Tension-compression asymmetry modelling:

strategies for anisotropy parameters identification.

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Agenda

- Motivation
- Objectives
- Constitutive model
  - Yield criteria
- Material parameters identification
- Cup drawing of a circular blank
  - Problem description
  - Results and discussion
- Other numerical examples

Motivation

In recent years, modern industries are increasingly relying in metals with outstanding thermal and mechanical properties

Titanium

…

Magnesium-Lithium alloys

Zirconium

- ✗ Poor formability
- ✗ High manufacturing costs

Motivation

Hexagonal close-packed materials (HCP)

Activation of single crystal deformation mechanisms

Slip with pronounced non-Schmidt effect

Tension-compression asymmetry

Motivation

Numerical Simulation!

Modelling → Functions capable of modelling T-C

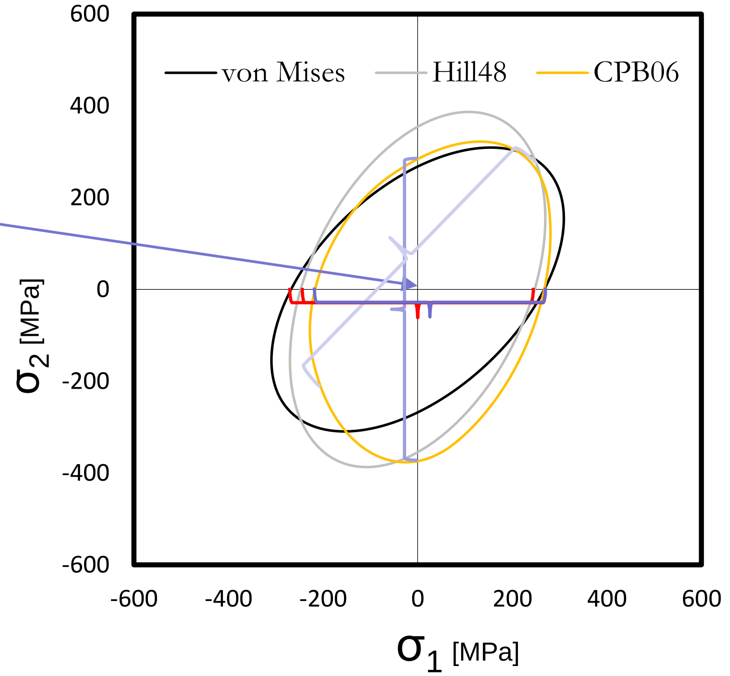
Characterization → Buckling effects (compression stress states)…

Motivation

Plastic response in metals

- Yield surface
- Flow rule
- Hardening law

Point-symmetry



Cazacu Barlat Plunkett, 2006, yield criterion allows modelling of tension-compression asymmetry

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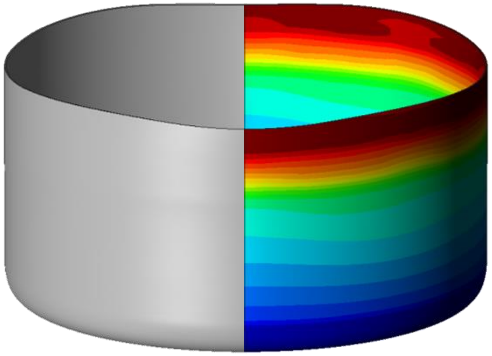
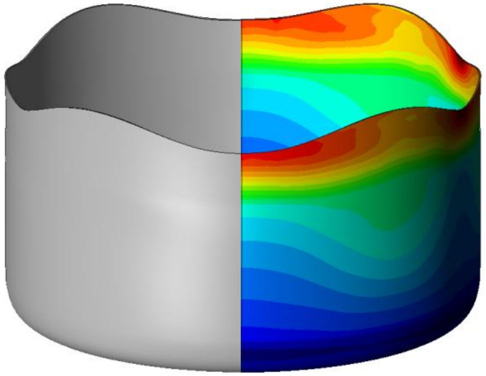
Objectives



- Anisotropy parameters identification for two yield criteria
  - CPB06
  - YLD91



- Influence of accounting for tension-compression asymmetry in the numerical simulation of a cup drawing

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Yield criteria

CPB06

- Equivalent stress given by

$$\bar{\sigma} = B\left[\left(\left|s_1\right| - k\, s_1\right)^a + \left(\left|s_2\right| - k\, s_2\right)^a + \left(\left|s_3\right| - k\, s_3\right)^a\right]^{\frac{1}{a}}$$

s_1, s_2 and s_3 are the principal stresses of $\mathbf{S} = \mathbf{C}\boldsymbol{\sigma}'$ and

$$B = \left[\frac{1}{\left(\left|\phi_1\right| - k\, \phi_1\right)^a + \left(\left|\phi_2\right| - k\, \phi_2\right)^a + \left(\left|\phi_3\right| - k\, \phi_3\right)^a}\right]^{\frac{1}{a}}$$

k and a are material parameters

Yield criteria

CPB06

$$B=\left[\frac{1}{\left(|\phi_1|-k\,\phi_1\right)^a+\left(|\phi_2|-k\,\phi_2\right)^a+\left(|\phi_3|-k\,\phi_3\right)^a}\right]^{\frac{1}{a}}$$

where

$$\begin{Bmatrix}\phi_1\\ \phi_2\\ \phi_3\end{Bmatrix}=\begin{Bmatrix}(2/3)C_{11}-(1/3)C_{12}-(1/3)C_{13}\\ (2/3)C_{21}-(1/3)C_{22}-(1/3)C_{23}\\ (2/3)C_{31}-(1/3)C_{32}-(1/3)C_{33}\end{Bmatrix}$$

$$\mathbf{C}=\begin{bmatrix}C_{11}&C_{12}&C_{13}&0&0&0\\ C_{12}&C_{22}&C_{23}&0&0&0\\ C_{13}&C_{23}&C_{33}&0&0&0\\ 0&0&0&C_{44}&0&0\\ 0&0&0&0&C_{55}&0\\ 0&0&0&0&0&C_{66}\end{bmatrix}$$

Yield criteria

YLD91

- Equivalent stress given by

$$\bar{\sigma} = \left\{\frac{1}{2}\left[|s_1 - s_2|^m + |s_2 - s_3|^m + |s_1 - s_3|^m\right]\right\}^{\frac{1}{m}}$$

Note:
m = 6 BCC
m = 8 FCC

s_1, s_2 and s_3 are the principal stresses of $\mathbf{S} = \mathbf{L}\boldsymbol{\sigma}'$ and

$$\mathbf{L} = \begin{bmatrix} (c_2 + c_3)/3 & -c_3/3 & -c_2/3 & 0 & 0 & 0 \\ -c_3/3 & (c_3 + c_1)/3 & -c_1/3 & 0 & 0 & 0 \\ -c_2/3 & -c_1/3 & (c_1 + c_2)/3 & 0 & 0 & 0 \\ 0 & 0 & 0 & c_4 & 0 & 0 \\ 0 & 0 & 0 & 0 & c_5 & 0 \\ 0 & 0 & 0 & 0 & 0 & c_6 \end{bmatrix}$$

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Anisotropy parameters identification

- The yield criterion should reproduce the material’s mechanical behavior

$$F(\mathbf{A}) = \sum_{\theta=0}^{90} w_{\sigma_\theta^T}\left(\sigma_\theta^{Y_T}(\mathbf{A})\big/\sigma_\theta^{Y_T} - 1\right)^2 + \sum_{\theta=0}^{90} w_{\sigma_\theta^C}\left(\sigma_\theta^{Y_C}(\mathbf{A})\big/\sigma_\theta^{Y_C} - 1\right)^2 + \sum_{\theta=0}^{90} w_{r_\theta}\left(r_\theta(\mathbf{A})/r_\theta - 1\right)^2$$
$$+ w_{\sigma_b}\left(\sigma_b(\mathbf{A})/\sigma_b - 1\right)^2 + w_{r_b}\left(r_b(\mathbf{A})/r_b - 1\right)^2$$

$\mathbf{A}$ - set of anisotropy parameters

$\sigma_\theta^{Y_T}$, $\sigma_\theta^{Y_C}$ - experimental yield stresses in tension and compression

r_θ - experimental *r*-values

σ_b - experimental biaxial yield stress

r_b - experimental disc compression test *r*-value

Anisotropy parameters identification

2090-T3 aluminum

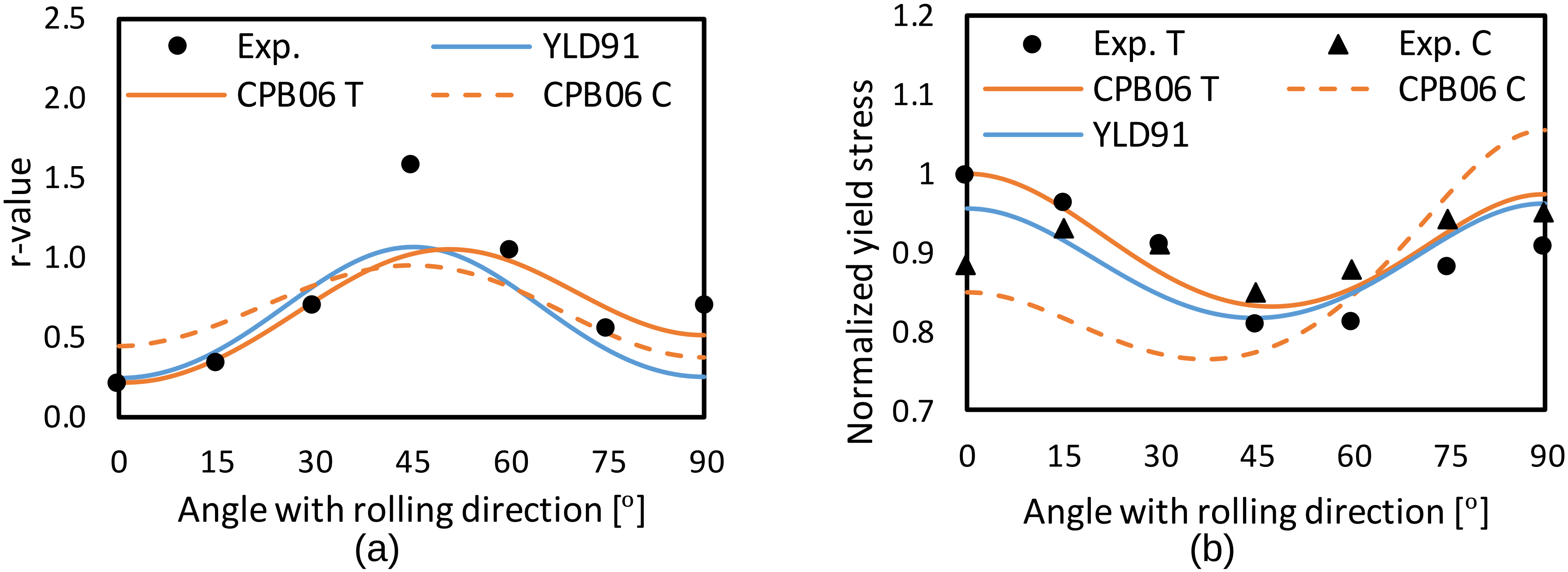

Figure 1. Experimental and predicted (a) *r*-value and (b) normalized yield stress.

- CPB06 shows a different behavior in tension and compression
- Though not very flexible.

Anisotropy parameters identification

2090-T3 aluminum

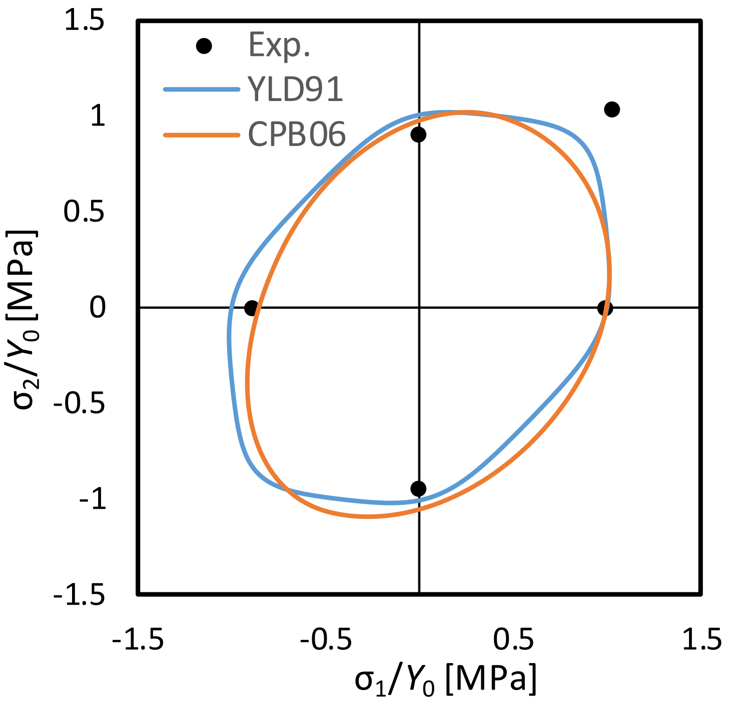

Figure 2. Predicted yield surfaces.

Table 1. Ratios obtained for the three principal axis.

	$\left(\sigma_1^T/\sigma_1^C\right)$	$\left(\sigma_2^T/\sigma_2^C\right)$	$\left(\sigma_3^T/\sigma_3^C\right)$
Experimental	1.1274	0.9549	-
CPB06	1.1756	0.9217	1.0361

Table 2. Experimental and numerically predicted biaxial tensile values.

	σ_b	r_b
Experimental	289.40	0.670
YLD91	230.83	0.971
CPB06	219.42	0.968

- Neither yield criterion accurately describes the biaxial point.
- Ratios are only an indication

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Problem description

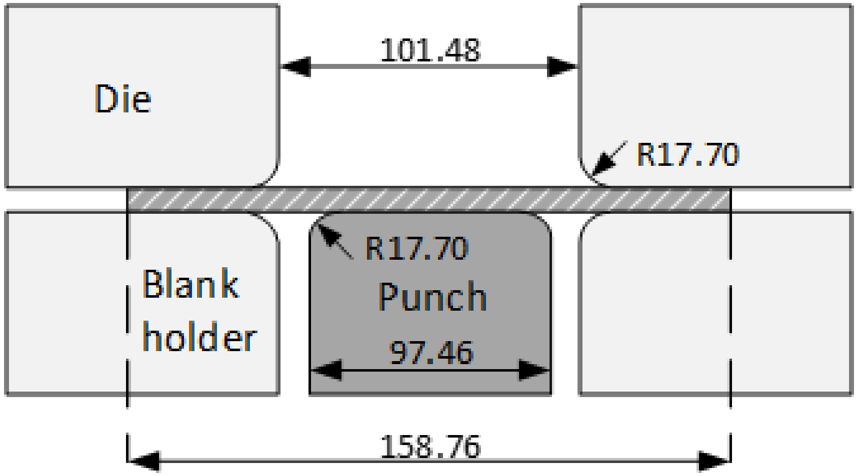


Figure 3. Schematic of the cup drawing and main dimensions.

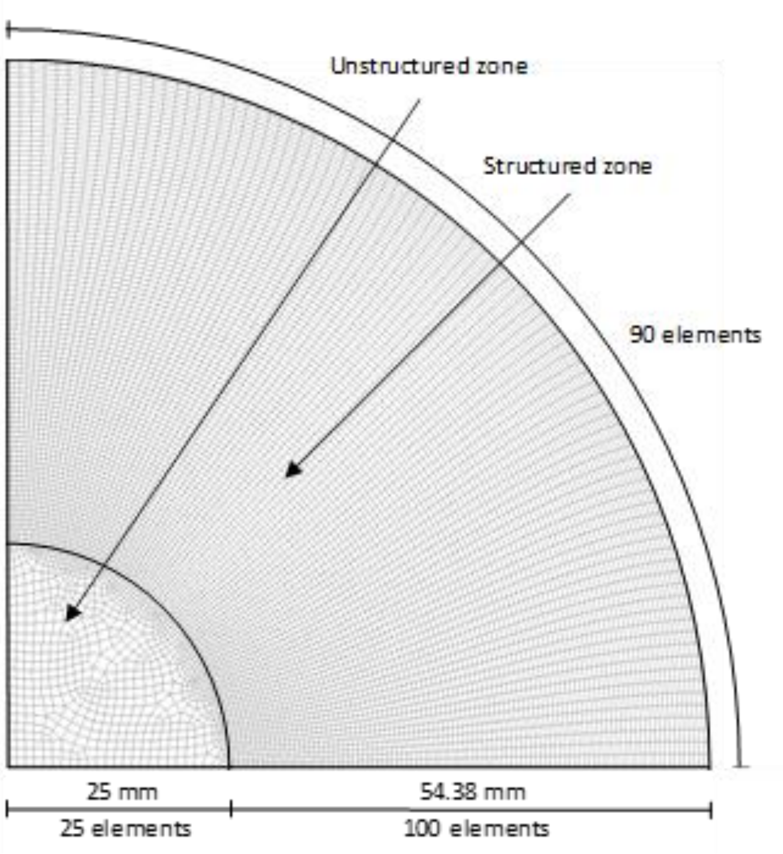
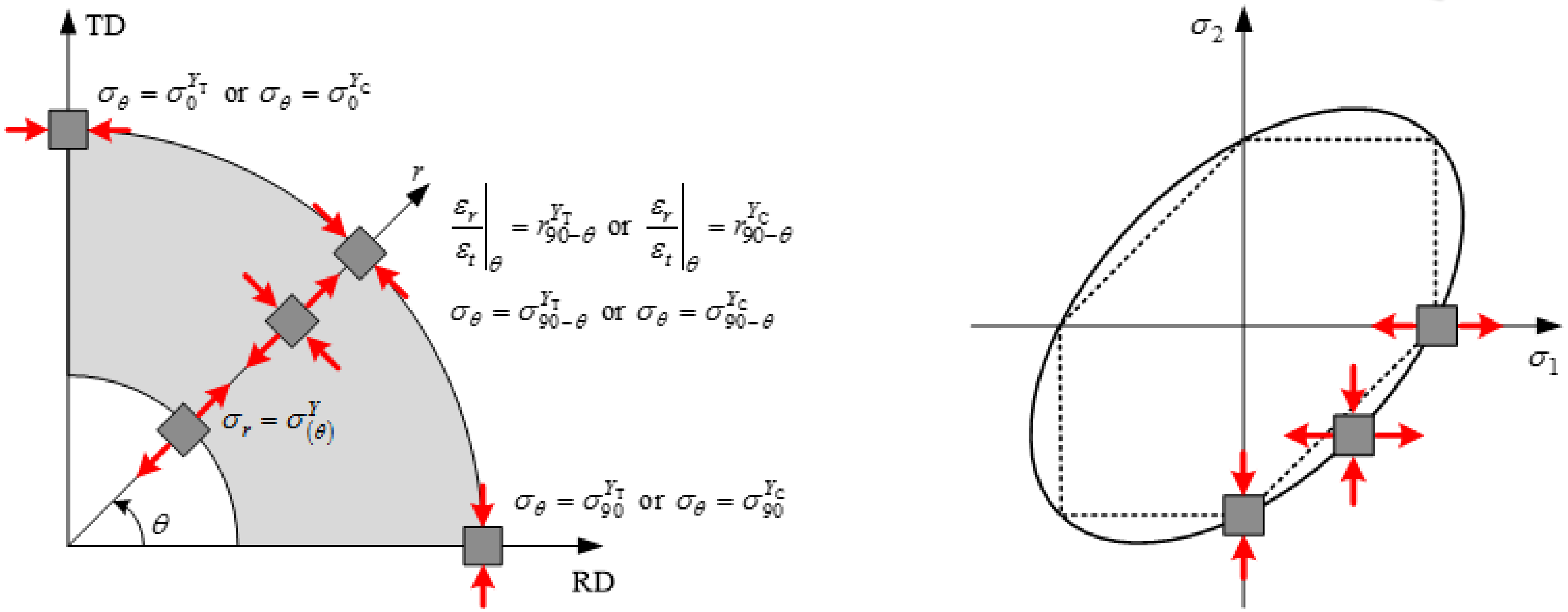


Figure 4. In-plane blank sheet discretization.

Results and discussion



(a) (b)

Figure 5. Deformation of an element on the flange: (a) stress states on the flange and (b) stress states on the yield surface (adapted from Yoon et al. 2011).

- The rim response in the Rolling Direction will be dictated by the material properties in the Transverse direction.

Results and discussion

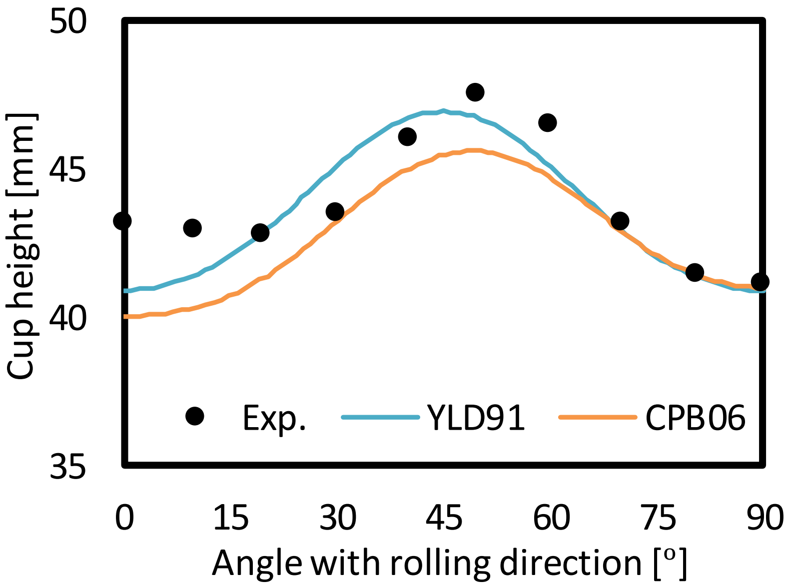


Figure 6. Comparison between experimental and numerically predicted cup height vs. angle from rolling direction.

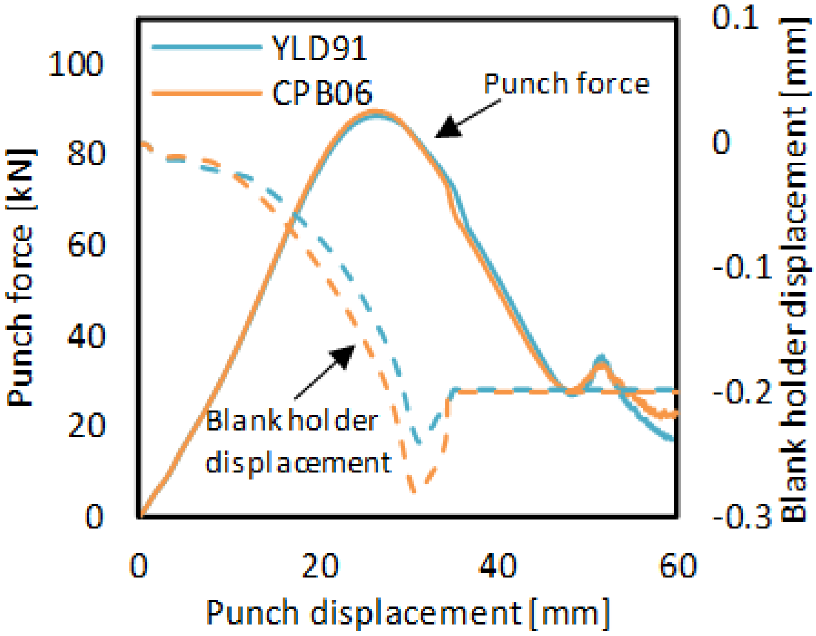


Figure 7. Numerically predicted punch force and blank holder displacement with punch displacement.

- CPB06 has a lower earing profile, coherent with latter yielding – higher yield stress in TD.
  - Also higher *r*-value at TD.

Results and discussion

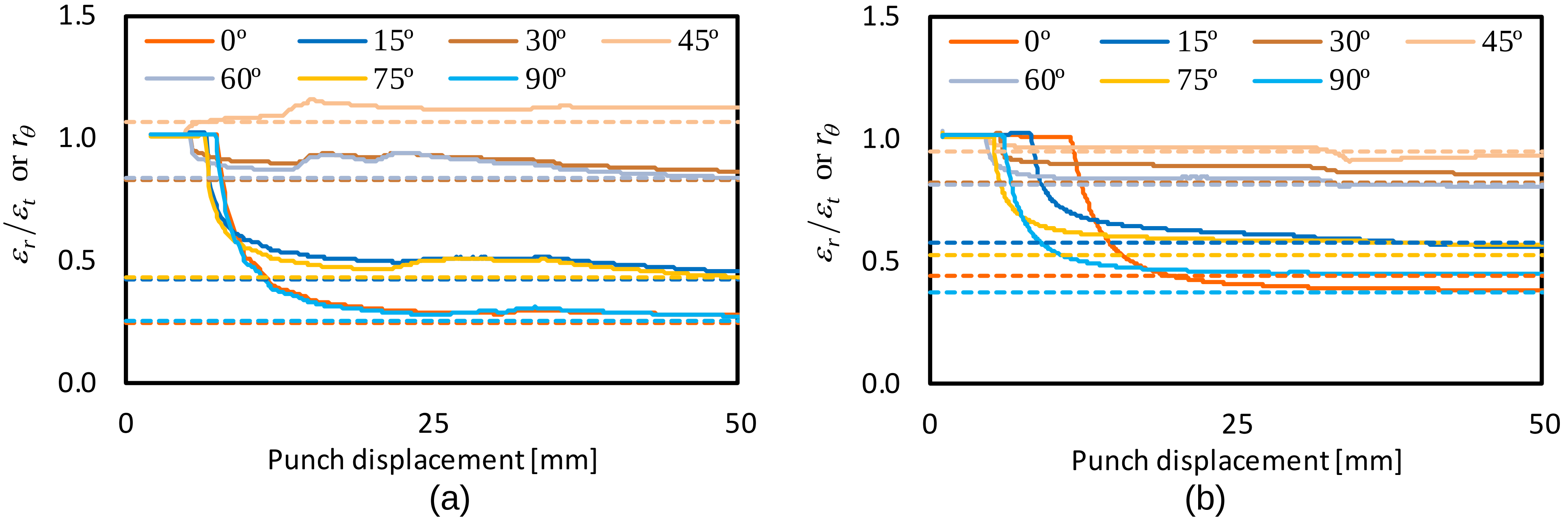


Figure 8. Evolution, with the punch displacement, of $\varepsilon_r/\varepsilon_t$ (solid lines) and *r*-values (dashed lines) estimated with (a) YLD91 and (b) CPB06 yield criteria.

- Both yield criteria predicted and calculated values are in very good agreement.
- Low blank-holder force allows not altering the stress state in the flange

Results and discussion

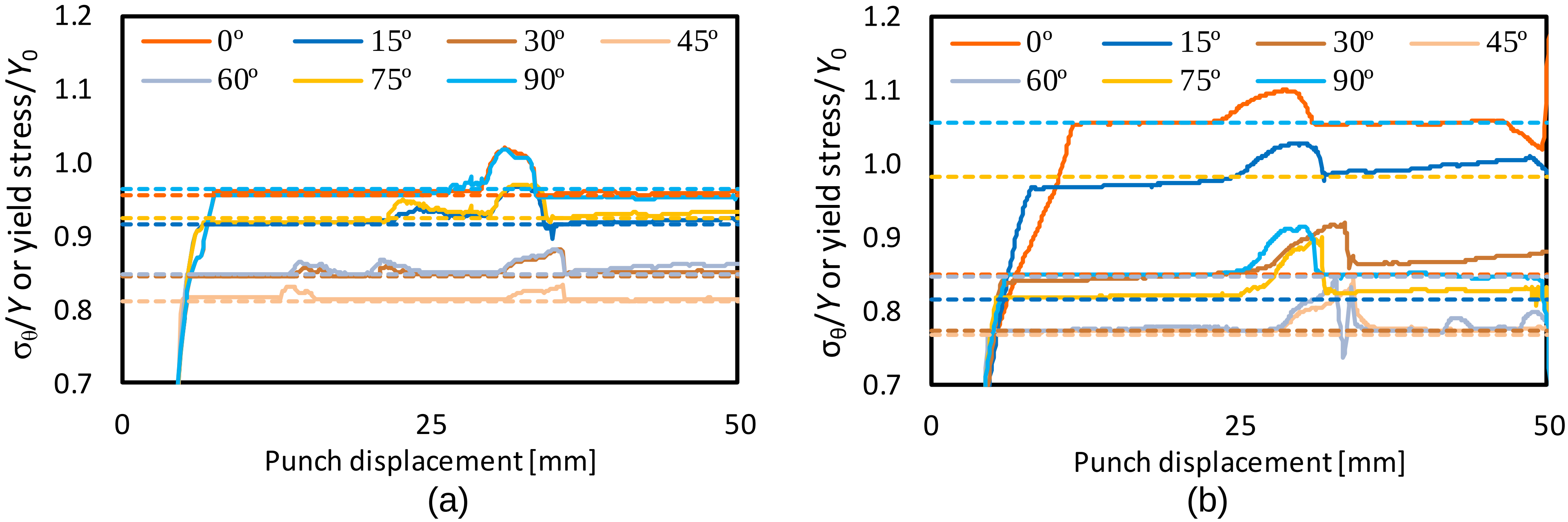


Figure 9. Evolution, with the punch displacement, of σ_θ/Y (solid lines) and ratio between yield stress (dashed lines) estimated with (a) YLD91 and (b) CPB06 yield criteria.

- Both yield criteria predicted and calculated values are in very good agreement.
- Low blank-holder force allows not altering the stress state in the flange

Results and discussion

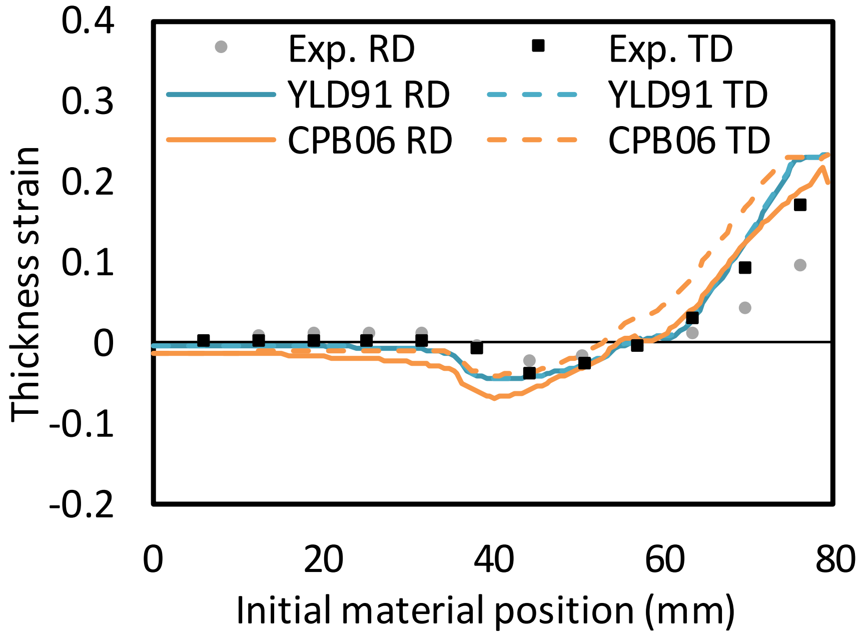


Figure 10. Evolution of the predicted and measured strain, for the YLD91 and CPB06 yield criteria, regarding the rolling and transverse directions.

- CPB06 predicts the difference between RD and TD.

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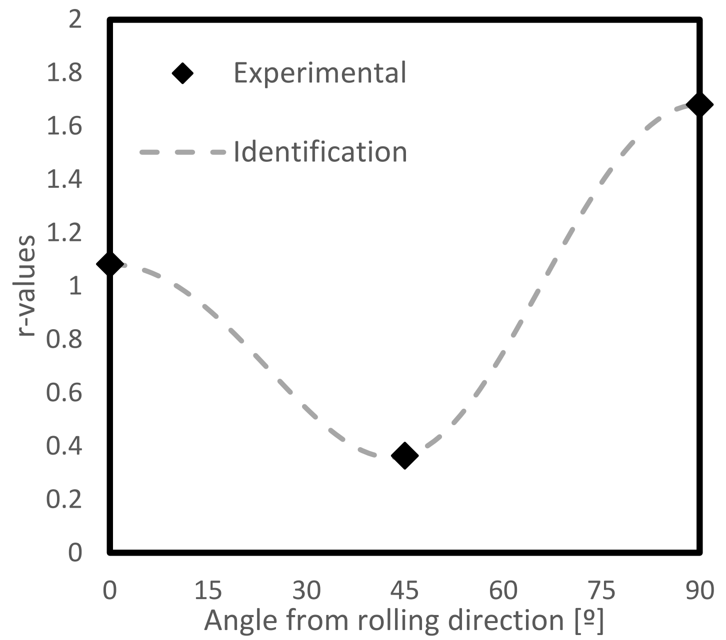
Other numerical examples

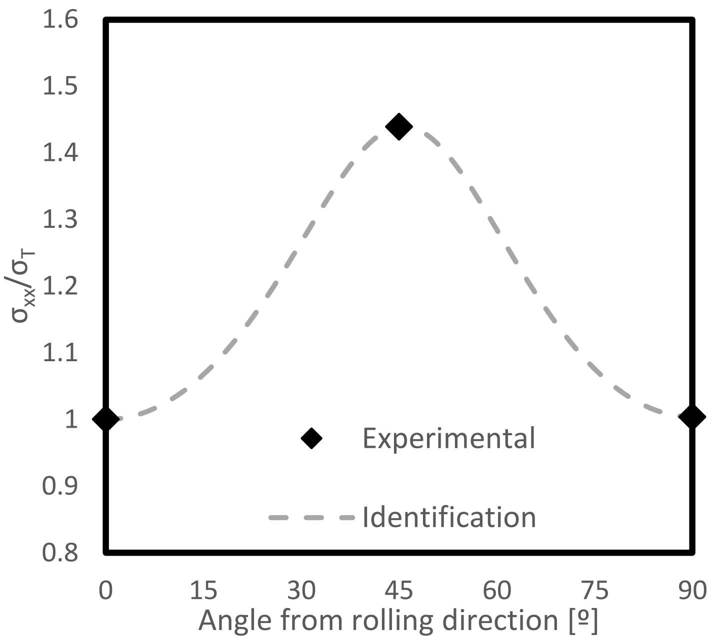
- Four-point bending test (Zirconium)

Zirconium

Other numerical examples

Mg-AZ31 magnesium alloy





	Exp	Id
σ_b	213,31	213,29
r_b	0,579	0,579

Example of an identification using only tensile results

Other numerical examples

- Four-point bending test (Zirconium)

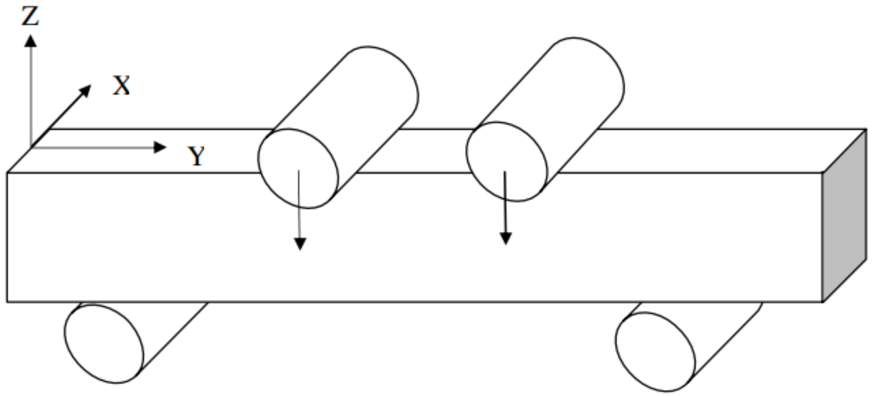


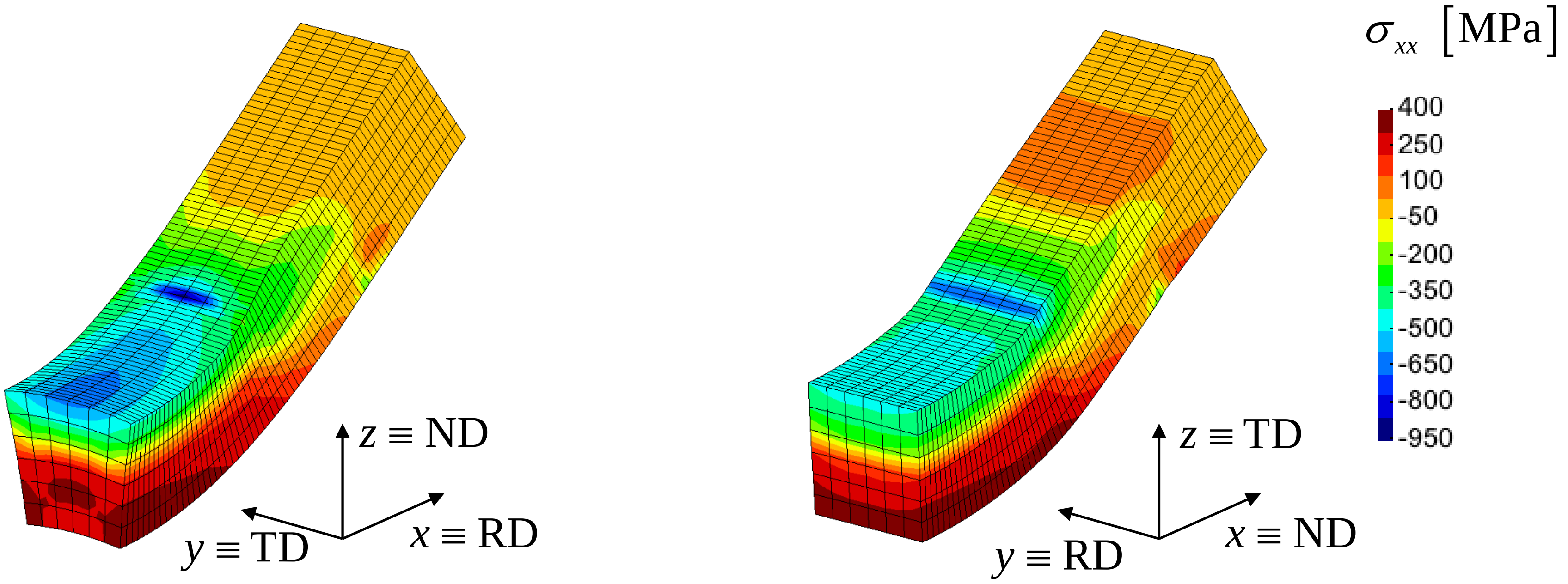
Figure 9. Evolution of the predicted and measured strain, for the YLD91 and CPB06 yield criteria, regarding the rolling and transverse directions.

Isotropic material $(\mathbf{C} = \mathbf{I})$ and $k = 0$

Other numerical examples

- Four-point bending test (Zirconium)

$$\frac{\sigma_{\mathrm{RD}}^{\mathrm{T}}}{\sigma_{\mathrm{RD}}^{\mathrm{C}}}=0.88;\quad \frac{\sigma_{\mathrm{TD}}^{\mathrm{T}}}{\sigma_{\mathrm{TD}}^{\mathrm{C}}}=0.96;\quad \frac{\sigma_{\mathrm{ND}}^{\mathrm{T}}}{\sigma_{\mathrm{ND}}^{\mathrm{C}}}=1.40$$

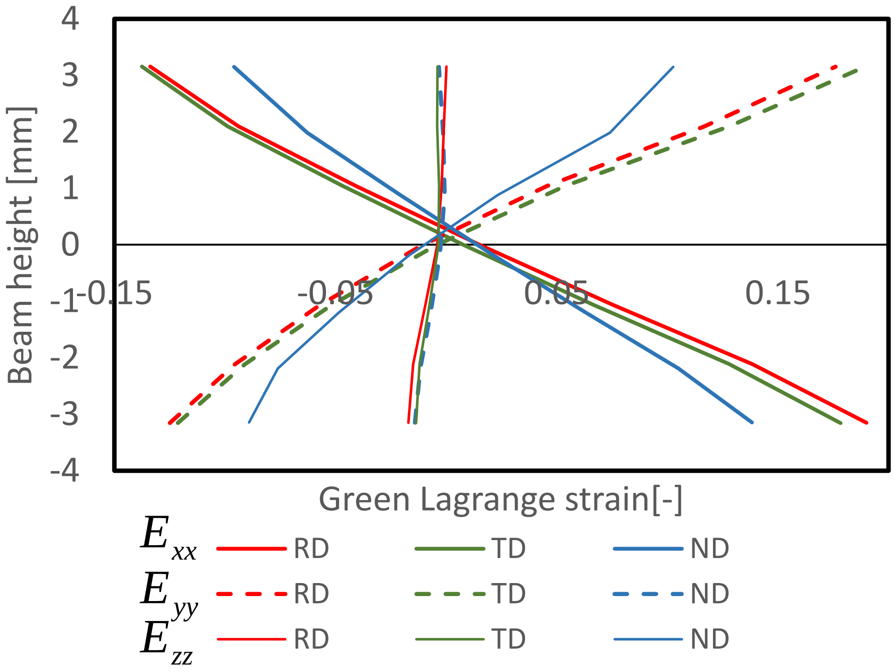


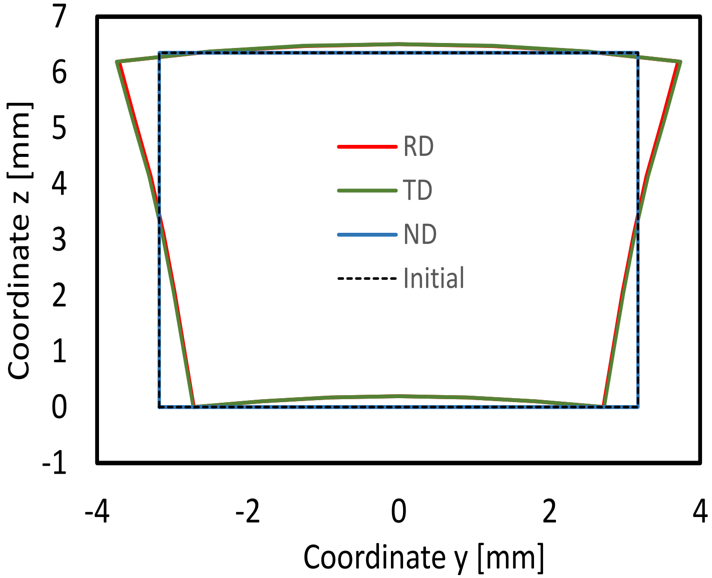
Rolling direction

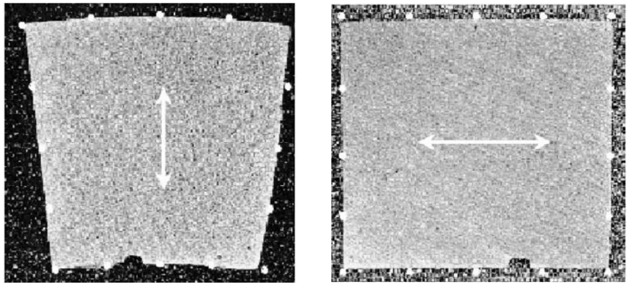
Normal direction

Other numerical examples

Four-point bend test (Zirconium) [2]







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