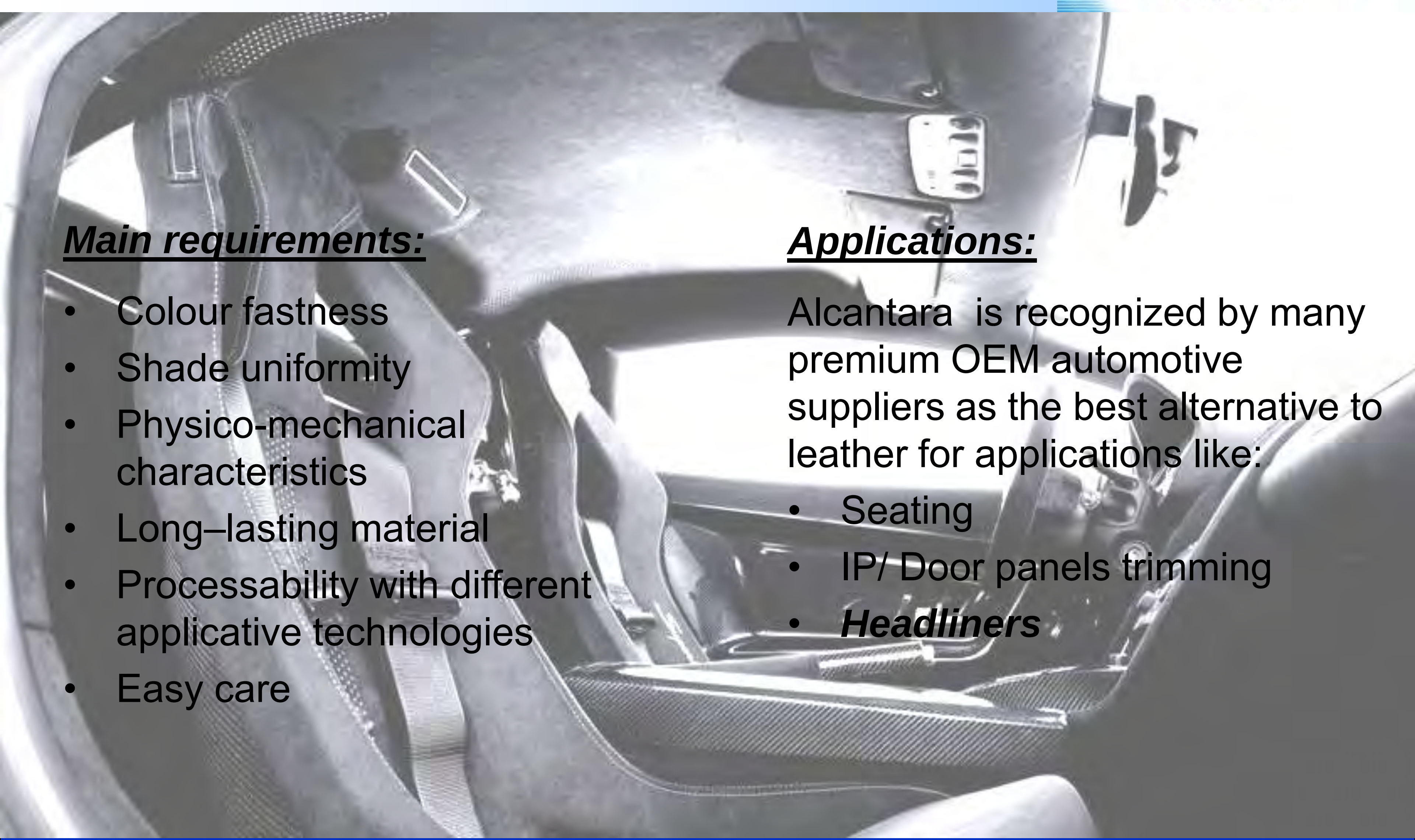
Alcantara® is a versatile material used by the most prestigious international companies in a variety of application sectors:

- AUTOMOTIVE
- FASHION & ACCESSORIES
- INTERIOR
- CONTRACT & YACHT

Alcantara® enhances design in all its forms!



Alcantara® - Automotive business area



Main requirements:

- Colour fastness
- Shade uniformity
- Physico-mechanical characteristics
- Long–lasting material
- Processability with different applicative technologies
- Easy care

Applications:

Alcantara is recognized by many premium OEM automotive suppliers as the best alternative to leather for applications like:

- Seating
- IP/ Door panels trimming
- ***Headliners***

Thermoforming of Alcantara® parts

- Alcantara® is not able to hold the shape by itself, so it must be always combined with a thermoplastic backing.
- The driving force to stretch the sheet into or onto a mould is provided either by vacuum or by a countermould.

“Simple” shape

↓

One-step moulding

(the covering and the backing are shaped together)

“Complex” shape

↓

Two-steps moulding

(the backing is pre-formed and placed onto the mould, then the covering is heated and glued on it, so to avoid wrinkles near small-ray curvatures)

Evaluation of thermoforming ability

If the covering is stretched far beyond its elastic limits - usually next to small hollows or reliefs - the material can either break or undergo a release of residual stresses (so detaching from the backing)

Traditional approach:

Empirical (trial-and-error)

- Use of “torture moulds” (*‹‹ Is the material able to withstand the most critical deformations expected for the final shape of the manufactured part? ››*)
- (*Worst case*) Smoothing of the sharpest edges of the final mould if some unexpected problem occurs.

Main drawbacks

- Expensive
- Time-consuming
- Rigid

New approach:

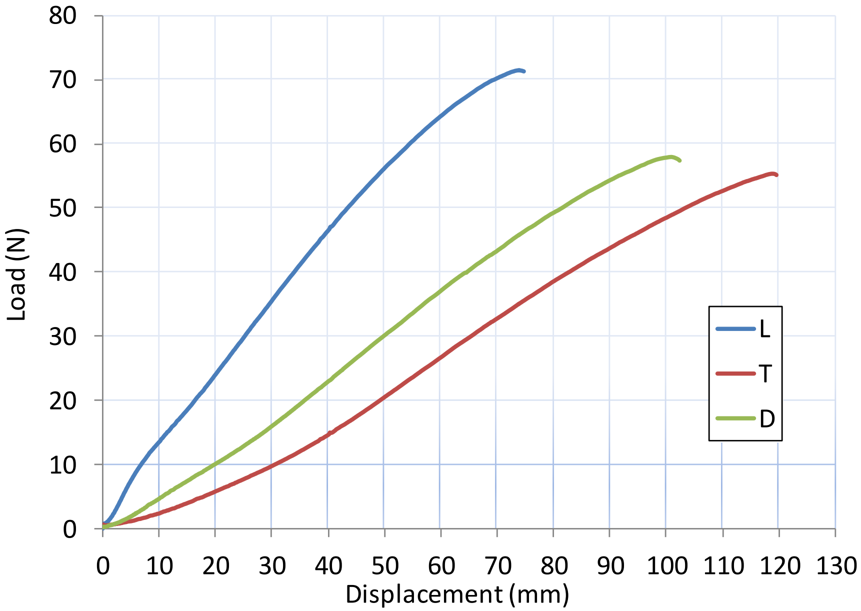
Software simulation

- Development of a software tool to:
  → Highlight critical points
  → Predict if the covering is able to withstand high local deformations

Main advantages

- Cost-effective
- Time-effective
- Versatile

Mechanical model



Load (N) / displacement (mm) curves at 90°C for the three directions analyzed: **warp (blue)**, **weft (red)**, **diagonal (green)**.

Experimental evidences:

1. Alcantara® is characterized by different mechanical performances in warp and weft directions
2. At deformations lower than 10% the material shows a nonlinear behaviour, probably due to the rearrangement of fiber distribution
3. During the process, the deformation occurs at an almost constant temperature

↓

Simplifying assumptions:

1. *The overall mechanical behaviour can be described by nonlinear orthotropic constitutive equations.*
2. *Any dependence on temperature can be neglected as a first approximation*
3. *Viscoelastic contributions are negligible.*

Mechanical model

Similar behaviours[1,2]:

→ “Soft composites” (e.g. fibre-reinforced rubber composites)

→ Biological tissues (e.g. arteries and tendons)

➥ A hyperelastic function was used to describe a material reinforced by families of fibres, whose mechanical properties depend on preferred fibre directions.

Typically, hyperelastic constitutive equations are based on the definition of a Helmholtz free-energy density Ψ, which can be expressed as a function of the invariants of the deformation tensor.

To take into account anisotropy, Ψ must be written as the sum of three terms:

$$\boxed{\Psi = \overline{\Psi}_g + \sum_i \overline{\Psi}_{fi} + U}$$

$$\overline{\Psi}_g = \frac{1}{2}\mu\left(\overline{I}_1 - 3\right)$$

(Neo–Hookean) energy density of the “ground matrix” (*g*)

$$\overline{\Psi}_{fi} = \frac{1}{2}\gamma_i\left(\overline{E}_i^2 - 1\right)$$

energy density of the *i-th* fibre family

$$U = -p\left(J_{el} - 1 + \frac{p}{2\kappa}\right)$$

volumetric contribution

E_i → Green-Lagrange strain-like quantity which characterizes the strain in the direction of the mean orientation $\mathbf{a}_{0i}$ of the *i-th* family of fibres:

$$\overline{E}_i = \delta\,\overline{I}_1 + \left(1 - 3\delta\right)\overline{I}_{4i} - 1$$

$$\overline{I}_{4i} = \mathbf{a}_{0i} \otimes \mathbf{a}_{0i} : \overline{\mathbf{C}} = \sum_{i,j}\left(\mathbf{a}_{0i}\mathbf{a}_{0i}\right)_{ij} C_{ij}$$

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1. Gasser, T.C., Ogden, R.W. and Holzapfel, G.A. 2006.
2. Tuan, H.S. and Marvalova, B. 2007.

Mechanical model – Nomenclature

$\mathbf{F}(\mathbf{X}) = \partial\chi(\mathbf{X})/\partial\mathbf{X}$, deformation gradient

$\mathbf{C} = \mathbf{F}^T\mathbf{F}$, right Cauchy – Green tensor

$J_{el} = \det(\mathbf{F})$, spherical (dilatational) elastic volume variation

$\overline{\mathbf{F}} = J_{el}^{-1/3}\mathbf{F}$, isochoric (distortional) deformation, $\det(\mathbf{F}) = 1$

$\overline{\mathbf{C}} = \overline{\mathbf{F}}^T\,\overline{\mathbf{F}} = J_{el}^{-2/3}\mathbf{C}$, modified right Cauchy – Green tensor

$\bar{\mathrm{I}}_1 = tr(\overline{\mathbf{C}}) = \overline{C}_{11} + \overline{C}_{22} + \overline{C}_{33}$, first modified invariant

μ → Shear modulus

γ_{i} → fiber deformation coefficients, one for each mean direction

δ → dispersion parameter related to the spatial distribution of fibres (*0 for ideal alignment*)

ν → Poisson coefficient (close to the upper limit 0.5 for weakly compressible materials)

$$\kappa = \frac{2\mu(1+\nu)}{3(1-2\nu)} \rightarrow \text{Bulk modulus}$$

For the volumetric contribution, assuming that Alcantara® can be treated as an almost uncompressible material, a value of $\nu = 0.499$ has been considered, which gives $\kappa = 499.67\mu$

Use of COMSOL Multiphysics

Determination of constitutive parameters

➯ An anisotropic hyperelastic neo-Hookean soft-matrix composite material is univocally identified by the following parameters:

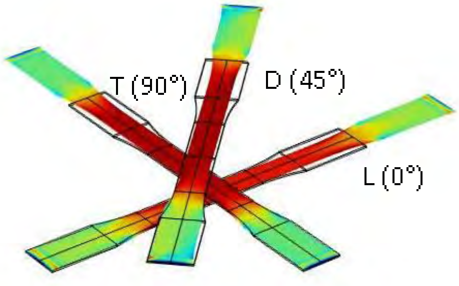
μ → isochoric strain energy density coefficient

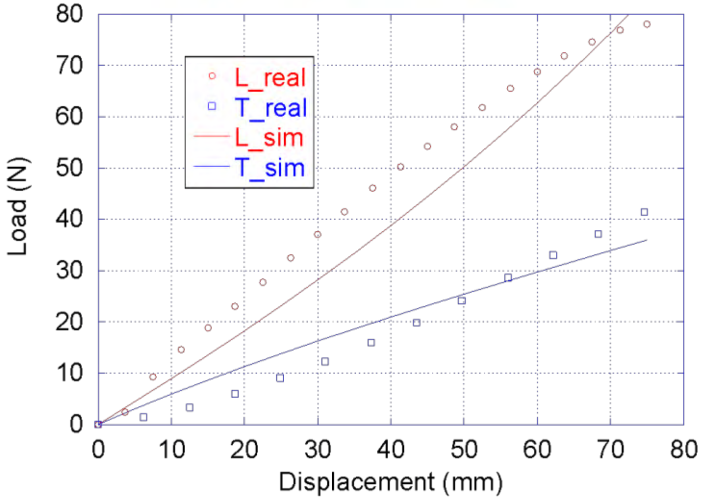
γ_1, γ_2 → fibre deformation coefficients (warp & weft directions)

Problem:
It is very difficult to get a direct measure of each characteristic parameter

Solution:
Reverse analysis of uniaxial tensile tests (@ 90°C).

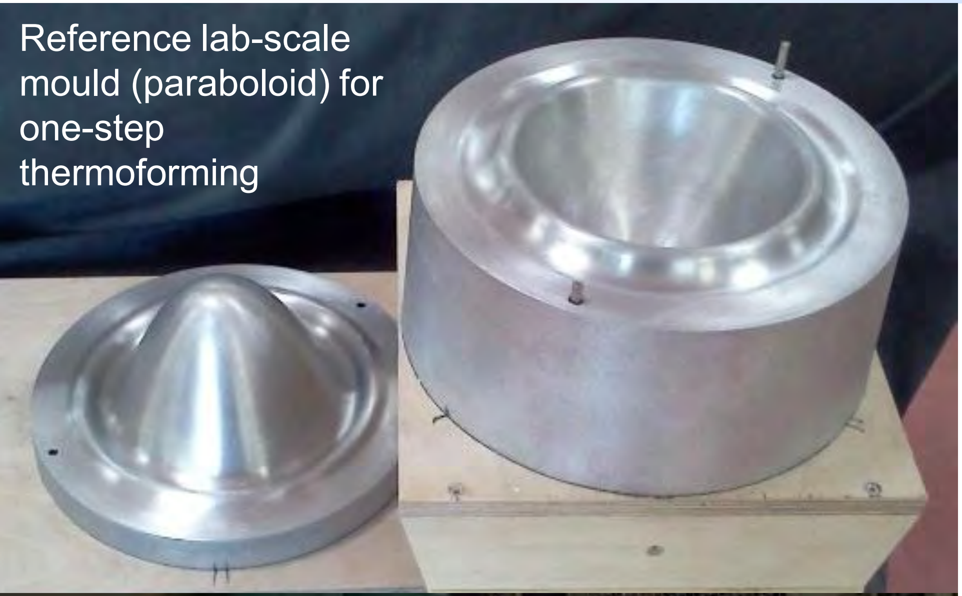
Therefore, COMSOL Optimization has been used to fit the simulation to real uniaxial tensile deformations of dogbone samples cut along 0°/45°/90° directions with respect to the selvedge:



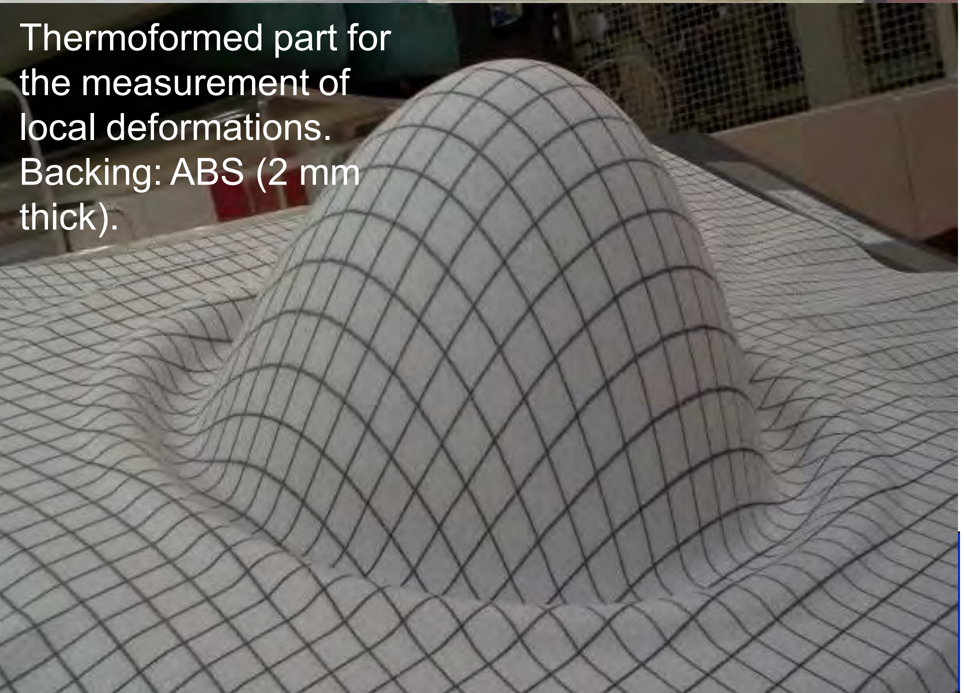


Real vs. numerical data for L and T uniaxial tests.

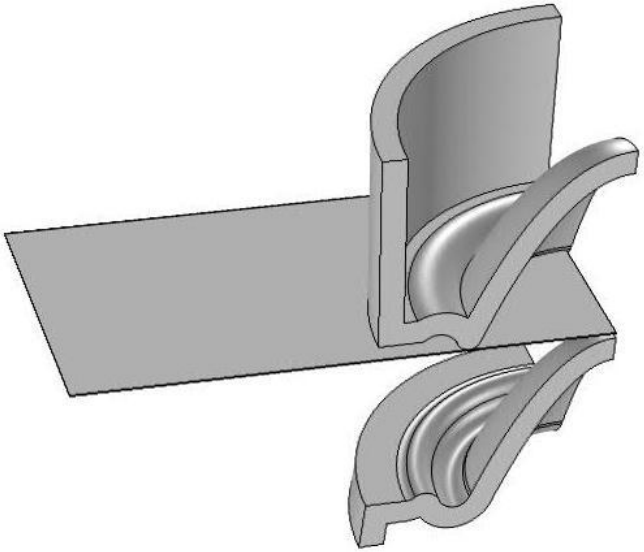
Case study: Pilot mould



Reference lab-scale mould (paraboloid) for one-step thermoforming



Thermoformed part for the measurement of local deformations. Backing: ABS (2 mm thick).



Simulation of thermoforming with a pilot mould

(*axial symmetry, very high local deformations*)

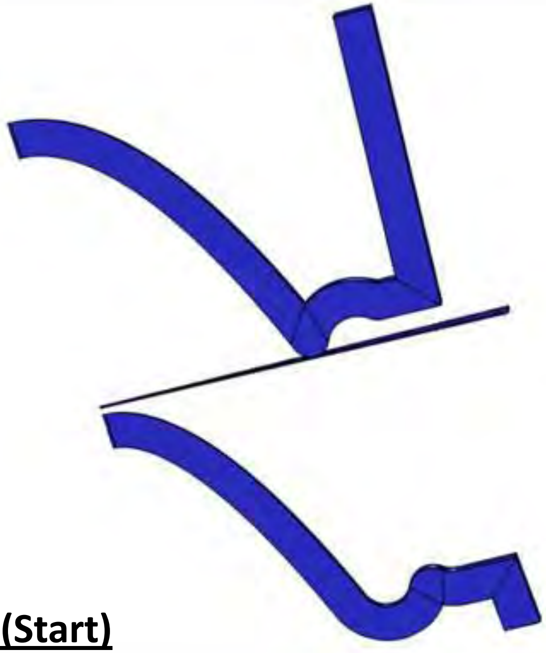
Boundary conditions:

→ Fabric fixed at the external boundaries;

→ Top mould (female) fixed;

→ Bottom mould (male) moving upwards at a constant speed (gap closed after 1 s);

→ Very high friction coefficient between the lower side of the fabric and the external surface of the male mould, to simulate the effect of the glue (acting instantaneously at the time of contact).



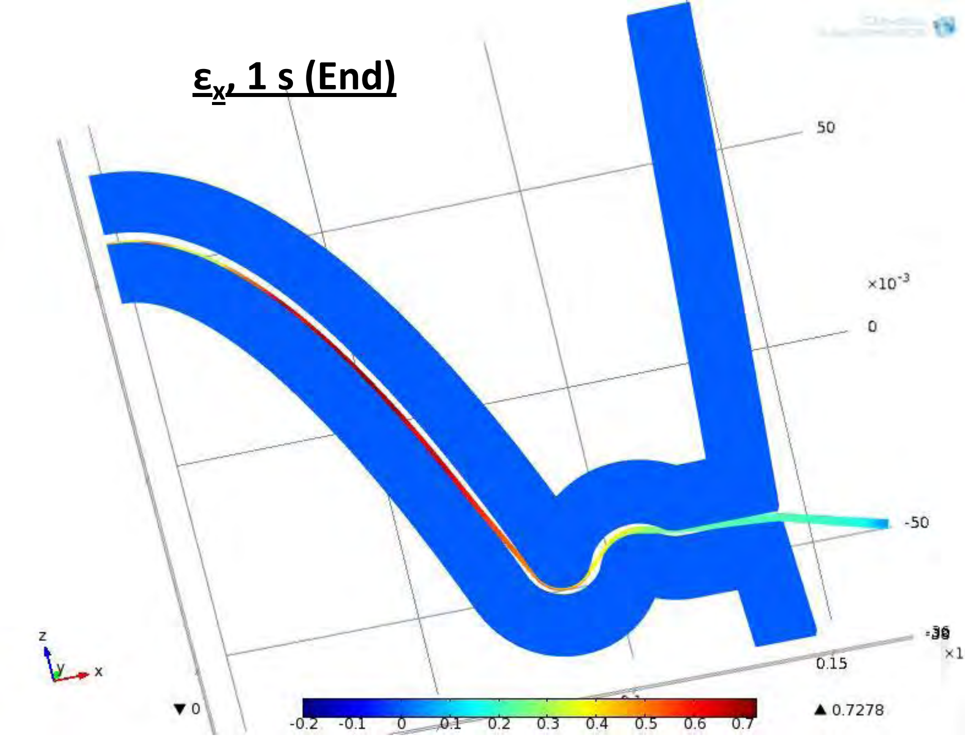
ε_x, 0 s (Start)

ε_x, 0.25 s

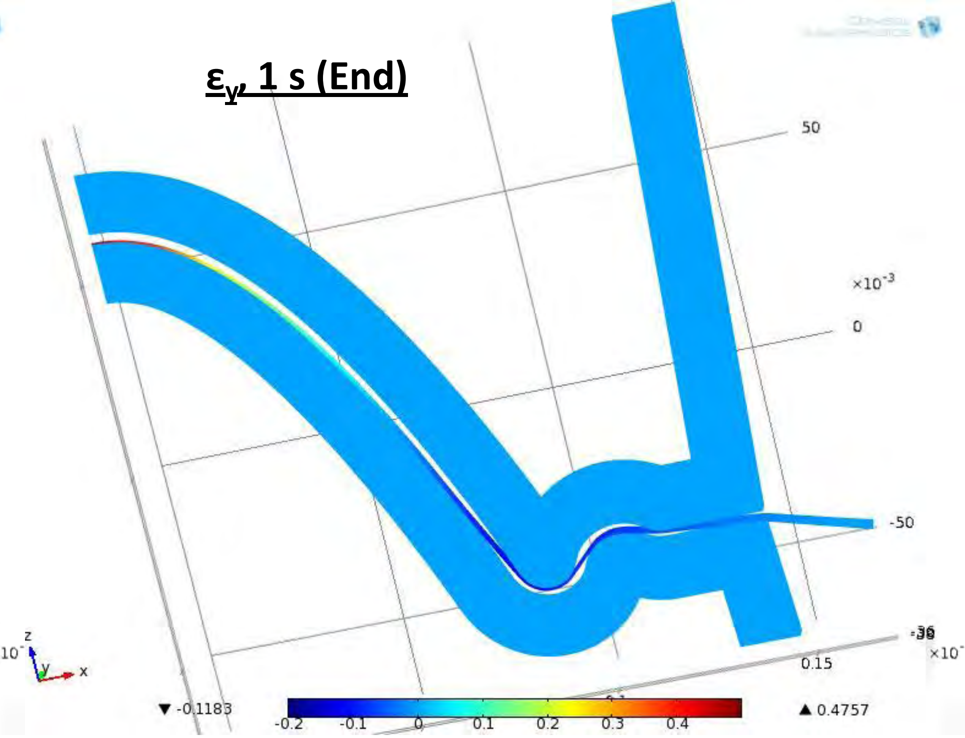
ε_x, 0.50 s

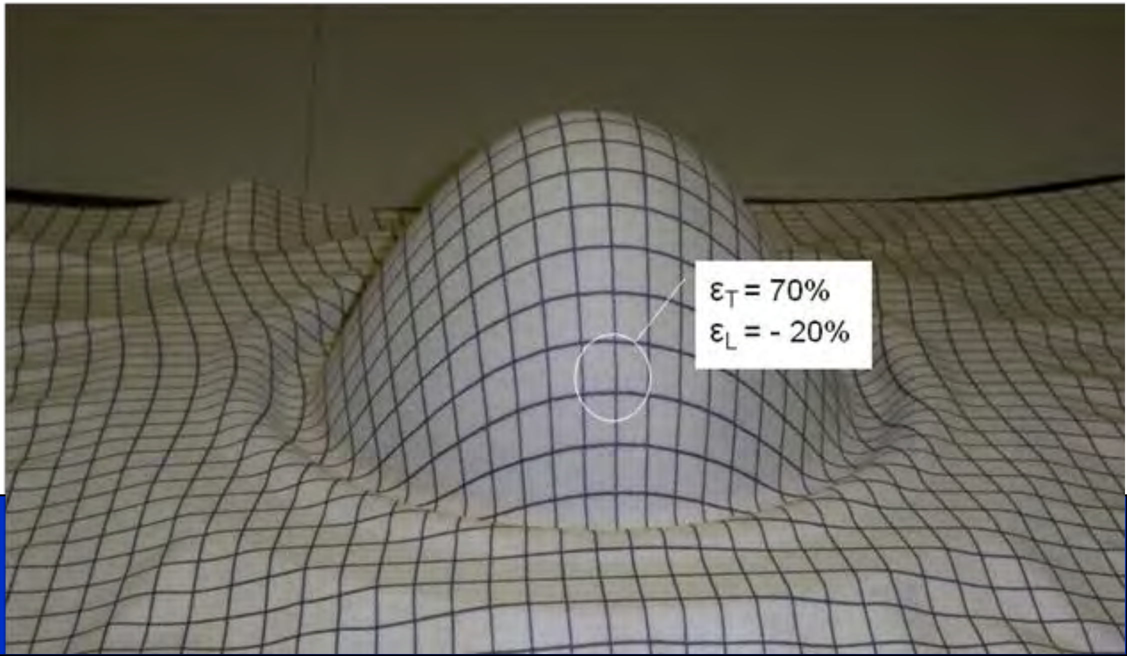
ε_x, 0.75 s

ε_x, 1 s (End)



ε_y, 1 s (End)





$\varepsilon_T = 70\%$

$\varepsilon_L = -20\%$

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Conclusions and future work

- An *orthotropic hyperelastic neo-Hookean model* has been proposed and verified for Alcantara® products, based on the definition of a free-energy density as a function of different contributions coming from both matrix and fibres
- The *constitutive parameters* were determined through a *reverse analysis of load/displacement curves* for dogbone samples cut along 0°/45°/90° angles with respect to the selvedge, which underwent uniaxial tensile tests at 90°C.
- The model showed a fair ability to predict the real behaviour of Alcantara® under plane stress conditions, so it was applied to the *simulation of thermoforming within a pilot mould*. Even in this case, a reasonable agreement between real and numerical results was found.
- The present work describes a first attempt to predict the mechanical behaviour of Alcantara® when it undergoes conditions of high temperature and pressure. Obviously, the above mentioned model can be enriched from many points of view, for example by using *more complex hyperelastic laws*, or by taking into account the *temperature dependence of material characteristic parameters*.
- If a good predicting ability will be demonstrated, this will allow the *application of the model to real case studies*, like thermoforming of car headliners.

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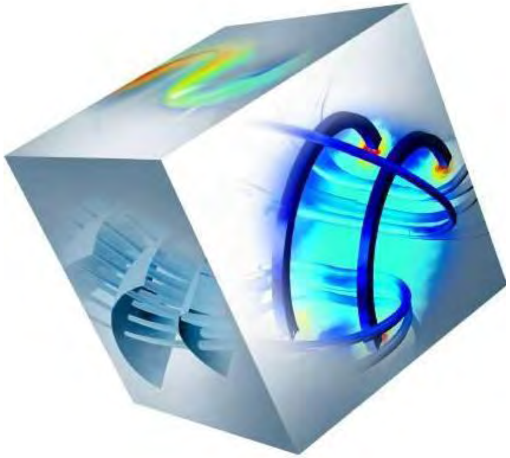

Alcantara® Research & Development

Thank you for your attention!

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