ESAFORM 2021 cup drawing benchmark of an Al alloy: critical follow up analysis of its potentials

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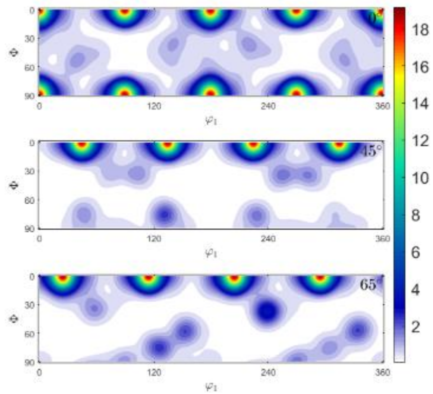
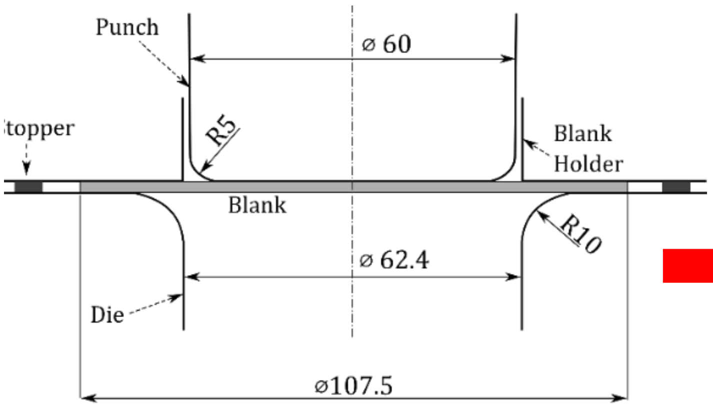
AGENDA

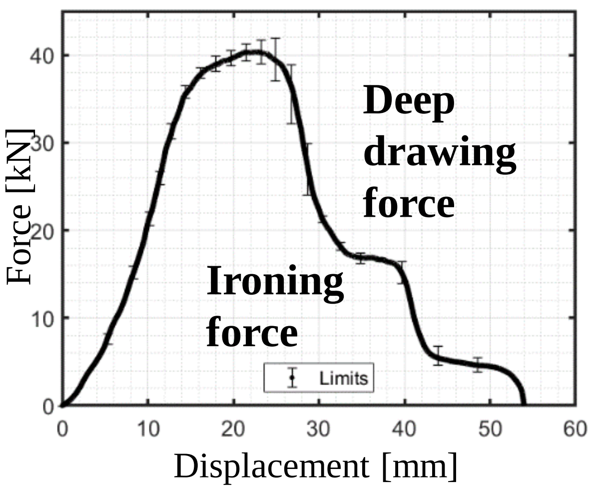
Summary of Benchmark article + Follow up actions

- ✓ Introduction *Anne Marie*
- ✓ Earing predictions *Oana*
- ✓ Force predictions *Marta*
- ✓ Conclusions *Anne Marie*

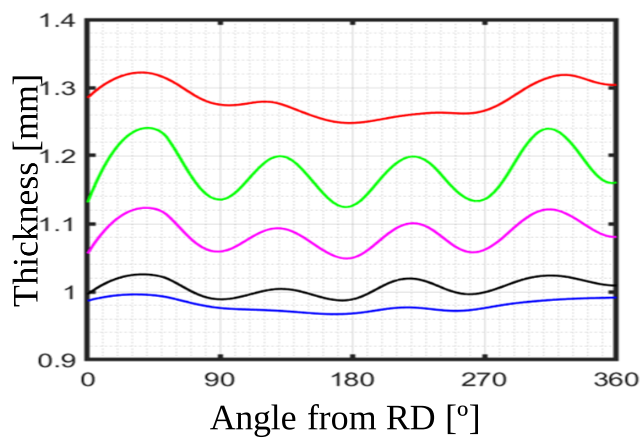


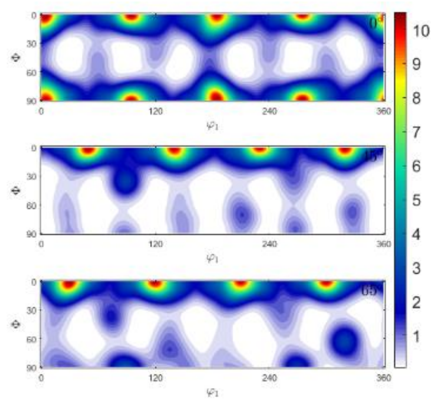
Initial texture





At different heights from cup bottom





Texture mid wall

Cup drawing of a circular blank (Φ =107.5mm) of AA 6016 sheet

ESAFORM Benchmark Spirit & Goals

Science, collaboration, friendships are the winners

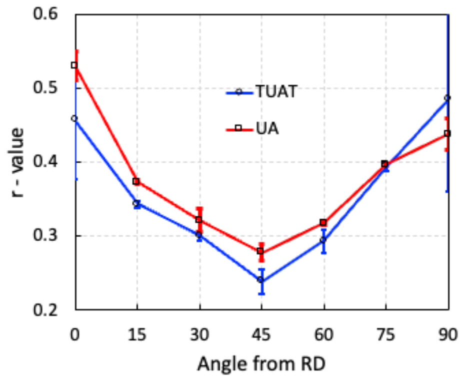
✓ Need for collaborative work to improve understanding

✓ Opportunity to explain sources of discrepancy in results

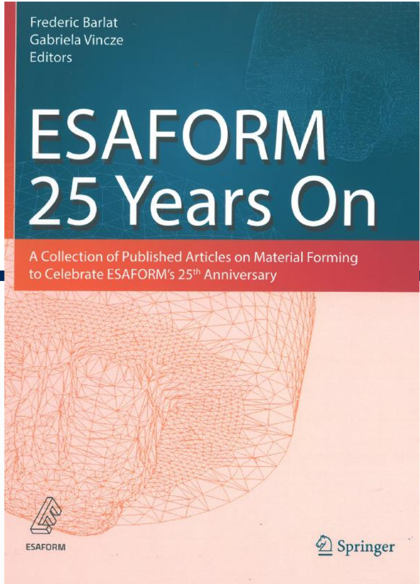
✓ Results shared in:
- public session at ESAFORM2021 conference
- open access article-Int. Jour. of Material Forming with contributions from all the participants

  with in-depth analysis of the results
- shared data in an open depository **Zenodo**

Not only Earing and Force-displacement:
- **Variability of experiments**
- **Identification methodology**
- **Yield locus and Lankford coefficient**
- **Interactions between experimentalists and modelers**



Called ref [1] hereafter



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Analysis of ESAFORM 2021 cup drawing benchmark of an Al alloy, critical factors for accuracy and efficiency of FE simulations

A.M. Habraken, T.A. Aksen,J.L. Alves, R.L. Amaral, E. Betaieb, N. Chandola, L. Corallo, D.J. Cruz, L. Duchêne, B. Engel,·E. Esener, M. Firat, P. Frohn-Sörensen, J. Galán-López, H. Ghiabakloo, L.A.I. Kestens, J. Lian, R. Lingam, W. Liu, J. Ma, L.F. Menezes, T. Nguyen-Minh, S.S. Miranda, D.M. Neto, A.F.G. Pereira, P.A. Prates, J. Reuter, B. Revil-Baudard, C. Rojas-Ulloa, B. Sener, F. Shen, A. Van Bael, P. Verleysen,·F. Barlat, O. Cazacu, T. Kuwabara, A. Lopes, M.C. Oliveira, A.D. Santos, G. Vincze,

International Journal of Material Forming **15**, Article number: 61 (2022)

How to use the article? Just focus on specific topic…

Material experimental characterization

Cup forming and measurement

Friction coefficients effect on FE results

Identification Validation of models

Constitutive law description

Features of FE simulations
Tables 10-12 [1]

Earing prediction

Effect of: constitutive law, Shell or Solid elements, Identification Methodology

Tables 36, 37, Figures 119-121[1]

Force prediction

Drawing & Ironing states

Effect of: constitutive law, Shell or Solid elements, Identification Methodology

Figures 117-118 [1]

Conclusions [1]

Hill 48 → Earing accuracy 3%

+ variable r-value + non-associ → 2%

Force & Earing Top Predictions

Facet 3D (continu. Shell),
Cazacu orthotropic (Solid ele.)

Codes, elements, contact / constitutive laws/ identification

FE Code
ABAQUS (explicit & implicit), DD3IMP, Lagamine, MARC, LS-DYNA, PAMSTAMP

F Element
Different types of Shell and Solid elements and refinements

Contact model
Penalty, Surface to Surface,..., Large range of constant friction coefficients

Experimental data
Texture; Tensile tests; Monotonic and reverse shear tests; bi-axial tests

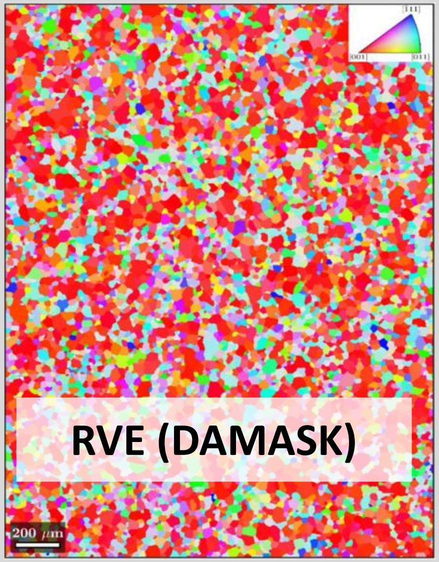
Crystal plasticity laws used for identification of phenomenological models
Facet 3D & ALAMEL, DAMASK, Full Taylor Model, Visco-Plastic Self-Consistent (VPSC)

Analytical yield laws
2D and 3D yield laws of Barlat and Cazacu (Yld89, Yld2000-2D, CB2001, Yld2004–18p, CPB06); Cazacu single crystal; associated & non associated Hill'48; Cazacu orthotropic (Caz2018-Orth), 4^{th} and 6^{th} polynomial models (HomPol4 & 6)

Polycrystalline Models (CP-FEM)
Minty, Cazacu Polycrystal

Hardening model - Isotropic: Voce, Swift; - Kinematic: Armstrong Frederick

Texture input - Homogenization procedure for Crystal Plasticity models



Crystal data set:
from 250
(Caz2018polycrys)
to 10.000 grains
(ALAMEL)

+

Homogenization Approach

Full Taylor assumption
$\varepsilon^{Macro} = \varepsilon^{Micro}$
(**Minty, Cazacu polycrystal**)

$\varepsilon^{Macro} = \varepsilon^{Applied\ on\ RVE}$
(**DAMASK** spectral method)

Relaxed Taylor assumption
& cluster of grains
(**ALAMEL**)

Self Consistent approach,
(**VPSC**)

Data set used for Identification:
Texture
+

- 7 exp. r- values and yield stresses for Cazacu polycrystal, and VPSC.
- 1 tensile curve in RD (Minty, ALAMEL, DAMASK)
- Facet 3D identified by virtual tensile tests with ALAMEL

Data sets for identification of yield function parameters

<table>
<tr><th>Tests</th><th>Tensile</th><th>Lankford
0° 45°
90°</th><th>Yield stress
0°</th><th>Yield stress
45° 90°</th><th>Yield stress
15° 30°
60° 75°</th><th>Bi-axial
=</th><th>Bi-axial
≠</th><th>Shear</th></tr>
<tr><td rowspan="7">Mechanical experiments

+ if *
virtual tests
(crystal plasticity)</td><td colspan="3">UCoimbra Hill48(A)</td><td colspan="5"></td></tr>
<tr><td colspan="4">USakarya Yld89</td><td colspan="4"></td></tr>
<tr><td colspan="5">REEF Caz2018-Orth - ULiege Hill48(A) -
USakarya HomPol 4 & 6</td><td colspan="3"></td></tr>
<tr><td colspan="6">UGent Yld2000-2D*, POSTECH Yld2000-2D & Yld2004-18p, NTNU Yld2004-18p*</td><td colspan="2"></td></tr>
<tr><td colspan="7">UCoimbra CB2001</td><td></td></tr>
<tr><td colspan="6">UAalto Hill48 (NA)</td><td></td><td></td></tr>
<tr><td colspan="8">UCoimbra CPBO6 ex2</td></tr>
</table>

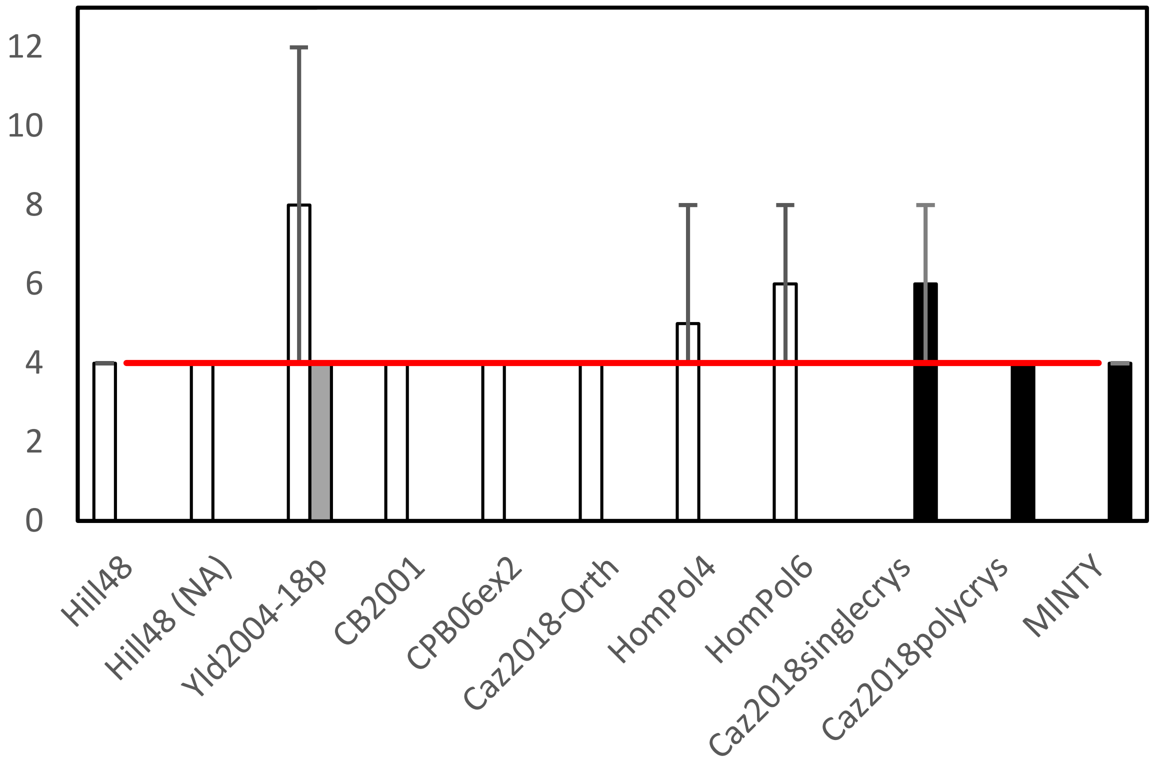
13 Teams involved, more than 13 Institutions

Katholieke Universiteit Leuven and Ghent University (Belgium)	KUL
Norwegian Univ. of Science and Tech. (Norway)& Northwestern Polytechnical Univ. (China)	NTNU
Pohang Univ. of Science and Tech. & Indian Institute of Technology Dharwad (Korea)	POSTECH
University of Florida (US)	REEF
Aalto University (Finland)	UAalto
University of Coimbra and University of Minho (Portugal)	UCoimbra
Ghent University (Belgium) and Delft University of Technology (Netherlands)	UGent
University of Liege (Belgium)	ULiege
University of Porto (Portugal)	UPorto
University of Sakarya, Bilecik Seyh Edebali University and Yildiz Technical University (Turkey)	USakarya
University of Siegen (Germany)	USiegen
University of Aveiro	UA
Tokyo University of Agriculture and Technology	TUAT

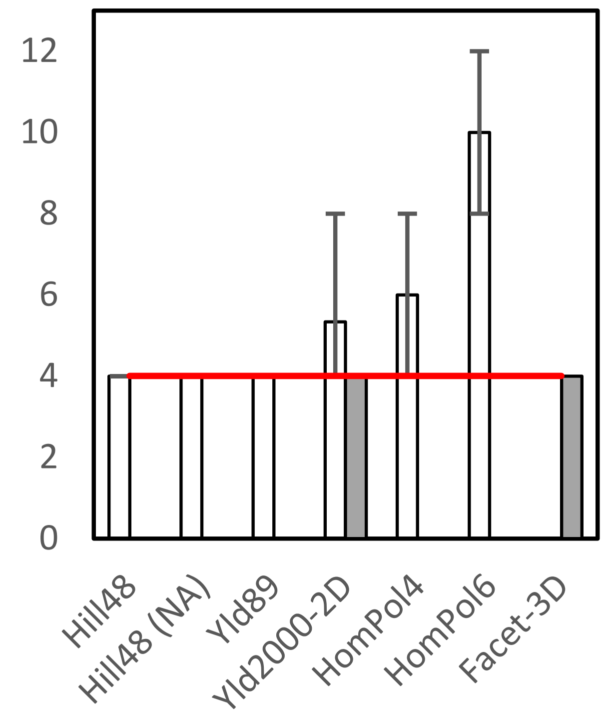
Number of ears

- Based on physical tests
- Based on physical tests + Virtual ones
- Constitutive law based on crystal plasticity
- Experimental drawing force

Most 3-D orthotropic yield functions → 4 ears, as in experiments



Solid elements

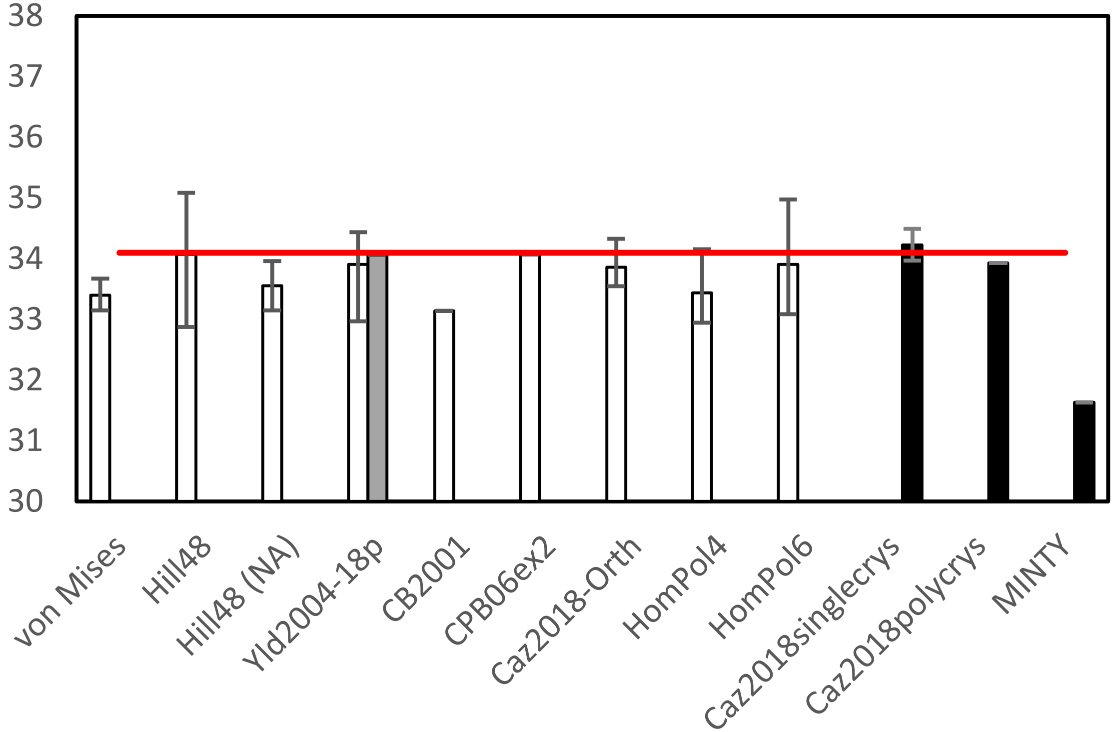


Shell elements.

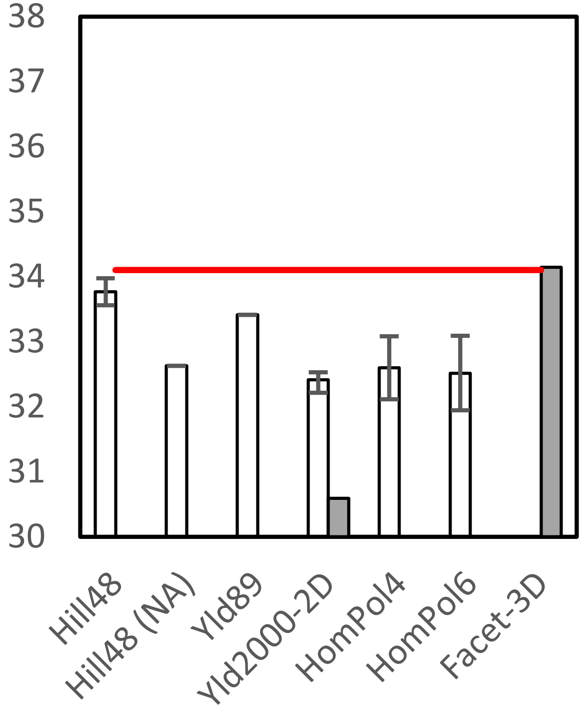
Average cup height well predicted by all models

- E.g. **von Mises** isotropic yield criterion
- Note: 2-D orthotropic yield functions Yld89, Yld2000-2D, HomPol4 and HomPol6
  → tend to underestimate particularly when combined with shell elements.

Based on physical tests
Based on physical tests + Virtual ones
Constitutive law based on crystal plasticity
Experimental drawing force

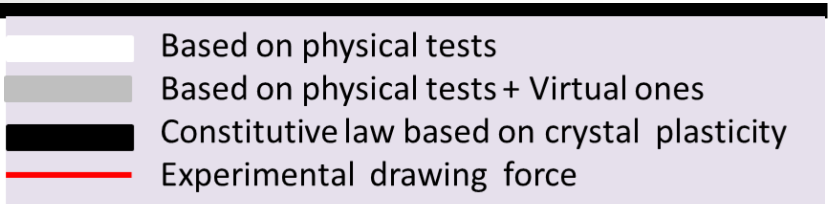


Solid elements



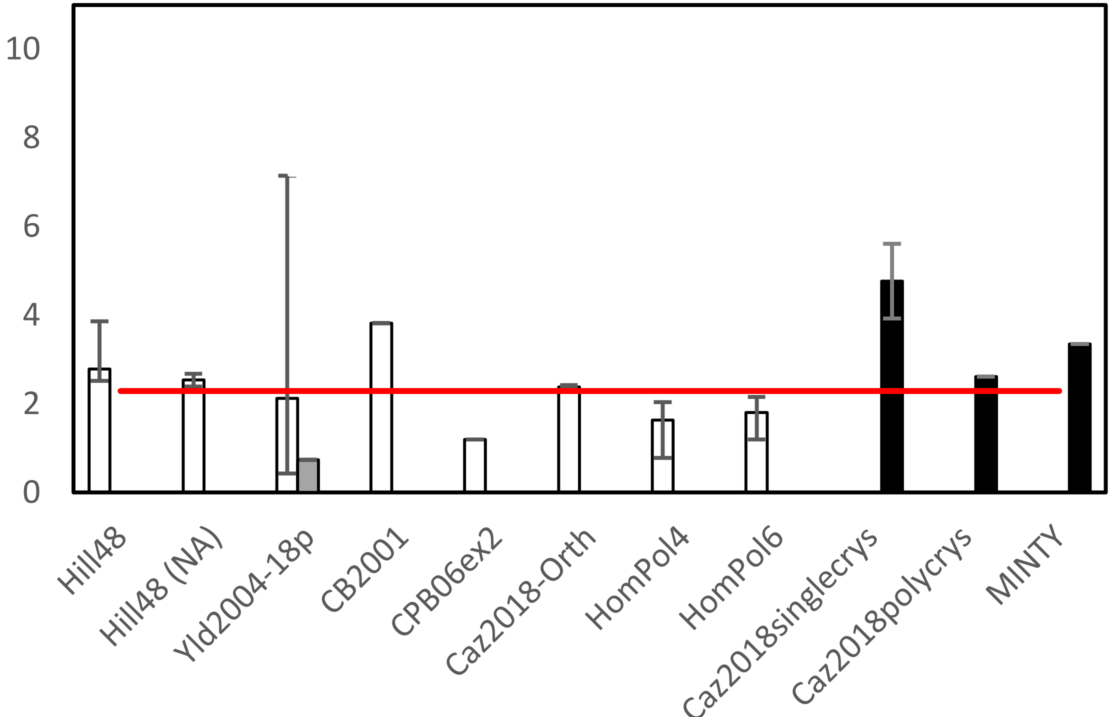
Shell elements.

Average amplitude of the earing profile

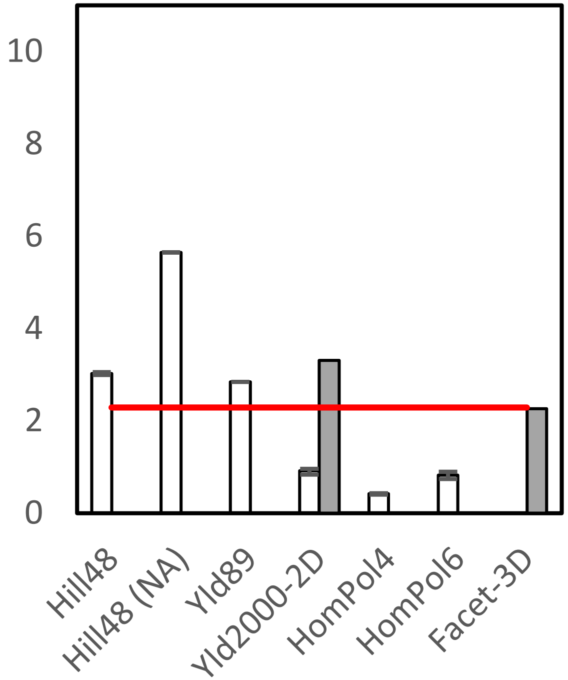


3-D orthotropic yield functions more accurate than 2-D orthotropic models -shell elements

7 accurate average predictions out of 12 solid models
versus 4 reasonable predictions out of 8 shell models



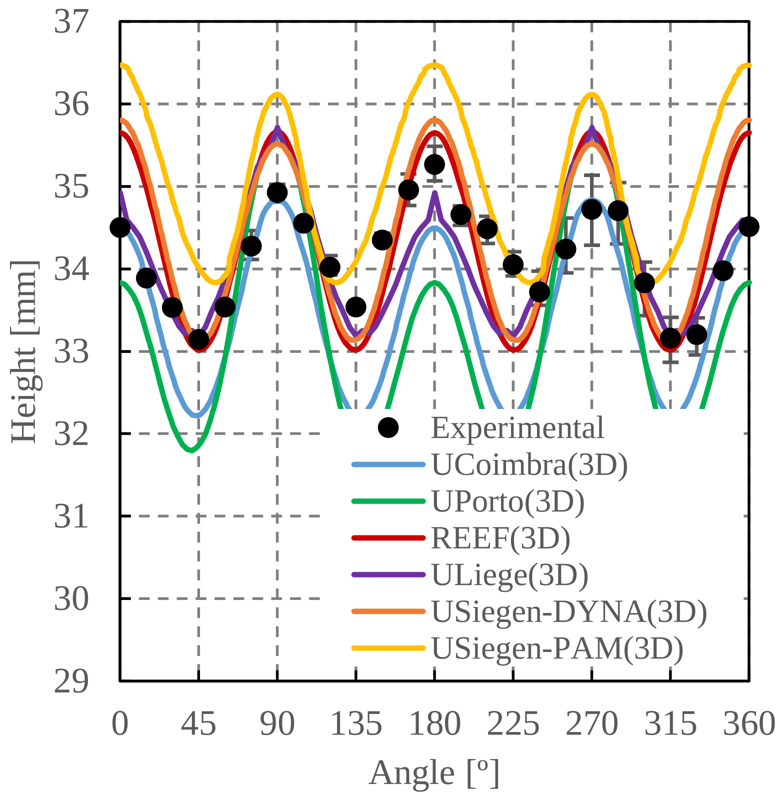
Solid elements



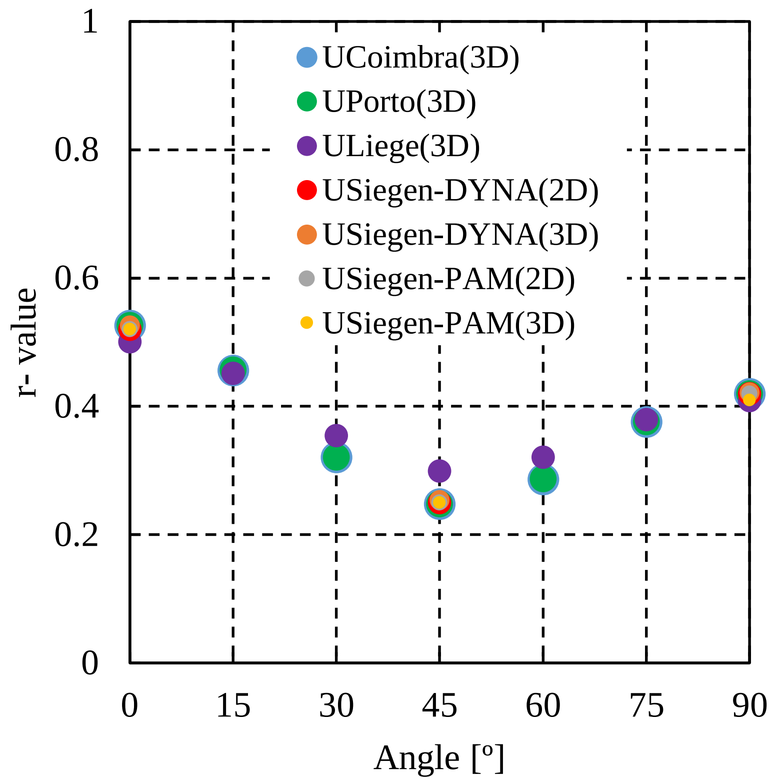
Shell elements.

Earing profile, Hill 48, ≠ mesh, implicit, explicit FE, friction coef.

- If the prediction of r-values anisotropy OK → It predicts 4 ears, with maxima at RD and TD & minima at 45º.
- Analytical identification, except ULiege



Solid elements, identification based on physical tests.



Predicted *r*-values with FE

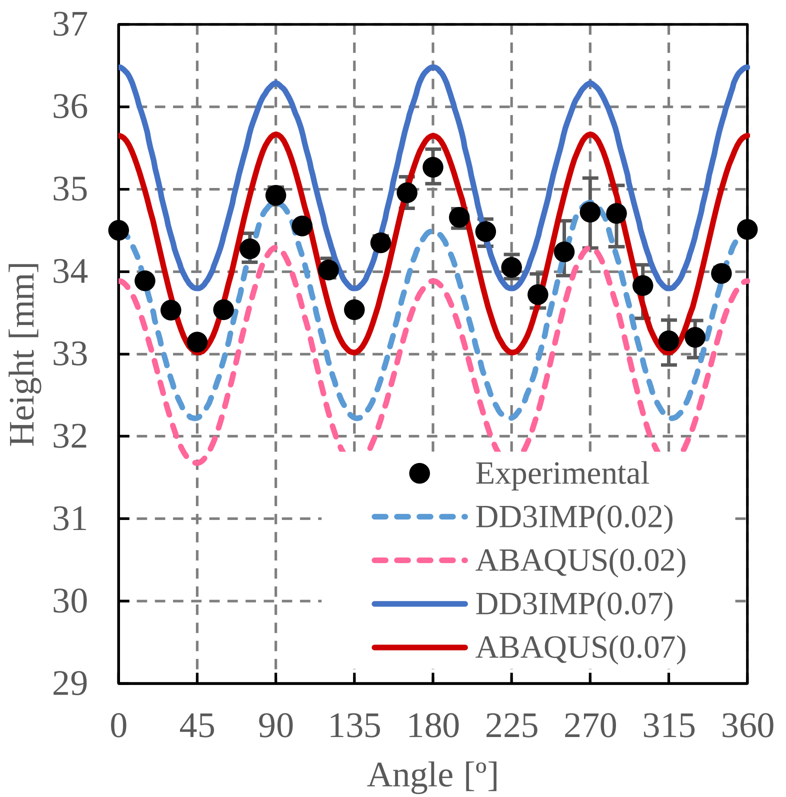
M.C. Oliveira, O. Cazacu, B. Revil-Baudard, D.M. Neto, P. Frohn-Sörensen, J. Ma, W. Liu, D.J. Cruz, A. D. Santos, A. Van Bael, H. Ghiabakloo, A.M. Habraken

Earing Profile Hill48

- The results of REEF (ABAQUS) and UCoimbra (DD3IMP) for 2 μ confirm that friction has:
  non-negligible impact on the average heigl
small impact on the average amplitude.

- **If the set of parameter is based on Lankford coefficients at 0º, 45º and 90º**
  the prediction dispersion = [**2.62; 2.69**] mm,

- Note: **Experimental amplitude of 2.29 mm**.



Comparison between experimental and predicted earing profile by using **Hill48 criterion** identified based on the Lanford coefficients.

Earing Profile & non-associated Hill48 model

3 teams – comparison not straightforward

μ = 0.01 to 0.075

- UAalto :

ABAQUS, solid element, non-associated Hill48 + textural hardening (**both yield criterion & flow potential evolve with the plastic strain**), Voce hardening.

→ very accurate earing average height & amplitude

- USiegen:

PAMSTAMP, shell, non-associated Hill48, Swift hardening

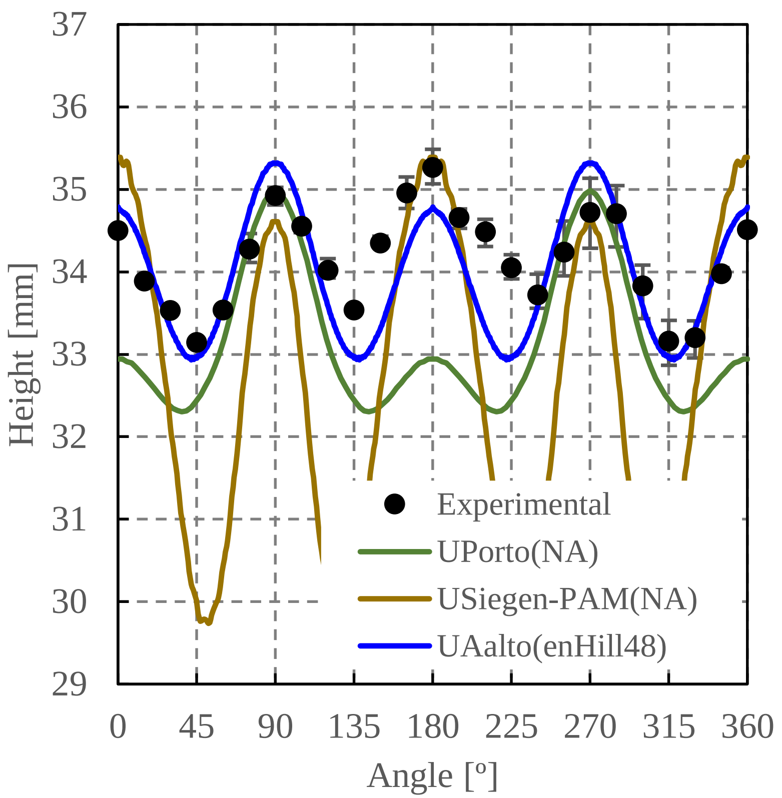
→ **unexpected results of yield stress at 45º**,

→ very large earing amplitude

- UPorto:

ABAQUS, solid element, non-associated Hill48, Swift hardening, **fixed die - blank holder gap**

→profile far from experiment but accurate amplitude in transverse direction

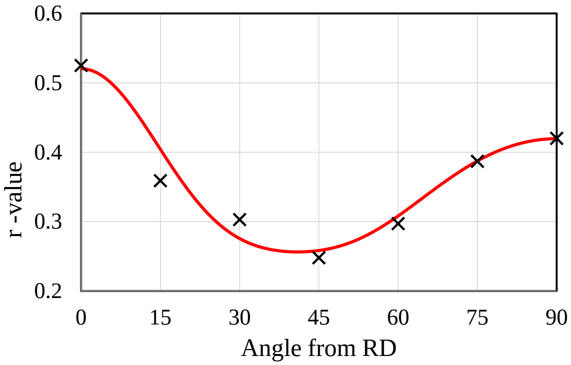


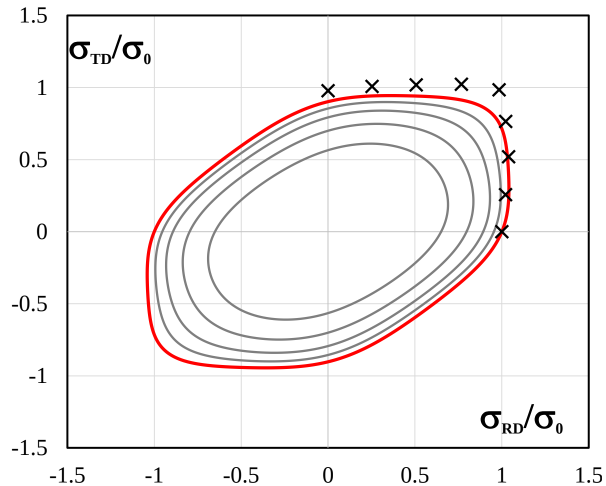
Comparison between experimental and predicted earing profiles by.**(NA) Hill48 criterion** with constant or evolving anisotropy parameters.

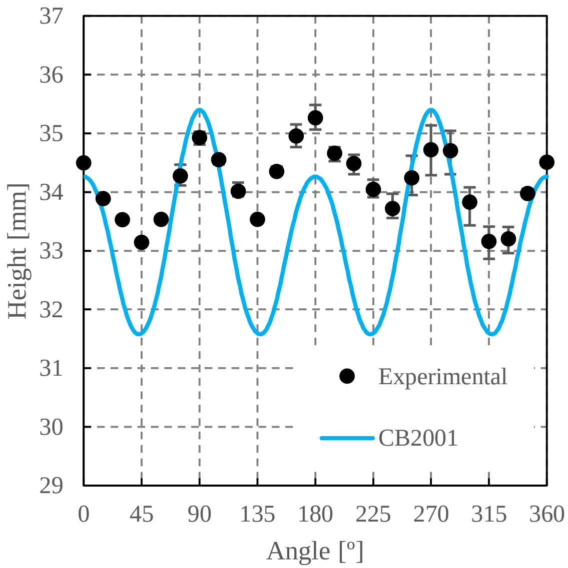
Earing Profile & Cazacu & Barlat (CB2001)

Earing Profile

- 3-D orthotropic yield function of **Cazacu & Barlat (CB2001)** predict experimental trends for in-plane anisotropy in r-values, yld stresses, earing: correct # of ears (4) and reasonable amplitude



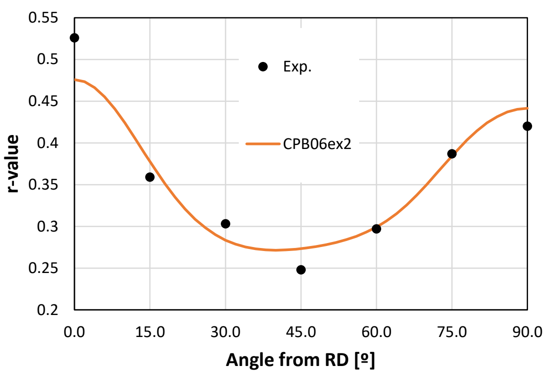


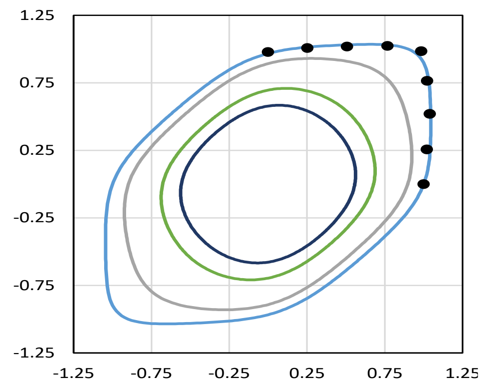


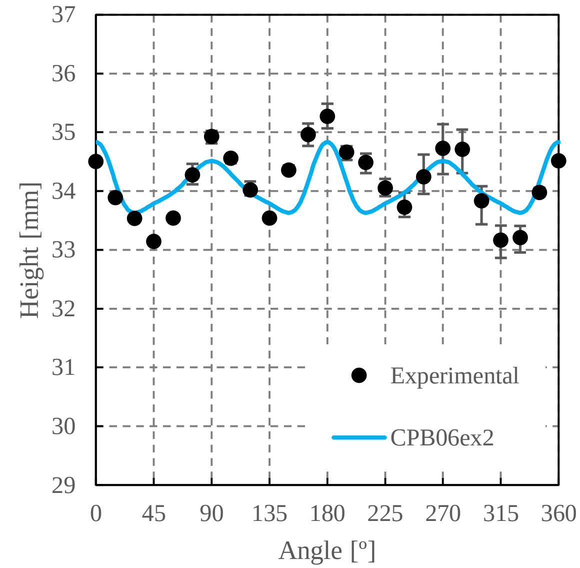
Earing Profile & CPB06ex2

Earing Profile

- 3-D orthotropic yield function of **CPB06ex2** predicts experimental trends for in-plane anisotropy in r-values, yld stresses, earing: correct # of ears (4) and reasonable amplitude



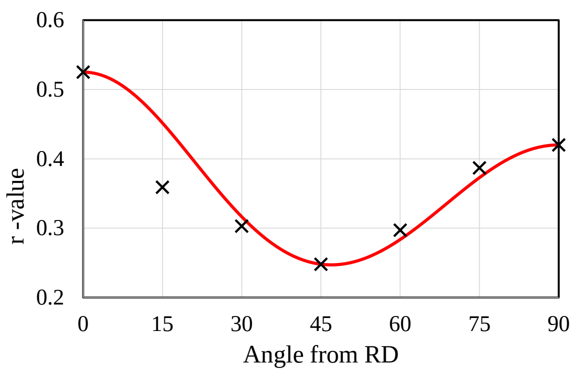


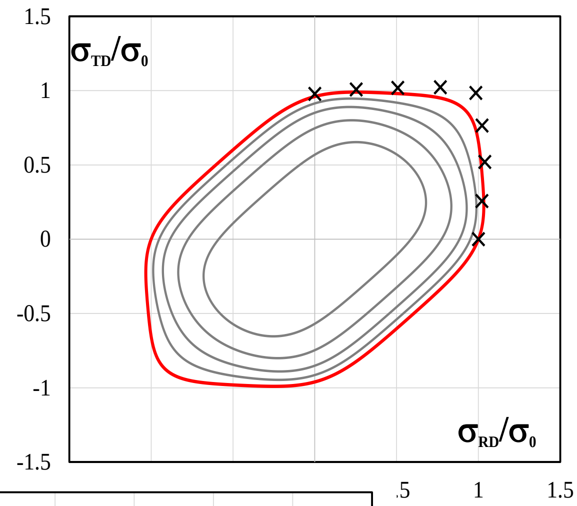


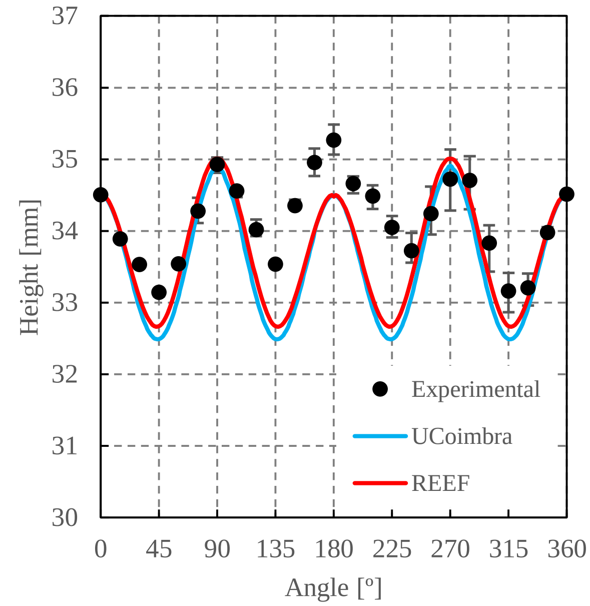
Results by Ucoimbra, DD3IMP, solid elements

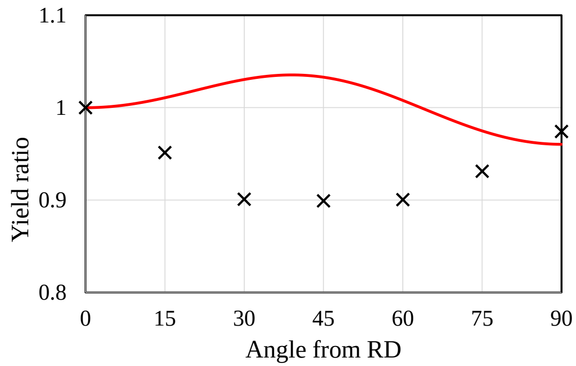
Earing Profile

- 3-D orthotropic yield function of **Cazacu(2018) orthotropic** predicts experimental trends for in-plane anisotropy in r-values, yld stresses, earing: correct # of ears (4) and global error of less than 0.01%



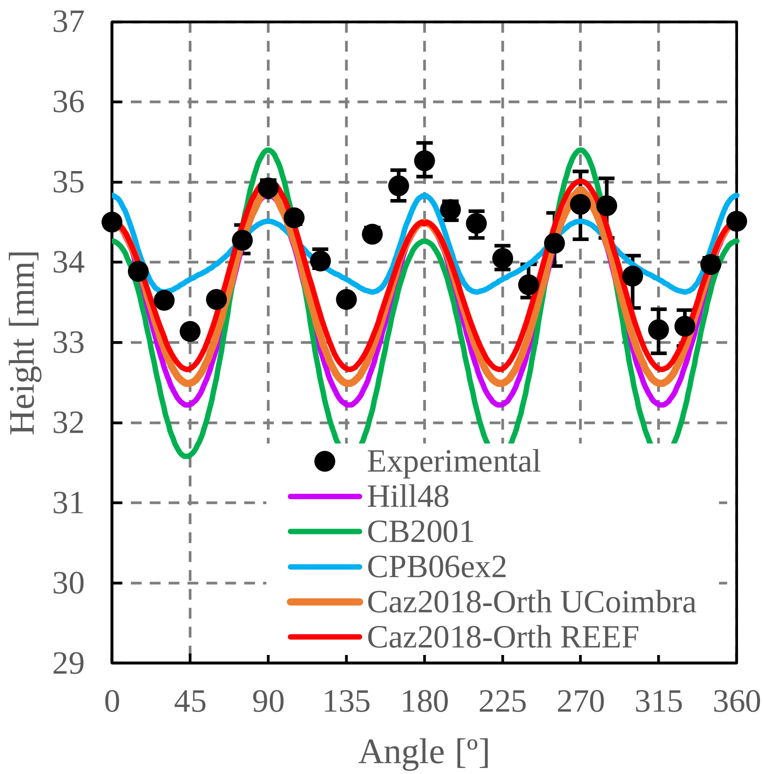




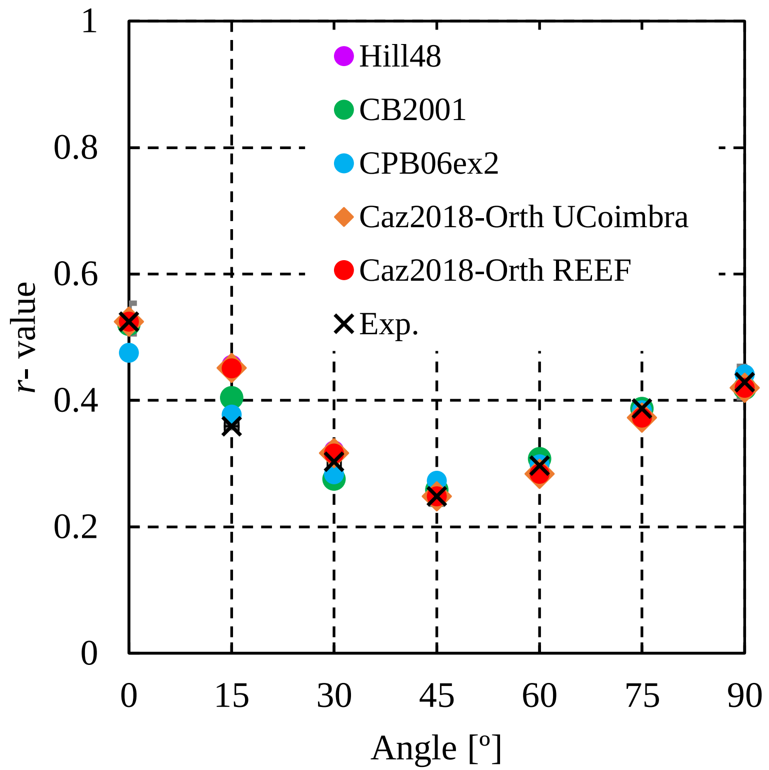


Earing Profile: Hill48, CB2001, CPB06ex2 and Caz2018-Orth

Similar prediction for: *r*-values, number of ears, average height
differences in amplitude, due to:
differences in mesh, implicit, explicit FE, friction coef.



Solid elements, identification based on physical tests.



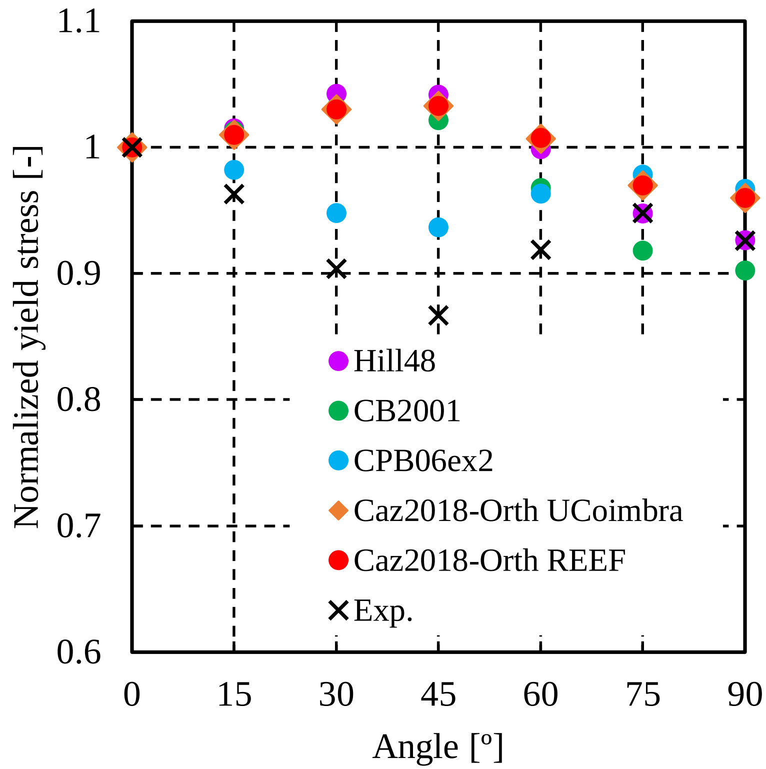
FE Predicted r-values.

Earing Profile: amplitude and number of ears

- Amplitude of the ears by 3-D orthotropic yield functions
  → correct number of ears

Same FE model (DD3IMP)- different yield functions, amplitude predictions

- CB2001 > Hill48
- Caz2018-Orth < Hill48
  closer to the experiments.
- CPB06ex2 : lowest amplitude



Predicted FE uniaxial flow stresses with the data set based on physical tests.

- Correlation:

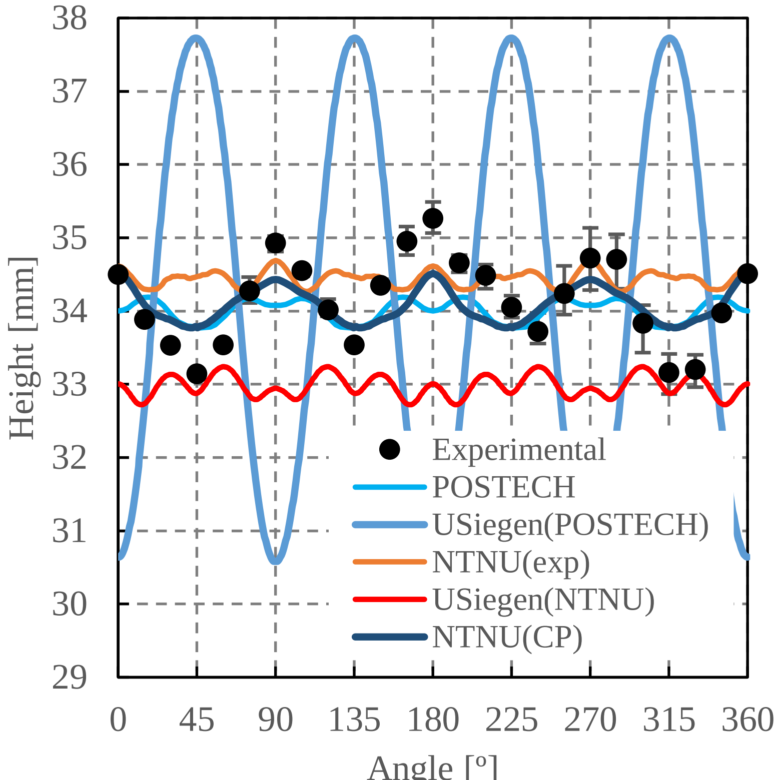
earing amplitude & in-plane variation of the normalized yield stresses ?

Earing Profile with Yld2004-18p - quite sensitive yield function

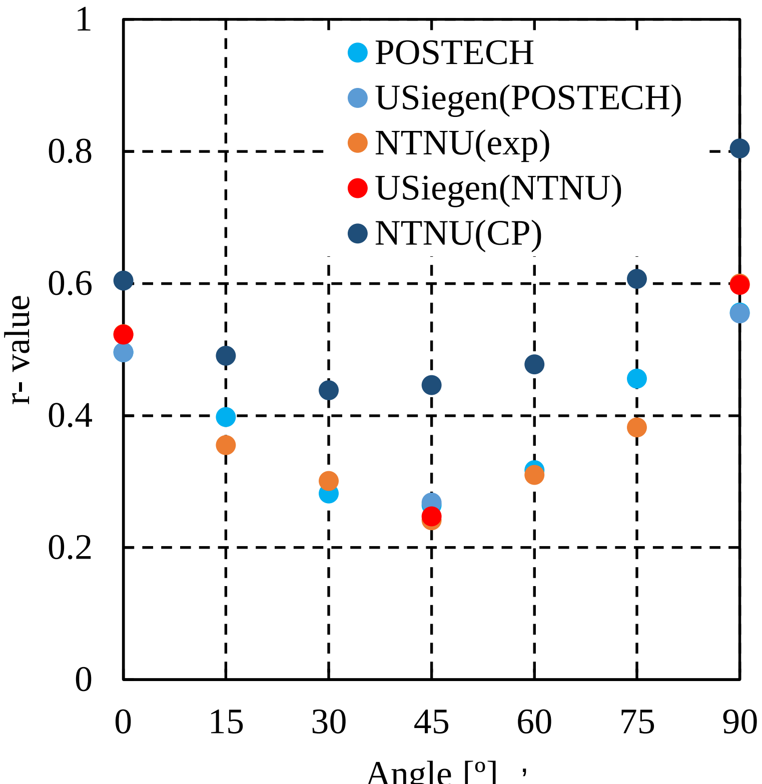
Depending on the identification procedure: 12 ears (low amplitude)
4 ears (medium amplitude) by NTNU model.

Note: **for same parameters** different results with

- ABAQUS (POSTECH) and LS-DYNA (Usiegen-POSTECH)
- ABAQUS (NTNU) and LS-DYNA (Usiegen-NTNU)



Predictions using identification from physical tests and/or virtual tests (solid elements)



FE Predicted r-values.

Summary for Yld2004-18p (1)

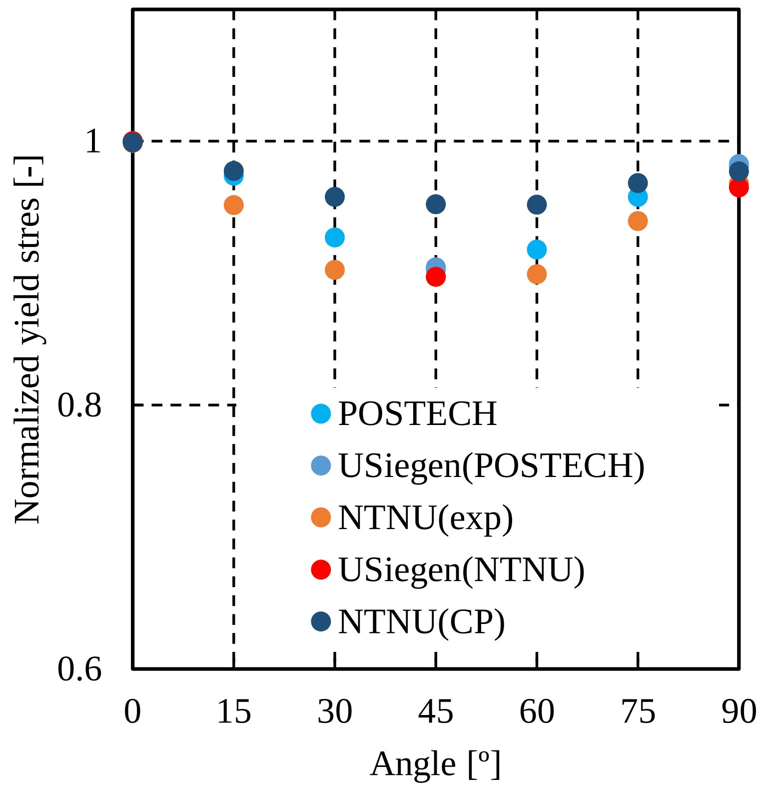
Note:

- Irrespective of the set of the anisotropy coefficients the predicted anisotropy in yield stresses is reasonable

- For the set of coefficients predicting 4 ears

→ earing amplitude 0.74 (NTNU)
7.15 (POSTECH)

Far from experiments and Hill48 prediction



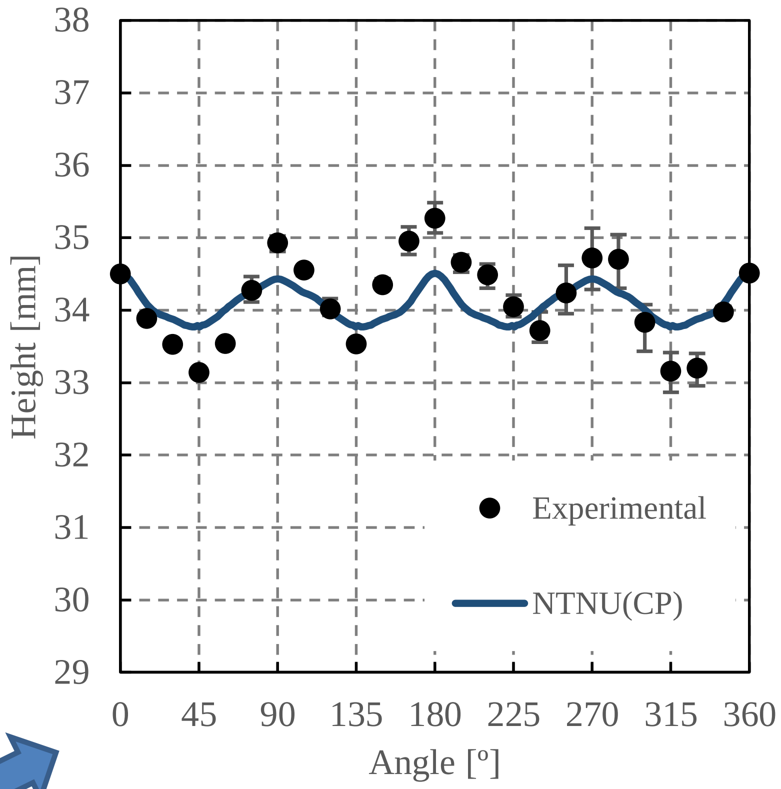
Predicted FE uniaxial flow stresses with identification based on physical tests and/or virtual tests .

Summary for Yld2004-18p (2)

- This variability of the simulation results points to very strong sensitivity:
  - in FE implementation
  - to the identification strategy of anisotropy parameters.

- Given that all sets lead to correct predictions of *r*-values & yield stresses directionalities, it does not guarantee accurate prediction of cup forming

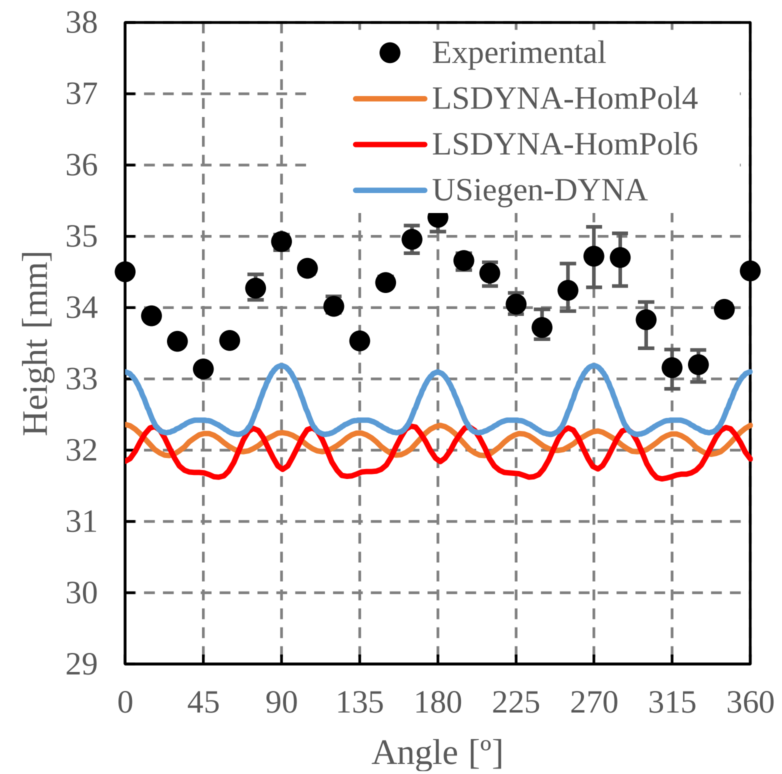
- Only the set of parameters identified using virtual crystal plasticity and exp. results
  + the implementation of NTNU in ABAQUS
  → an acceptable result,
  although the earing amplitude is
  underestimated.

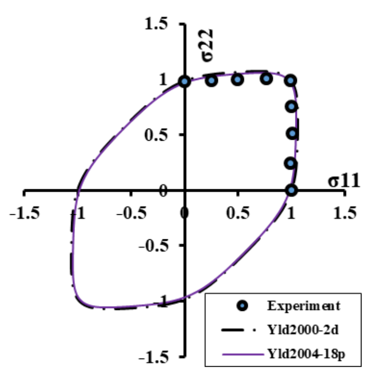


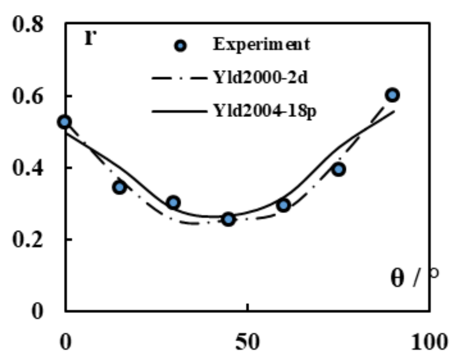
Experimental and predicted earing profile by **Yid2000-2D** or **HomPol4** and **HomPol6**.

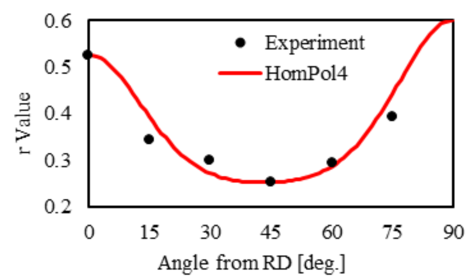
- 2-D orthotropic yield criteria HomPol4, HomPol6, Yld2000-2D
  → 8 ears predictions

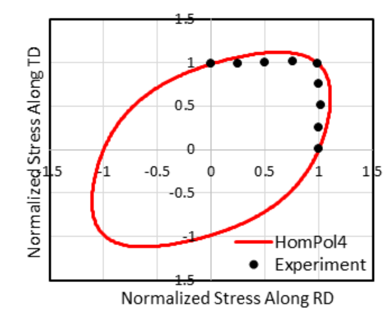
- All these yield criteria → similar description of the in-plane distribution of the *r*-values !!!









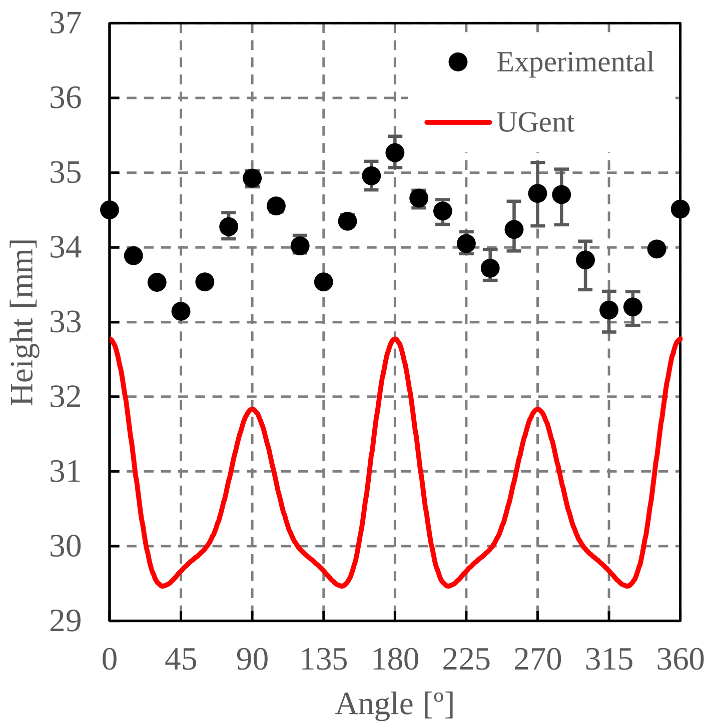


Earing Profile - Yld2000-2D (UGent)

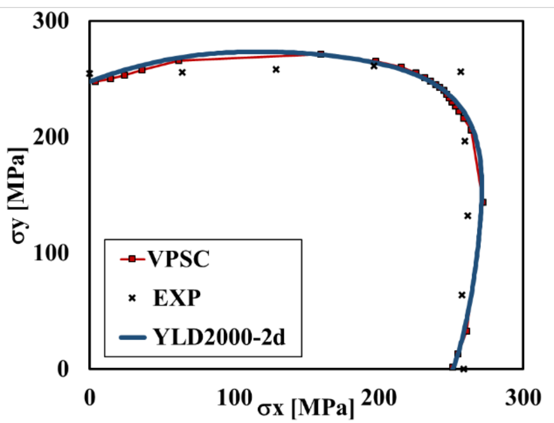
Virtual tests (crystal plasticity) complementing the physical test data, enable a better qualitative prediction of the earing profile

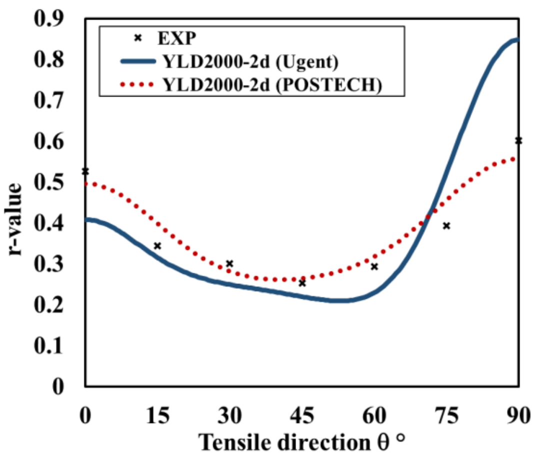
-Shell element (ABAQUS implicit – S4R), UGent identification based on VPSC simulations:

→ underestimation of the average height,



Experimental and predicted earing profile by **Yld2000-2D (UGent)** with anisotropy parameters based on physical and virtual crystal plasticity tests





Earing Profile - Global error of crystal plasticity models

- Polycrystal FE simulations based on set of single crystal behaviour (MINTY and Cazacu2018polycrys
→ correct *r*-values, number of ears
→ + for Cazacu2018polycrys, average height and earing amplitude.

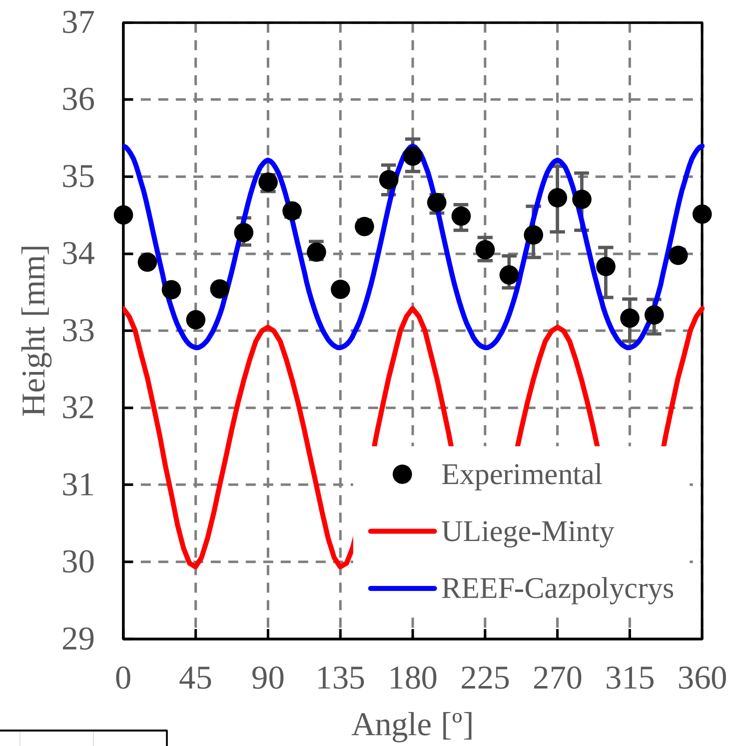
- Cazacu2018polycrys earing predictions belong to the group of models with a low global error

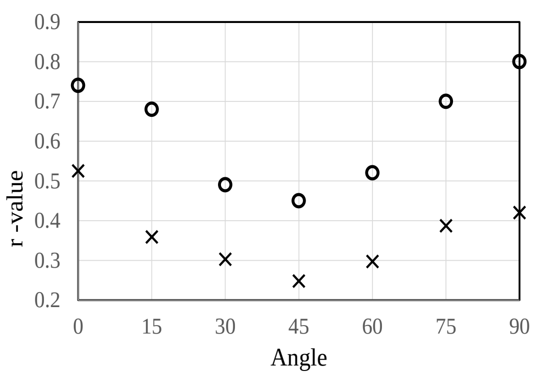
(**0.02**: Hill48 Lagamine, Hill48(NA) ABAQUS, Caz2018-Orth ABAQUS and DD3IMP, HomPol4 and HomPol6 MSC.Marc, Facet-3D ABAQUS).

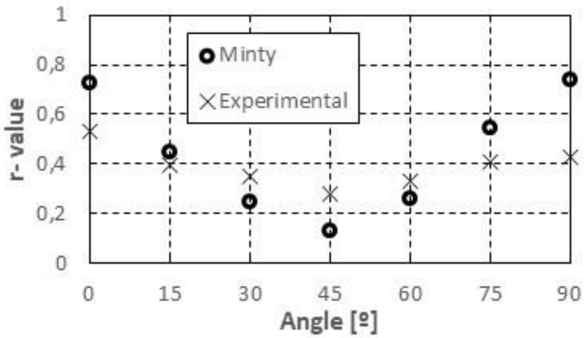
$$\text{Global error} = \left(\frac{n_{avg}^{num} - n_{avg}^{exp}}{n_{avg}^{exp}}\right)^2 + \left(\frac{h_{avg}^{num} - h_{avg}^{exp}}{h_{avg}^{exp}}\right)^2 + \left(\frac{a_{avg}^{num} - a_{avg}^{exp}}{a_{avg}^{exp}}\right)^2$$

n_{avg} – number of ears
h_{avg} – average height
a_{avg} – average amplitude

Comparison between experimental and predicted earing profile by **MINTY** and **Cazacu2018polycrys**







Earing Profile - Shell versus Solid, Solid-Shell elements

- None of the shell FE simulations attains the threshold of **0.01** global error

It is related to their inability to predict ironing.

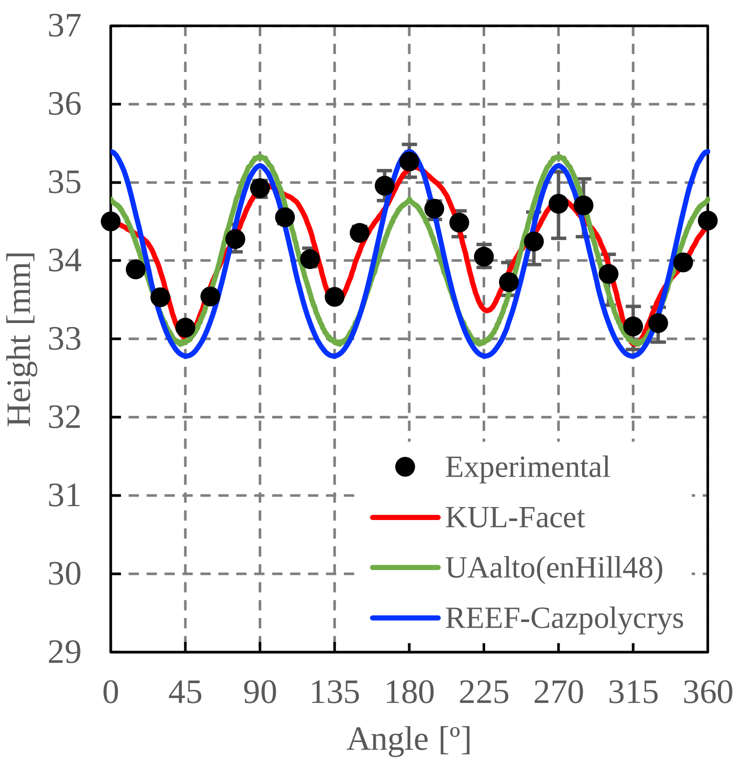
- Simulations with solid or continuum-shell elements

3 models → global error values < **0.002**:

3-D orthotr. Hill48(NA) identified by UAalto,
Caz2018-Orth, identified by REEF
Facet-3D model-KUL approach (continuum-shell element).

- Different models → similar results

It highlights the robustness of the orthotropic yield functions and the experience of the analysts.

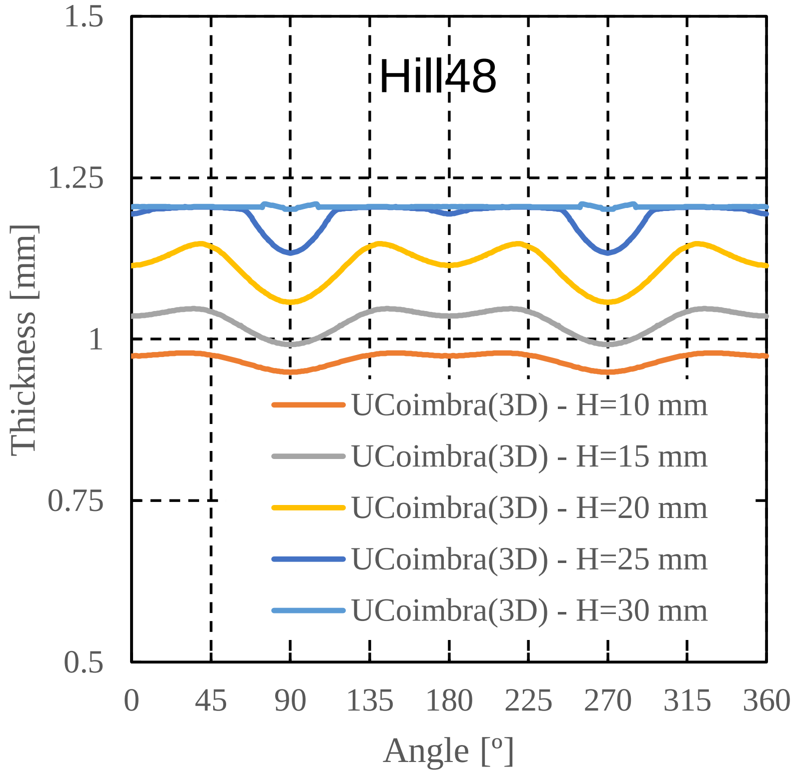


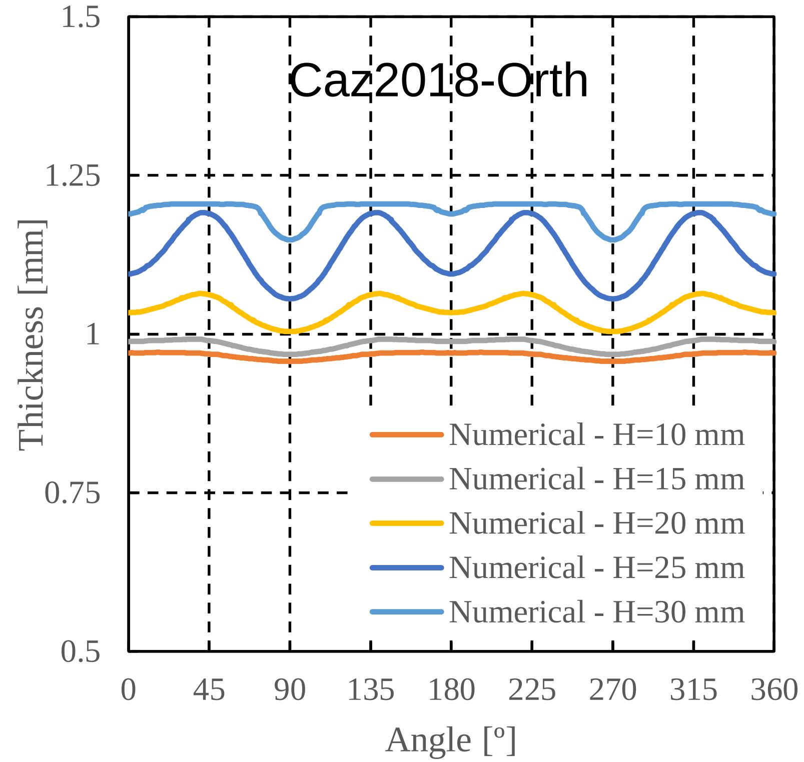
Experimental and predicted earing profile by **Hill48**, **Facet-3D** and **Cazacu2018polycrys** models.

Thickness evolution along the cup circumference

- All FE models predicting 4 ears → similar trends,
  maximum at 45º & minima at RD and TD

- Different amplitudes along the circumferential direction highlight the influence of the shape of the yield locus



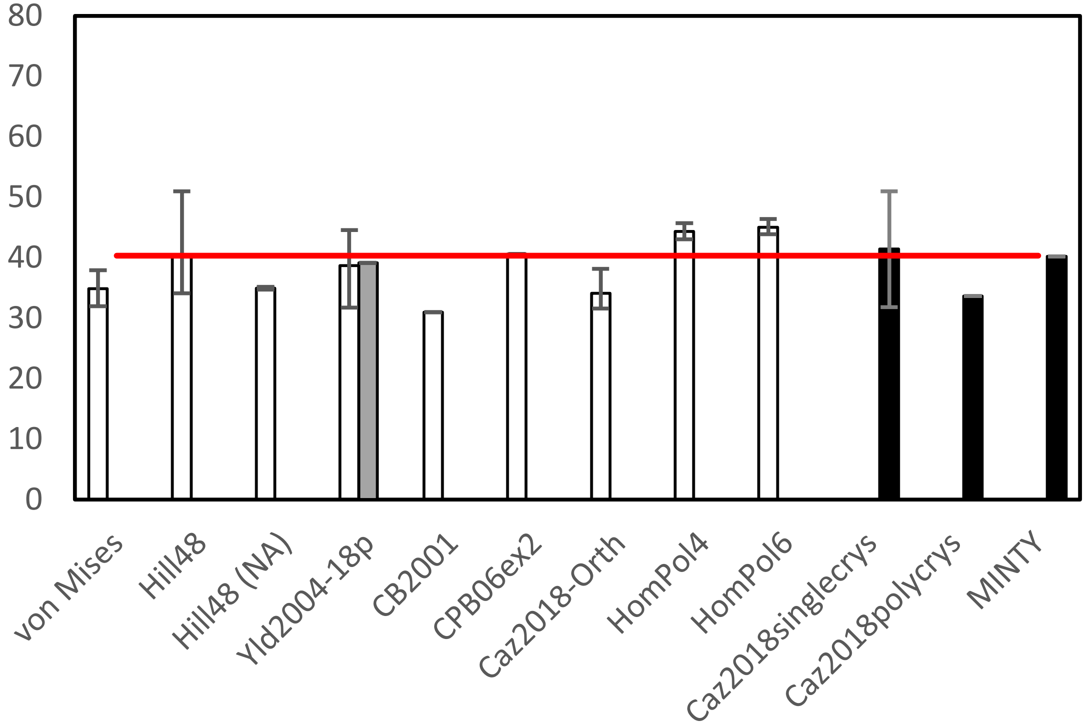


Thickness along the cup circumference at different heights *H* = 15, 20, 25 and 30 mm from the cup bottom, DD3IMP code.

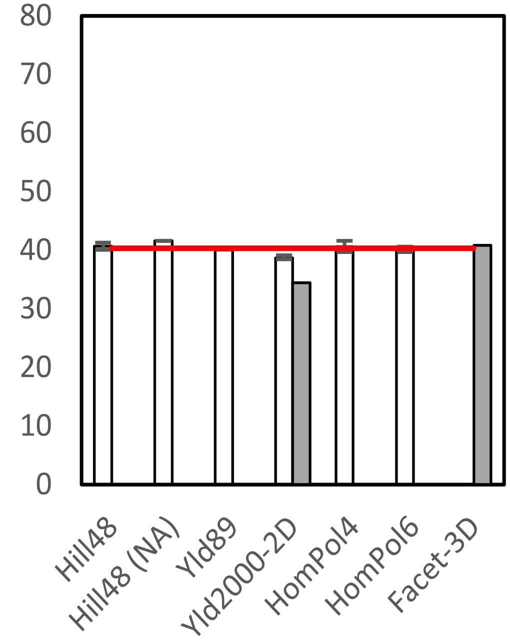
Punch Force results

Based on physical tests
Based on physical tests + Virtual ones
Constitutive law based on crystal plasticity
Experimental drawing force

1st peak = cup drawing, with the adjustment of the friction coefficient (within a reasonable physical range).



Solid elements (μ=0.01 up-to μ=0.100)



Shell elements (μ=0.07 or higher values)

Effect of friction coefficient - Punch Force

- REEF, Ucoimbra:

solid elements

Results for friction coefficient (μ=0.02):

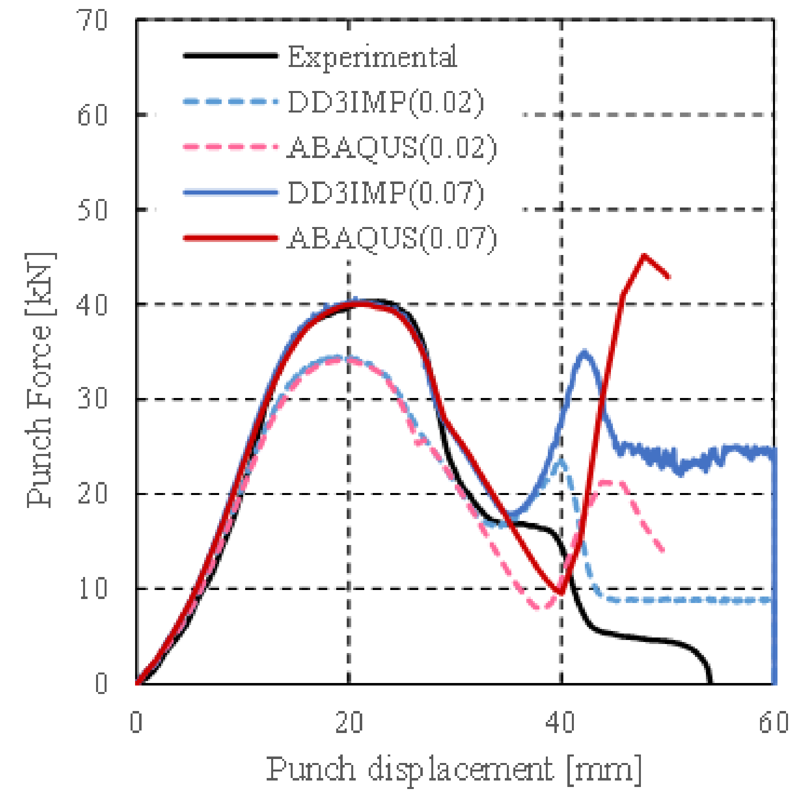
→ underestimation of the drawing force.

- If simulation μ=from 0.05 until 0.1 with

solid elements:

→drawing force peak more accurate than shell elements with μ= 0.07 and ↗

Hill 48

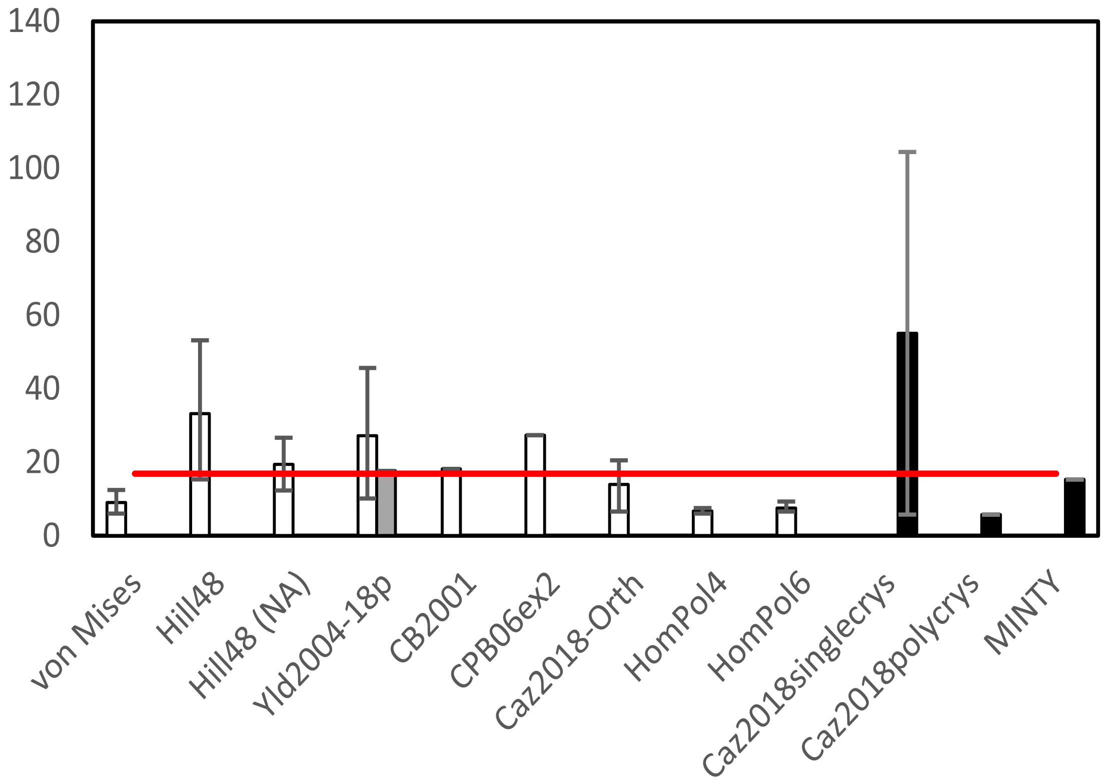


Results for two different values of μ 0.02 and 0.07

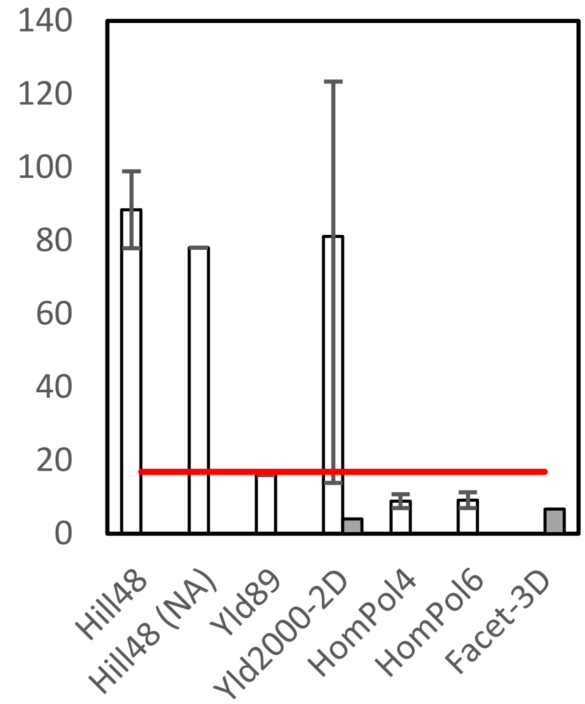
Ironing force results

Based on physical tests
Based on physical tests + Virtual ones
Constitutive law based on crystal plasticity
Experimental drawing force

- **2nd Peak :** most FE predictions too high (worst for shell elements) except for ABAQUS + S4R element (Ugent) and for ABAQUS + SC8R element (KUL).



Solid elements



Shell elements.

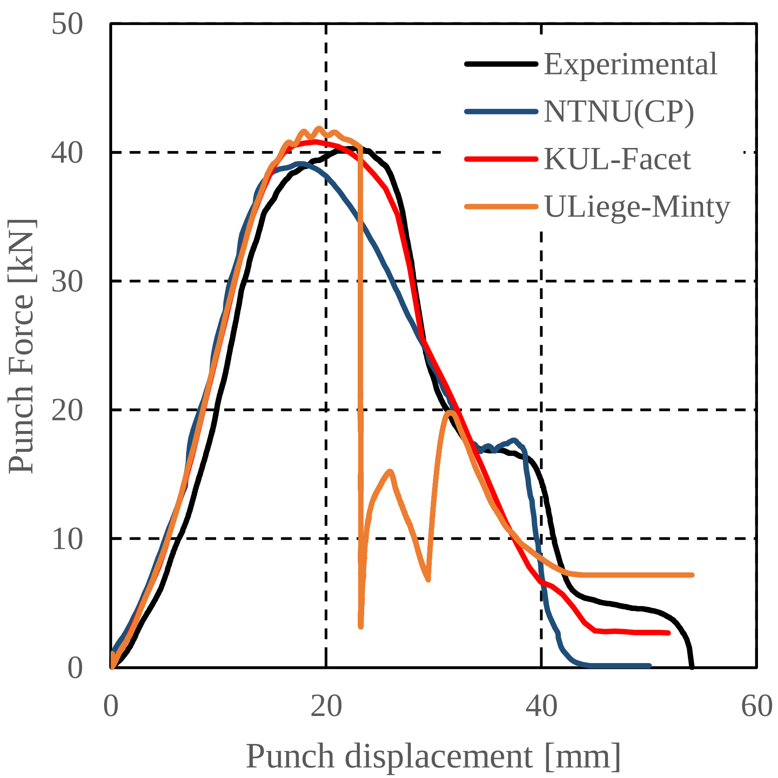
Punch Force results

- 3 interesting configurations:

  - **Yld2004-18p -**ABAQUS implicit – solid element from **NTU,** an identification based on 7 virtual tensile tests (Damask with an FFT approach, 7509 grains in a RVE and a physical tensile test in RD).

  - **FACET-3D** – ABAQUS explicit - continuum shell from **KUL**, an identification based on 200 virtual tests relying on 10 000 grains and the ALAMEL crystal plasticity model (however the force is underestimated)

  - **MINTY** – Lagamine implicit - solid element from **ULiege,** an interpolation yield locus approach based on 1000 crystals and a simple Full Taylor plasticity approach; (however the start of the ironing stage is not correctly predicted).



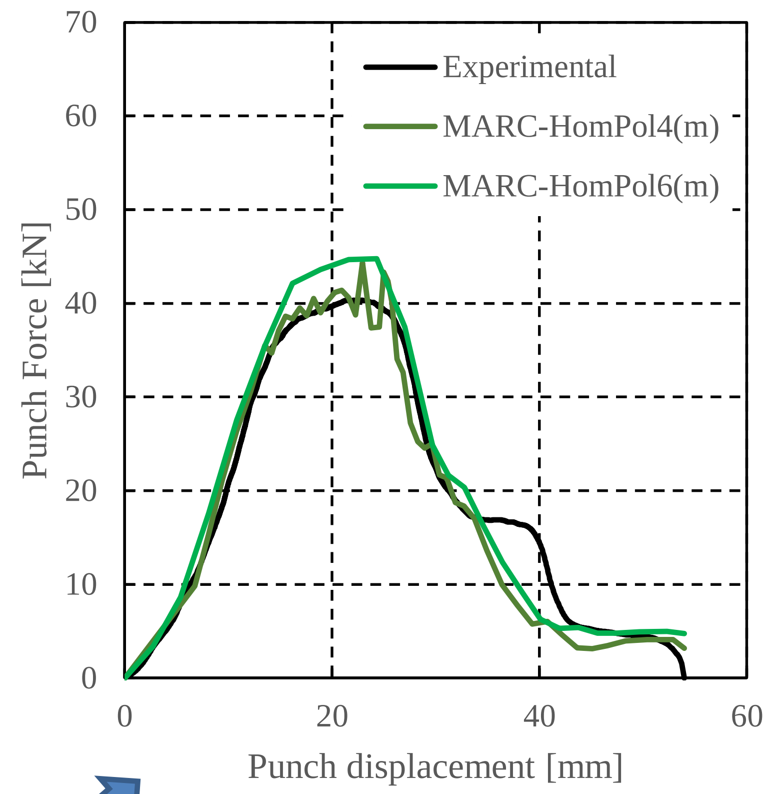
crystal plasticity computations to complement physical tests in the identification of the yield functions may improve the prediction of the ironing force.

Ironing force results

- Solid formulation → more realistic ironing force.
- Is overestimation due to tool rigidity ?
- Elastic tool behaviour would slightly widen the drawing gap with very large surface pressures ?

→ lower force is expected.

- Improved accuracy of the ironing force and shape of the force curve if simulations use an increased clearance
  (USakarya with Yld89, HomPol4 and HomPol6).



EXACT follow up 2022 : Influence of the tool stiffness

Cup with a thickness higher than the gap between the punch and the die?

Simulations were performed with rigid tools for reference (Rig)

→ modelling of the tool deformation:

- ✓ modelling the tools as deformable bodies (Def1 and Def2)
- ✓ adjusting the stiffness of the surfaces describing the tool (Def3)

	Rig1	Rig2	Rig3	Def1	Def2	Def3
Software	DD3IMP	PAMStamp	Abaqus	DD3IMP	PAMStamp	AutoForm
Forming tools	Rigid	Rigid	Rigid	Deformable	Deformable	Deformable
Finite elements: type	Solid	Solid	Solid-Shell	Solid	Solid	Solid-Shell
and number	15408	55560	9743**	23313	171405	9390***
Hardening law	Swift	Swift	Swift	Swift	Swift	Swift
Yield criterion	Hill48	Hill48	Facet-3D	Hill48	Hill48	Facet-3D
Friction coefficient	0.06	0.075	0.09	0.06	0.075	0.09
CPU time*	3h02m	3h33m	2h46m	16h04m	37h48m	1h18m

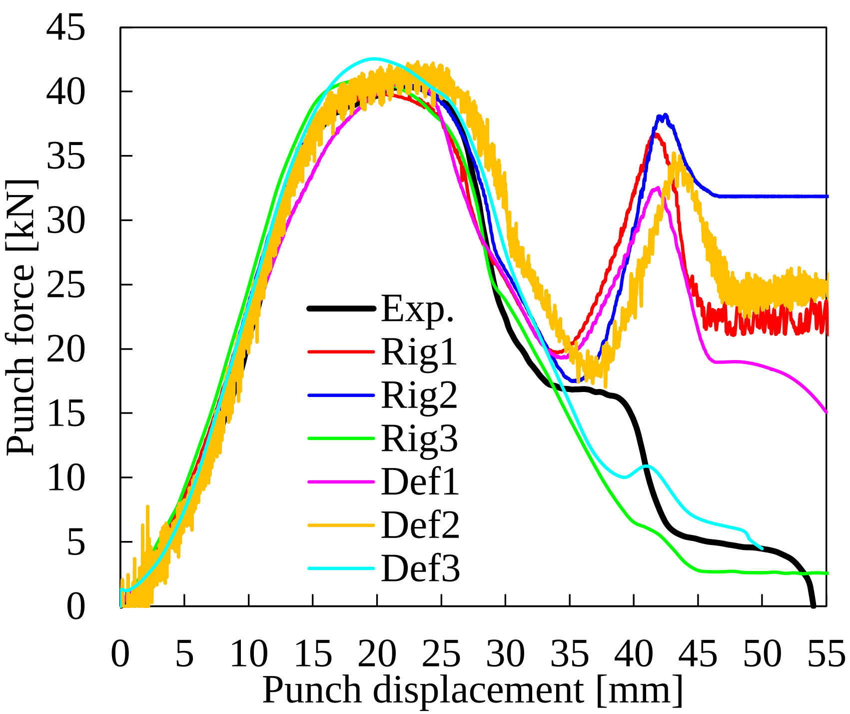
EXACT follow up 2022 : Influence of the tool stiffness

Rigid or deformable tools?

- negligible impact on the drawing stage,
(maximum value dictated by the friction coef.)

- maximum value of the ironing force ↘
with deformable tools and solid elements
for the blank.

- If blank in solid-shell elements, slight
increase of the ironing force
(but different codes so??).



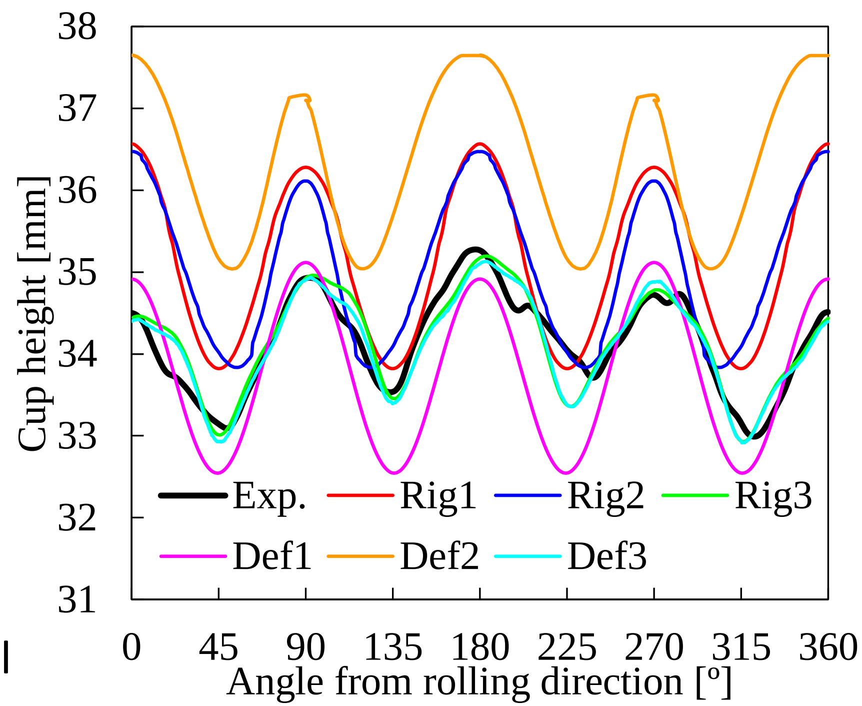
Experimental and predicted punch force-displacement curves using rigid (Rig) and deformable tools (Def).

EXACT follow up 2022 : Influence of the tool stiffness

- Rig1 and Rig2 : similar average height & trend,
- Def1: lower cup height,
- Def2: higher cup height.

- For solid-shell element: impact of deformable tools negligible (Rig3 and Def3).

- Not symmetric earing profile because the initial position of the blank was off set, to improve the comparison with the experimental results

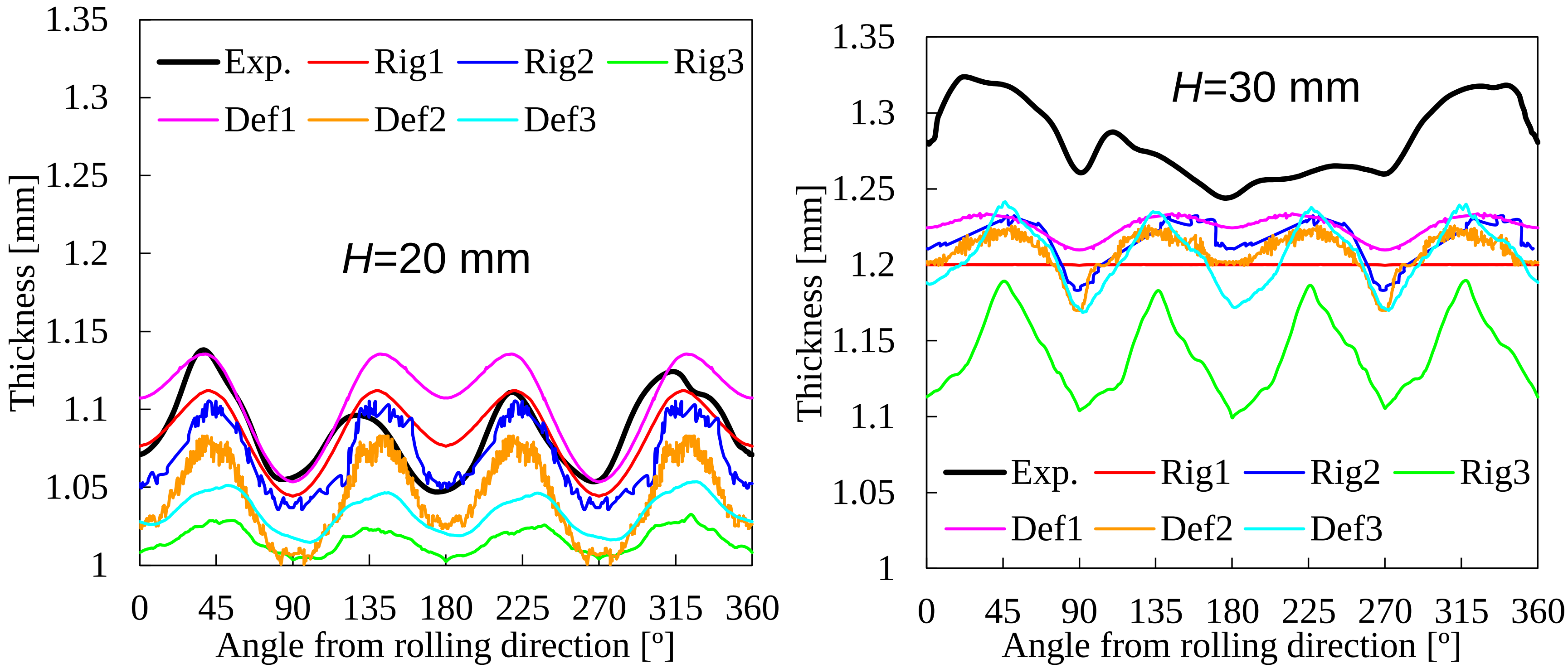


Comparison between experimental and predicted earing profile using rigid and deformable tools.

EXACT follow up 2022 : Influence of the tool stiffness

- Rigid tools + solid elements (Rig 1 and Rig2) // experimental one for 20 mm height

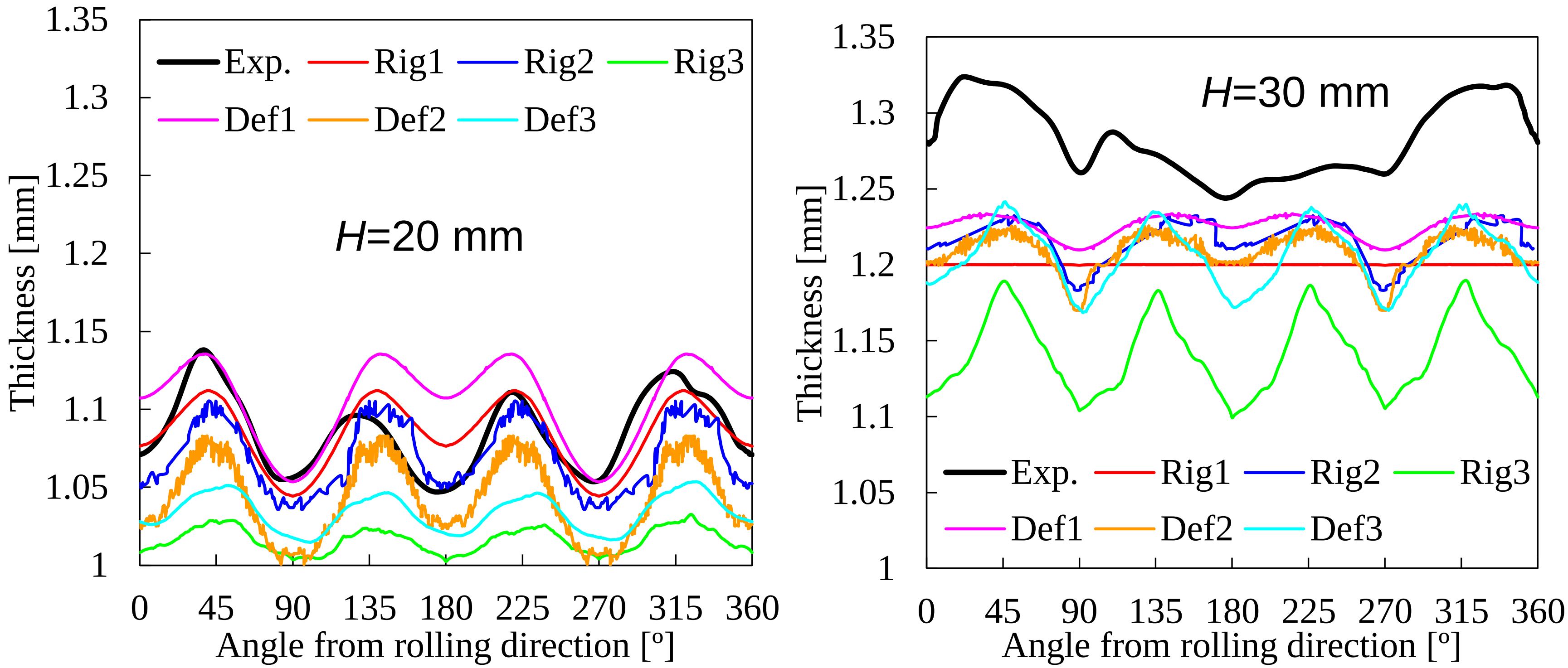
- For 30 mm height: Rig 1 constant thickness equal to the gap (1.2 mm)
  Rig2 predicts a slightly higher value



Experimental and numerical wall thickness distribution along the circumferential direction

EXACT follow up 2022 : Influence of the tool stiffness

- deformable tools + solid elements:
  Def1 highest thickness values for both heights,
  Def2 underestimates the thickness value for both heights.

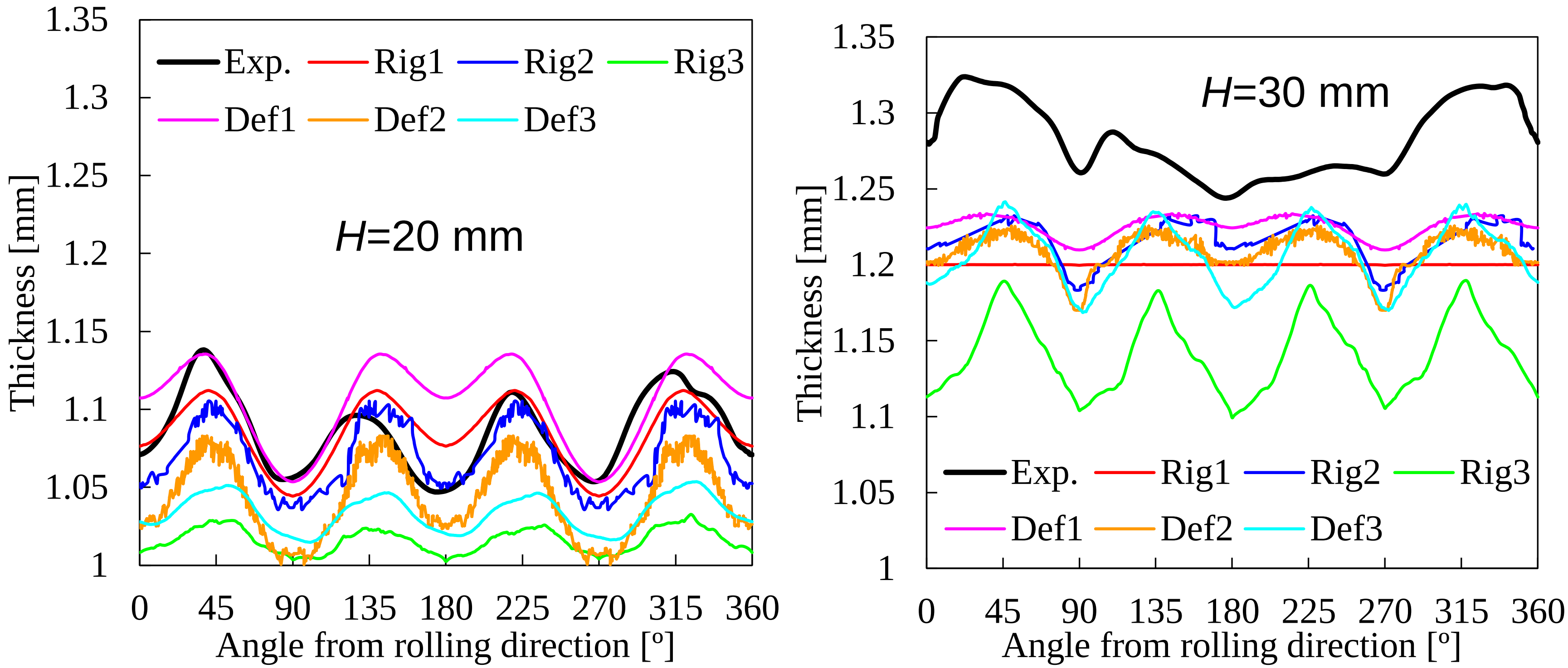


Experimental and numerical wall thickness distribution along the circumferential direction

EXACT follow up 2022 : Influence of the tool stiffness

- For solid-shell elements (Rig3 and Def3), thickness estimation improves when considering deformable tools.

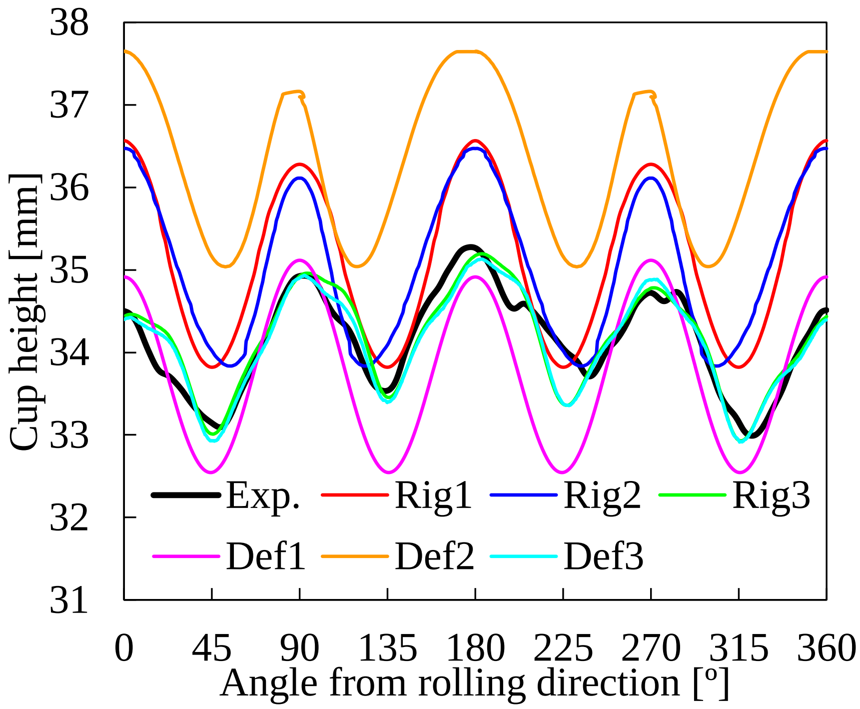
→ thickness values on the top of the cup higher than the gap between the die and the punch, like in the experiment.



Comparison between experimental and numerical wall thickness distribution along the circumferential direction

EXACT follow up 2022 : Influence of the tool stiffness

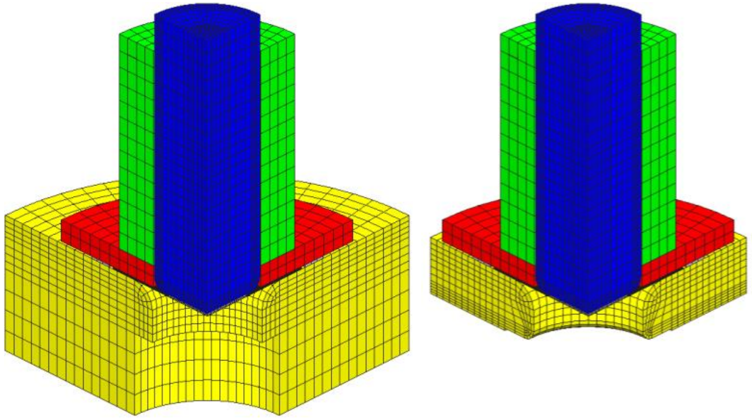
- Regarding the earing profile:
  Rig1, Rig2 similar average cup height and trend
  Def1 lower cup height
  Def2 higher cup height

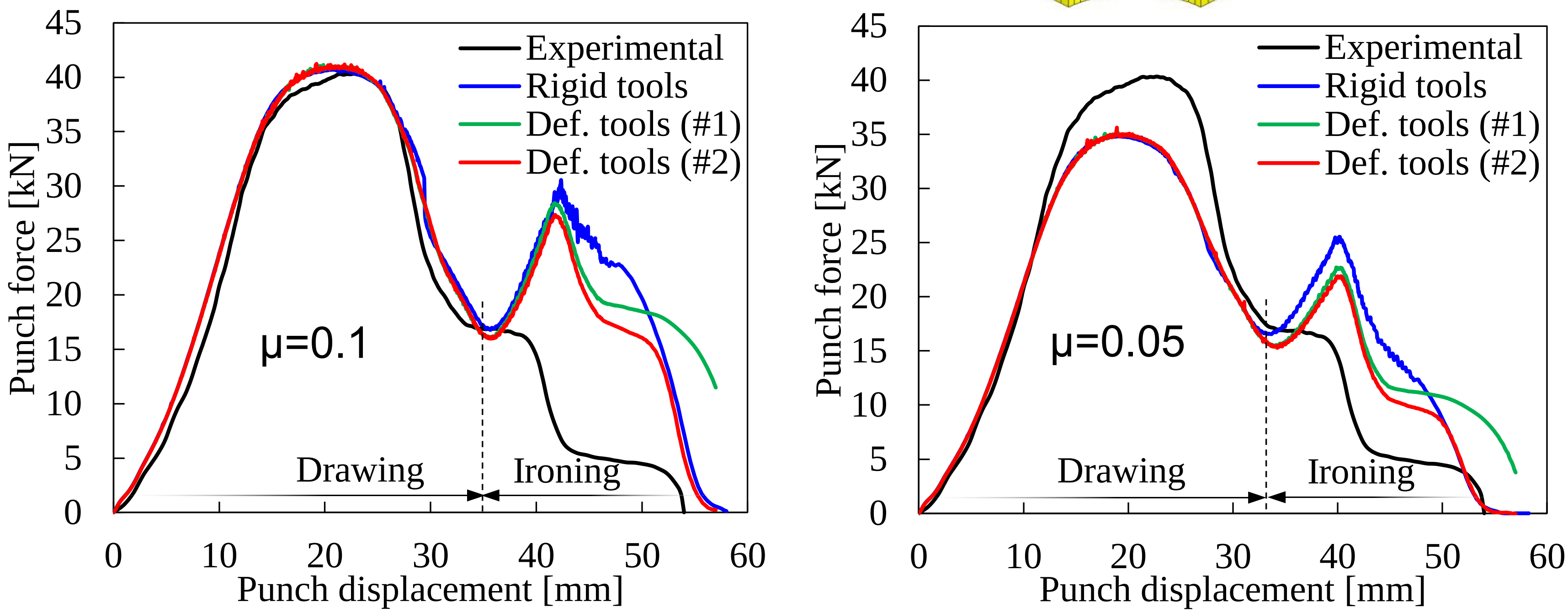


Experimental and numerical wall thickness distribution along the circumferential direction

EXACT follow up 2022 : Influence of the tool stiffness

- Deformable tools: influence of the geometry
- Moreover, the results for the ironing stage are always quite sensitive to friction



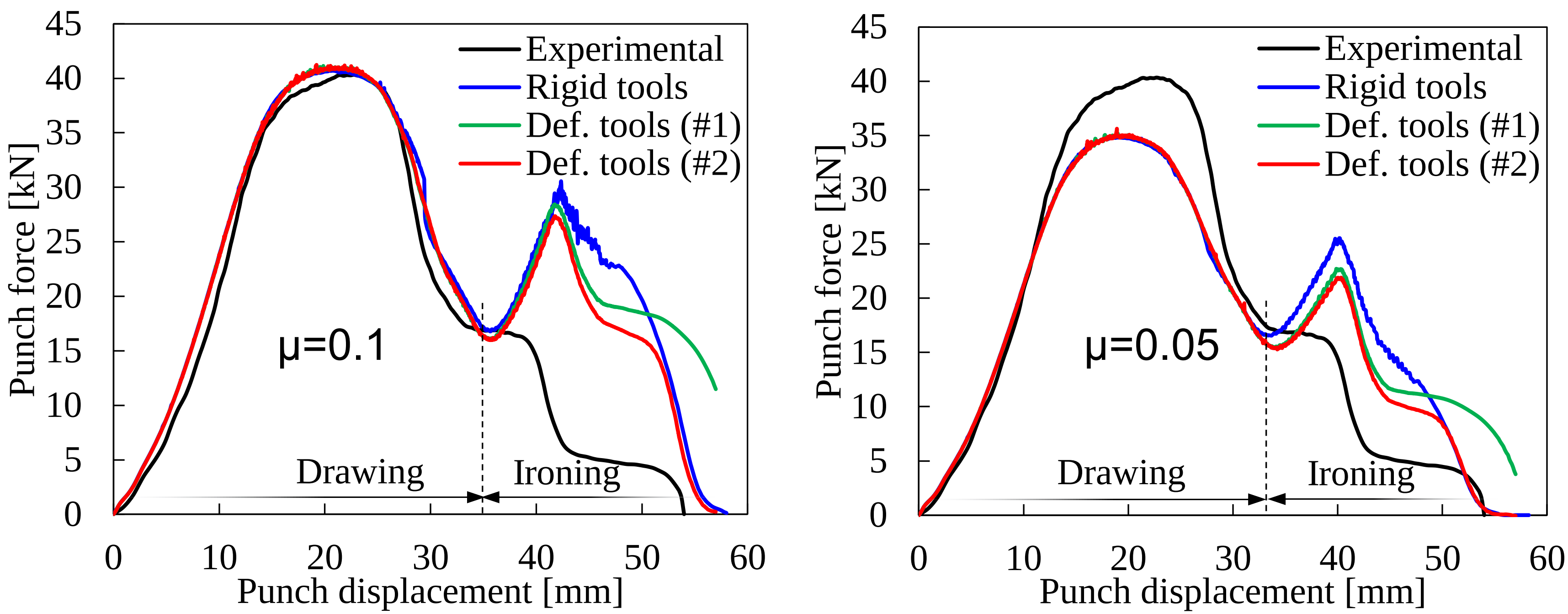


Experimental and numerical punch force evolution using different values of friction

EXACT follow up 2022 : Influence of the tool stiffness

- The ironing force ↘ when the elastic deformation of the forming tools is considered.
Slight increase of the die opening diameter and of the gap due to the high contact pressure.

- The bigger differences in the punch force only arise after 45 mm of punch displacement.

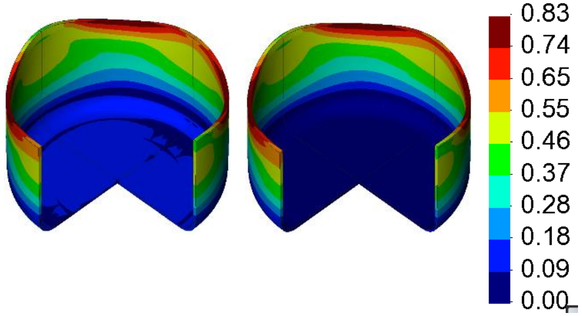


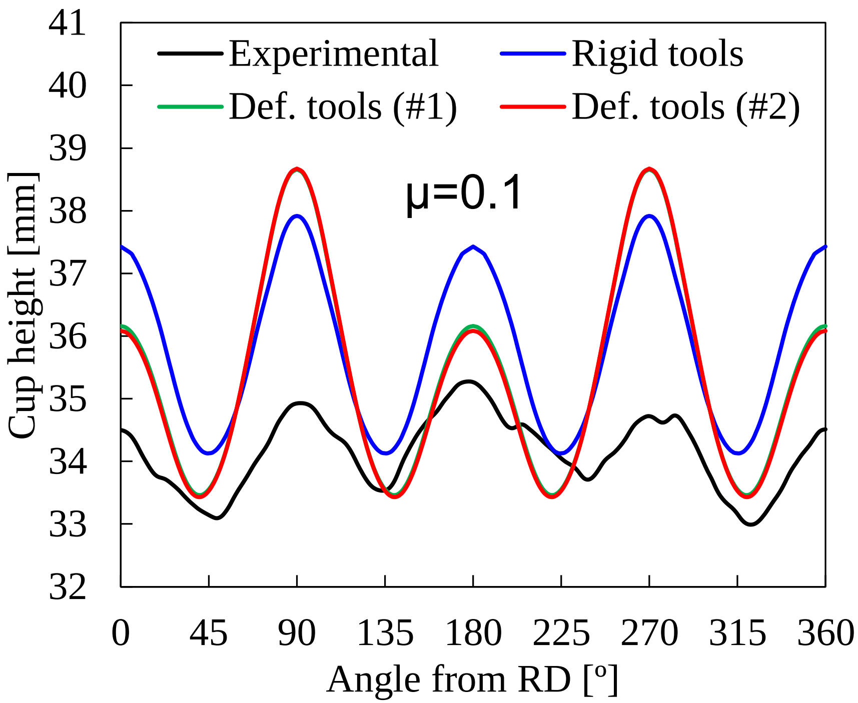
Experimental and numerical punch force evolution using different values of friction coefficient

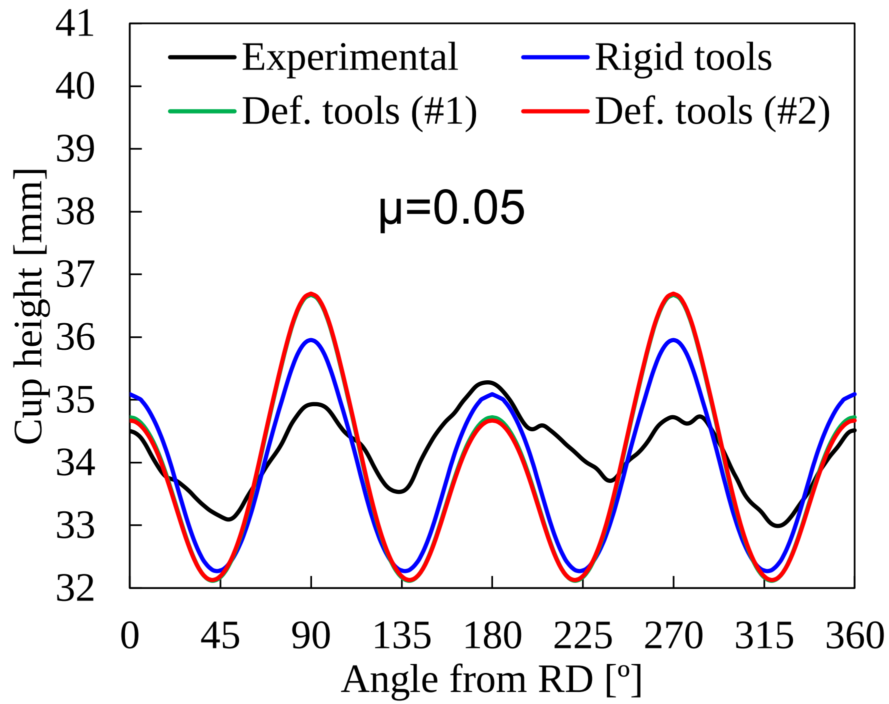
EXACT follow up 2022 : Influence of the tool stiffness

- The elastic deformation of the tools: cup height ↗ in TD and ↘ in the RD

Clear for μ=0.1, corroborating the uneven distribution of the contact forces in the flange for anisotropic materials.



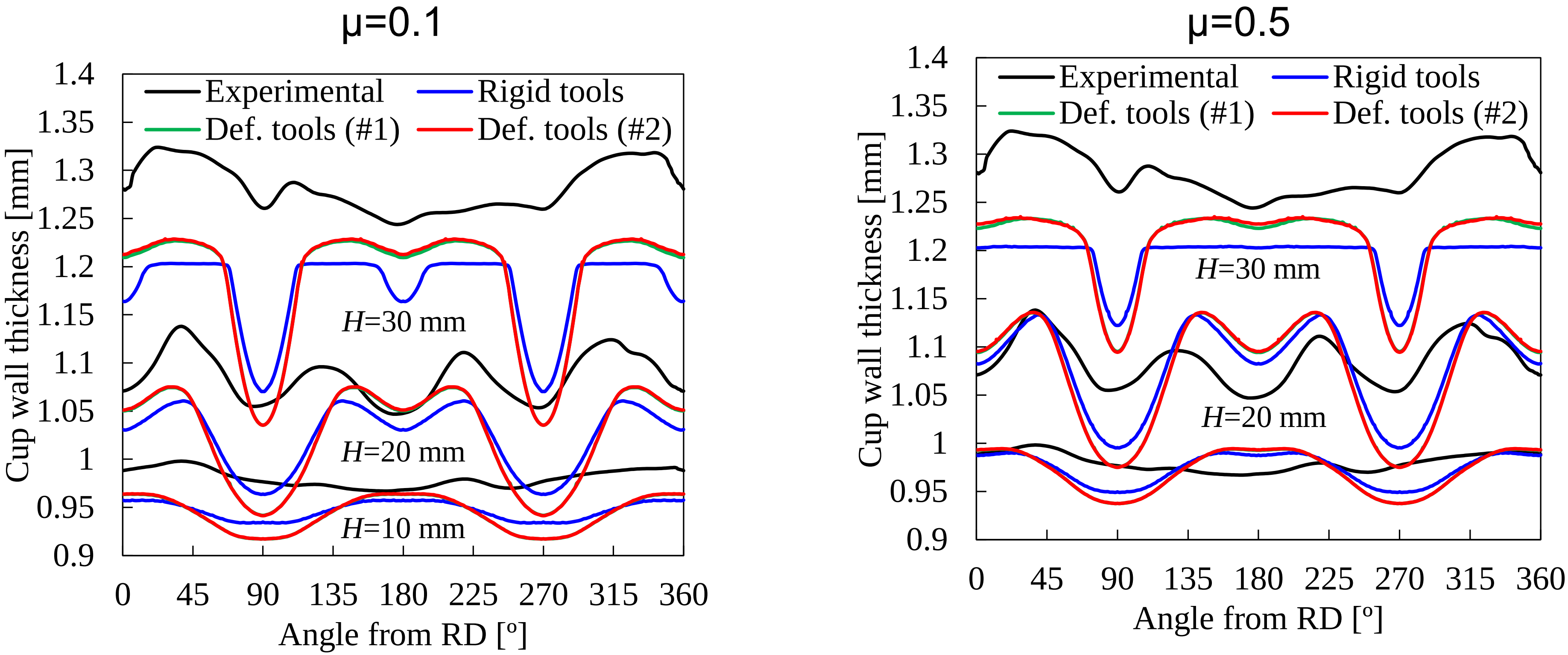




Experimental and numerical earing profile using different values of friction coefficient in the numerical analysis

EXACT follow up 2022 : Influence of the tool stiffness

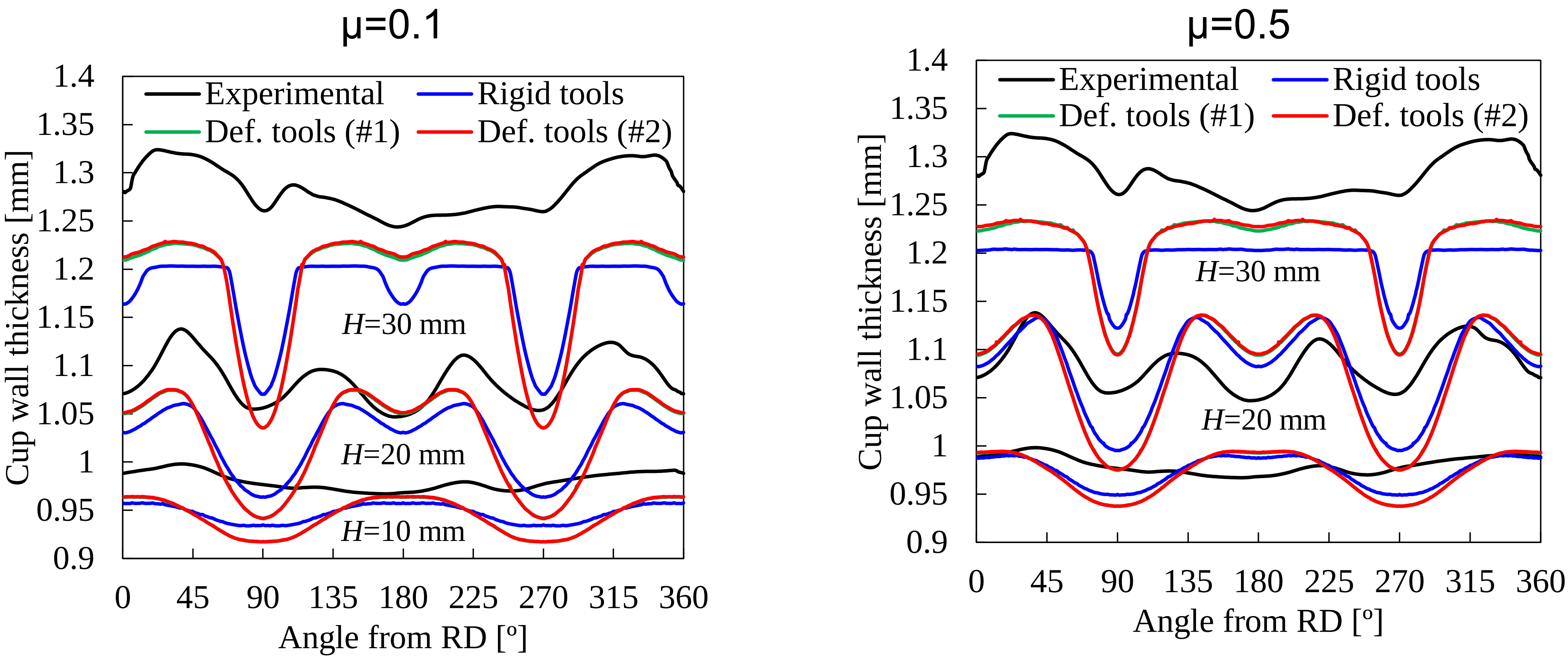
- Material anisotropy effect: non-uniform thickness along the circumferential direction.
- Predicted thickness using deformable tools higher around RD and lower around TD (in comparison with the prediction obtained with rigid tools).



Experimental and numerical cup wall thickness distribution along the circumferential

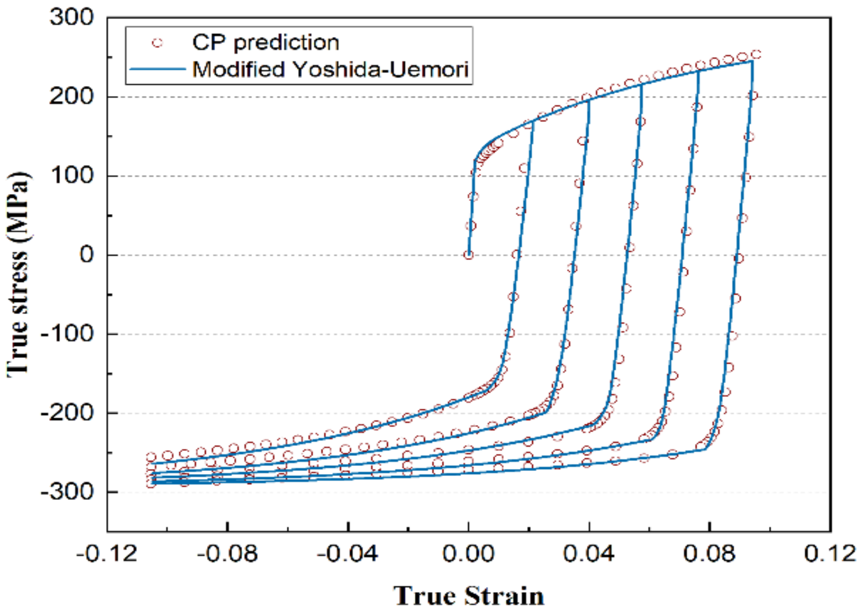
EXACT follow up 2022 : Influence of the tool stiffness

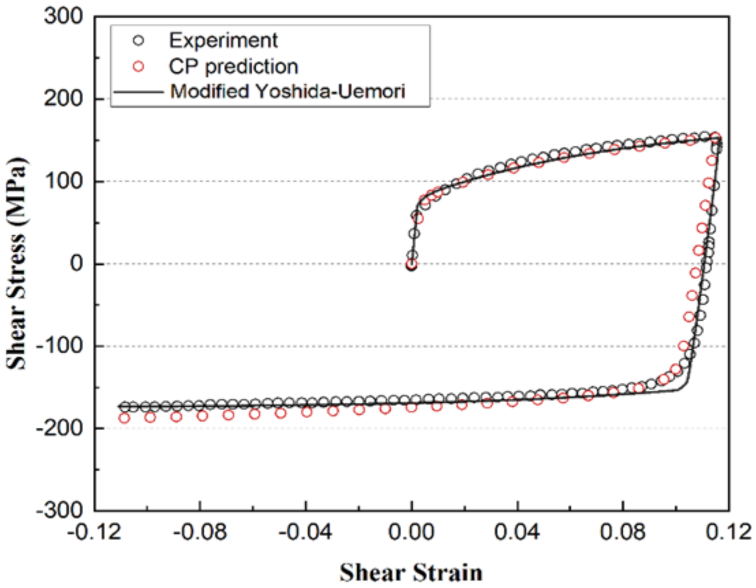
- Nevertheless, the ironing force is still higher than the experimental one, although the drawing force is clearly underestimated. This corroborates the difficulties in describing both process conditions using a constant value for the friction coefficient.



Experimental and numerical cup wall thickness distribution along the circumferential

EXACT follow up 2022 : Use of material data base





- DAMASK Crystal Plasticity Model prediction
- Yld2004-18p yield function coupled with modified Yoshida and Uemori kinematic hardening model (a yield surface and a bounding surface)
-Experimental reverse shear test

Messages from EXACT ESAFORM Benchmark 2021

- Same set of experiments for the material parameter identification,
Trained scientists using the well-known **Hill48 model** (≠ codes, meshes, element types)
→ similar predicted earing profiles.
7 participants out of 8 have a **global error for the earing profile smaller than 3% for** this strong cube texture material.
Hill48 model can lead to adequate predictions of the earing profile.

- For the identification of the parameters: **particular relevance was given** by the participants **to the description of the anisotropy of the Lankford coefficients**, because of its strong impact on the earing profile.
→ **need of accurate experiments.**

- **The identification methodology is a key point to generate reliable results.**

This article highlights how the careful parameter selection approach of some modelers led to accurate results.

The choice of a representative set of crystals,
The analysis of Lankford coefficient evolution or not
The need of pre-validation checks,
Need of a larger training than applying simple analytical formula to identify Hill48 model, from constant Lankford coefficients in 3 directions.

This identification work request skilled scientists.

Messages from EXACT ESAFORM Benchmark 2021

- Six types of data.
  - ❑ Tensile flow stress anisotropy,
  - ❑ r-value anisotropy,
  - ❑ yield locus (biaxial tests),
  - ❑ earing profile,
  - ❑ force evolution in cup forming
  - ❑ monotonic and reverse shear tests are available.

none of the models could accurately describe the complete picture.

- Yield stress anisotropy under uniaxial loadings not well predicted, particularly the one at 45°, by most of the models (including the ones based on crystal plasticity).

Not critical for the correct prediction of the earing profile relevant for other processes

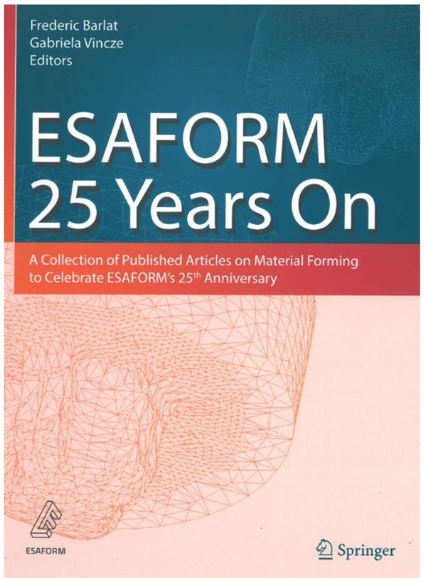
- The strong collaboration between experimental and numerical teams prevents the easy assumption, common for simulation teams, to just think that there is a problem in the experiments.

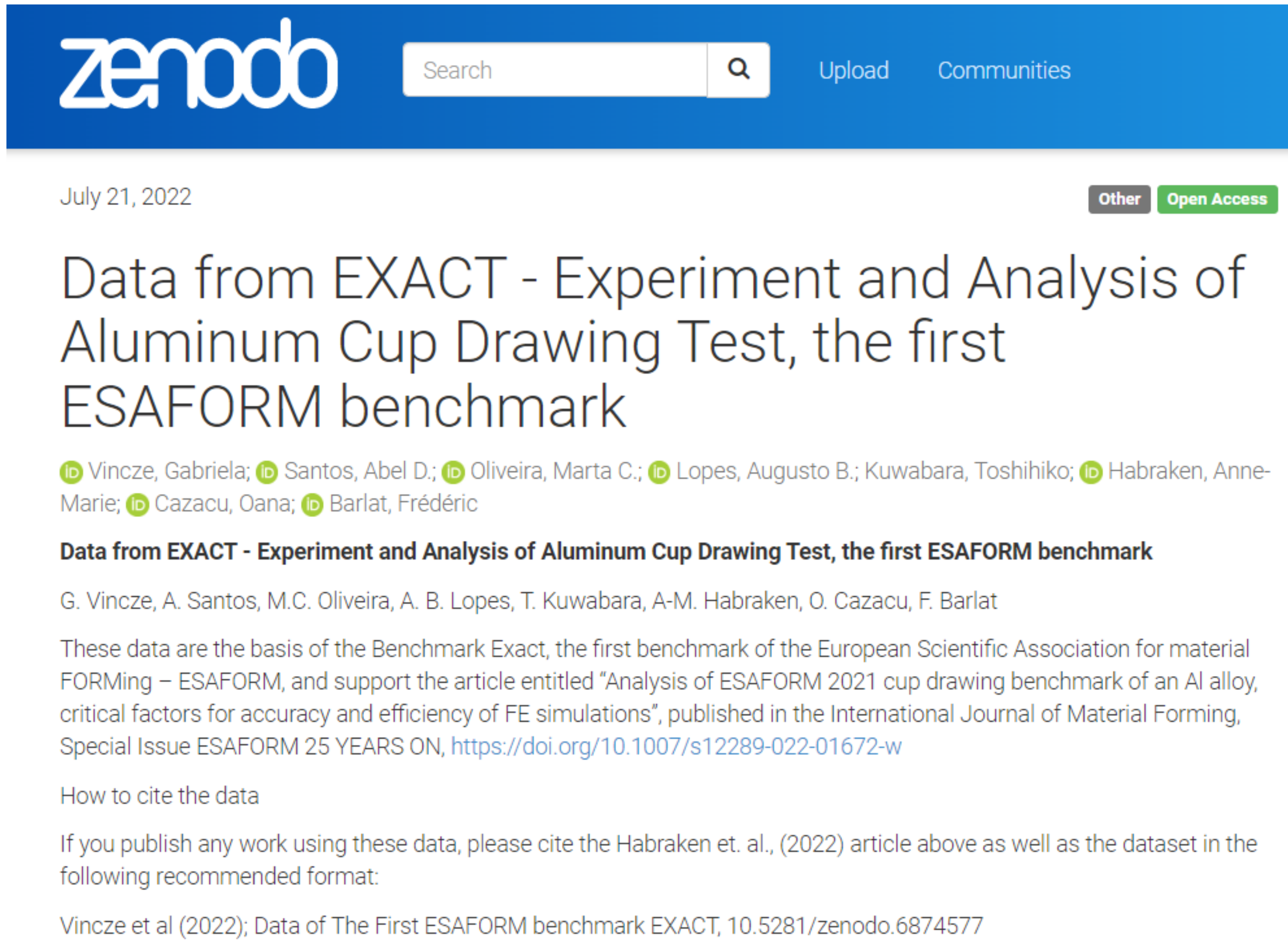
  → fruitful discussions about clearance, defects in the blank positioning and measurements.

  →The need for further investigation in tool deformation, contact modelling and friction measurements is itself a result from the benchmark.

EXACT Result Analysis and Material Data

- Open access article IJMF Habraken et. al 6, 2022 - detailed analysis of experiments, material parameter identification, simulation results
- Material data Vinze et al. : https://zenodo.org/record/6874577#.Y4YhzHbMKyA





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Other Open Access

Data from EXACT - Experiment and Analysis of Aluminum Cup Drawing Test, the first ESAFORM benchmark

Vincze, Gabriela; Santos, Abel D.; Oliveira, Marta C.; Lopes, Augusto B.; Kuwabara, Toshihiko; Habraken, Anne-Marie; Cazacu, Oana; Barlat, Frédéric

Data from EXACT - Experiment and Analysis of Aluminum Cup Drawing Test, the first ESAFORM benchmark

G. Vincze, A. Santos, M.C. Oliveira, A. B. Lopes, T. Kuwabara, A-M. Habraken, O. Cazacu, F. Barlat

These data are the basis of the Benchmark Exact, the first benchmark of the European Scientific Association for material FORMing – ESAFORM, and support the article entitled "Analysis of ESAFORM 2021 cup drawing benchmark of an Al alloy, critical factors for accuracy and efficiency of FE simulations", published in the International Journal of Material Forming, Special Issue ESAFORM 25 YEARS ON, https://doi.org/10.1007/s12289-022-01672-w

How to cite the data

If you publish any work using these data, please cite the Habraken et. al., (2022) article above as well as the dataset in the following recommended format:

Vincze et al (2022); Data of The First ESAFORM benchmark EXACT, 10.5281/zenodo.6874577

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