CEMMPRE · U C ·

# Formability assessment of a cup drawing under complex nonlinear strain paths

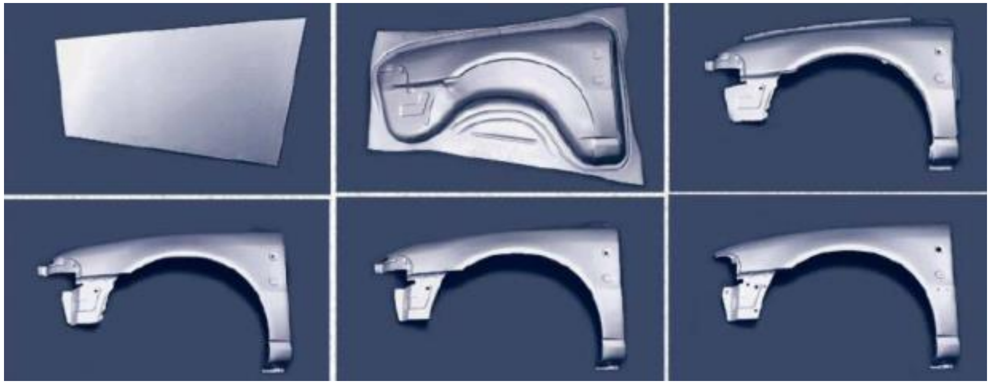
**P.D. Barros**[1], **R.R. Amaral**[2], **M.C. Oliveira**[1], **A.D. Santos**[2,3], **J.L. Alves**[4] **and L.F. Menezes**[1]

[1]CEMMPRE, Centre for Mechanical Engineering, Materials and Processes, University of Coimbra
[2]INEGI, Institute of Science and Innovation in Mechanical and Industrial Engineering, Porto
[3]FEUP, Faculty of Engineering, University of Porto
[4]CMEMS, Center for Microelectromechanical Systems, University of Minho

# Agenda

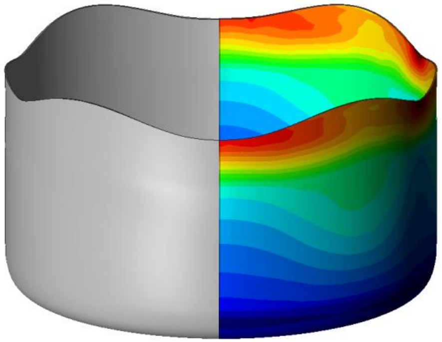
- Motivation
- Objectives
- Material mechanical behavior
- Numerical model
- Results
- Conclusions

Nowadays, sheet metal forming processes are designed and optimized virtually.

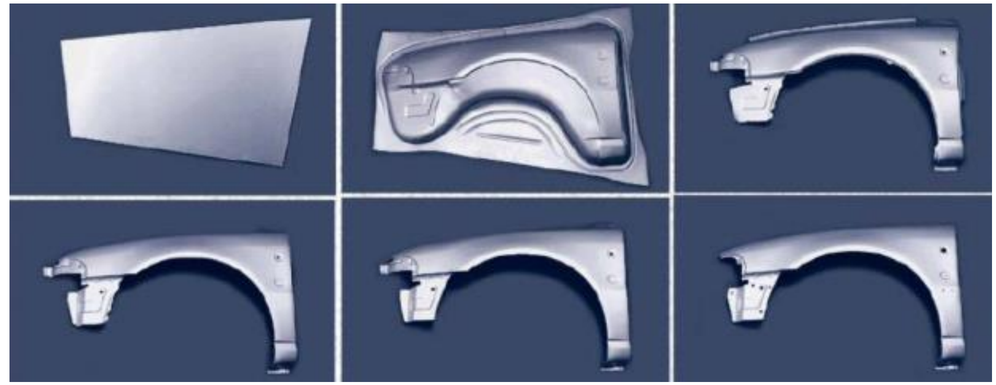


The use of Finite Element Analysis allows

- Decrease in time to market life cycle;
- Notable savings in terms of money, time and effort in the design, production and set-up of new formed parts.

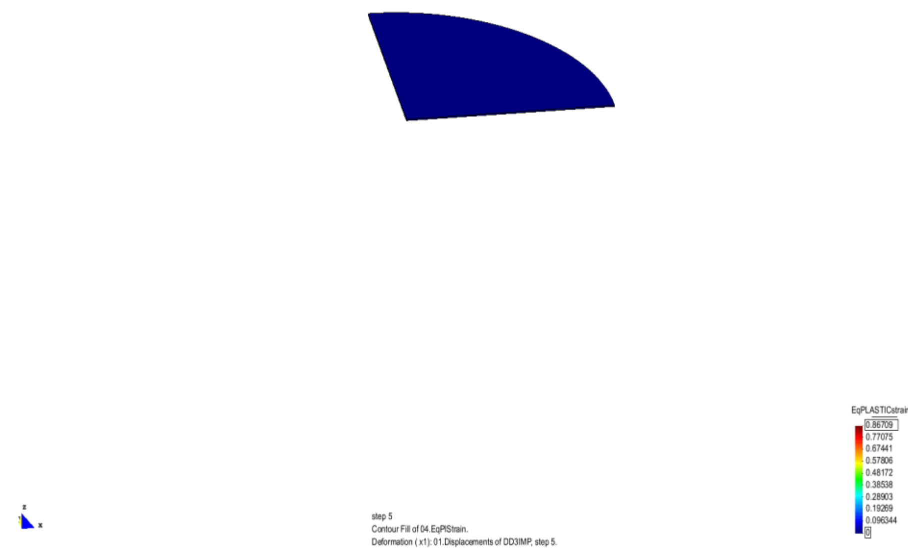


Nowadays, sheet metal forming processes are designed and optimized virtually.



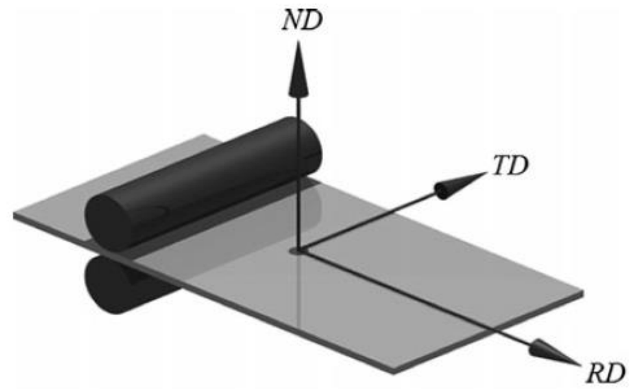
The use of Finite Element Analysis allows

- Decrease in time to market life cycle;
- Notable savings in terms of money, time and effort in the design, production and set-up of new formed parts.



Sheet metals generally exhibit anisotropy of their mechanical properties.

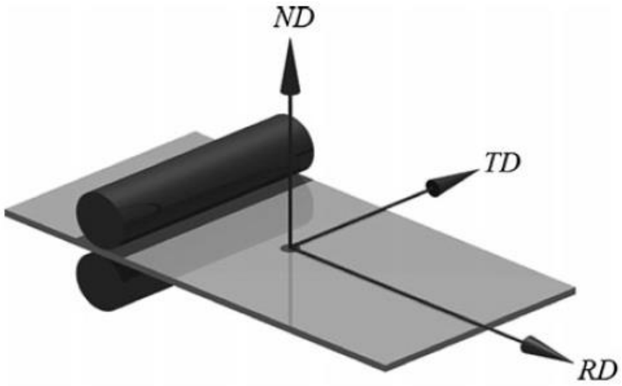
The rolling process induces a particular anisotropy characterized by the symmetry of the mechanical properties with respect to the three orthogonal planes, i.e. orthotropy.



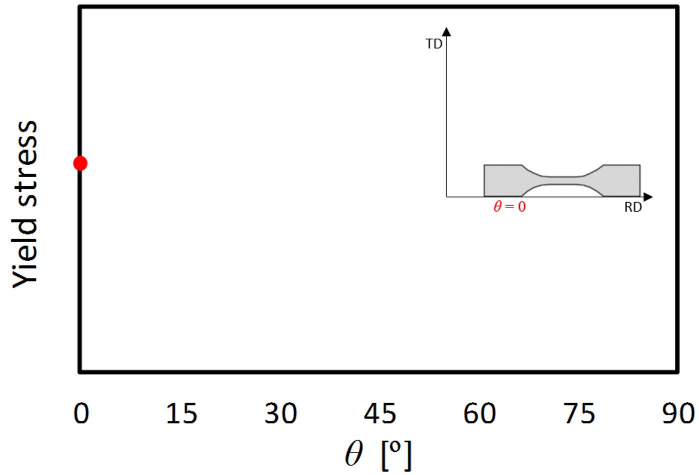

As this process makes the metal sheets orthotropic, different mechanical behaviors are expected for different loading directions and conditions.

Sheet metals generally exhibit anisotropy of their mechanical properties.

The rolling process induces a particular anisotropy characterized by the symmetry of the mechanical properties with respect to the three orthogonal planes, i.e. orthotropy.




As this process makes the metal sheets orthotropic, different mechanical behaviors are expected for different loading directions and conditions.



# Plastic response in metals

Crystal plasticity models

- More precise
- More complex
- Numerically expensive

Phenomenological models

- Less precise
- Less complex
- Numerically efficient

## Plastic response in metals

Phenomenological models

- Yield surface
- Flow rule
- Hardening law

The anisotropy parameters must be identified such that the yield criterion reproduces the material's mechanical behaviour as close as possible

**Numerical prediction of failure of a can –** Benchmark 1, Numisheet 2016

**Blank**

**Draw + Redraw**

**Expansion**

- Verify the capability to predict variations of the yeld stresses and *r*-values in the plane of the sheet metal;
- Failure timing and location;
- Earing and thickness profiles after reverse redraw.

# **Material mechanical behavior –** AA5352

*Cazacu & Barlat 2001 yield criterion (CB2001)*

$$\left(J_2^0\right)^3 - c\left(J_3^0\right)^2 = 27\left(\frac{Y}{3}\right)^6$$

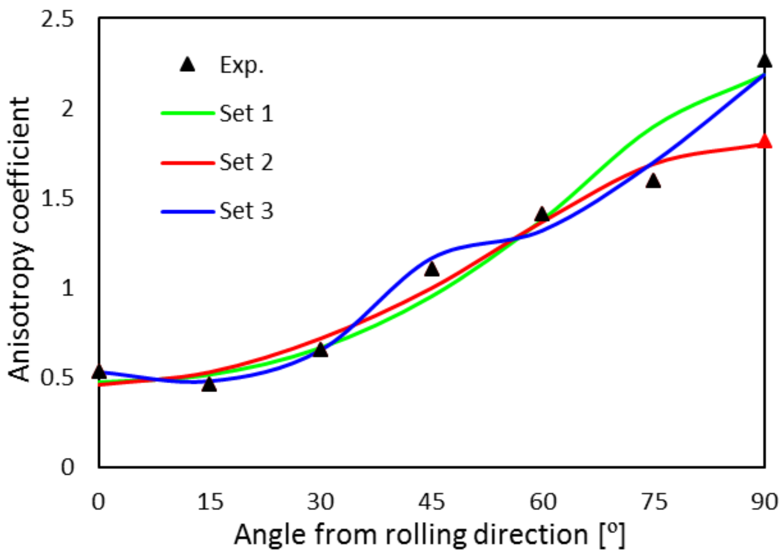
$$J_2^0 = \frac{a_1}{6}(\sigma_{11}-\sigma_{22})^2 + \frac{a_2}{6}(\sigma_{11}-\sigma_{33})^2 + \frac{a_3}{6}(\sigma_{11}-\sigma_{33})^2 + a_4\sigma_{12}^2 + a_5\sigma_{13}^2 + a_6\sigma_{23}^2$$

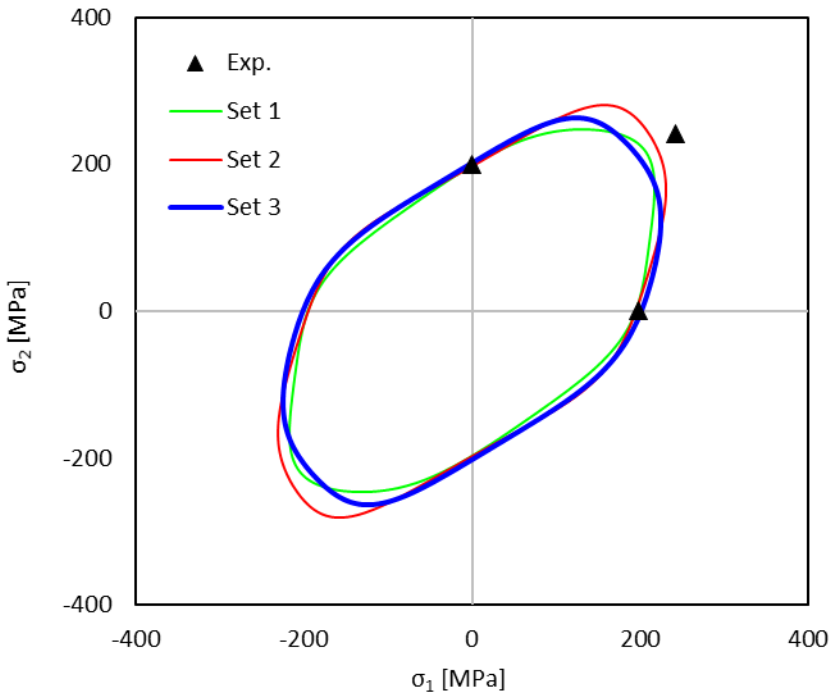
$$\begin{aligned} J_3^0 = {} & (1/27)(b_1+b_2)\sigma_{11}^3 + (1/27)(b_3+b_4)\sigma_{22}^3 \\ & + (1/27)[2(b_1+b_4)-b_2-b_3]\sigma_{33}^3 \\ & - (1/9)(b_1\sigma_{22}+b_2\sigma_{33})\sigma_{11}^2 - (1/9)(b_3\sigma_{33}+b_4\sigma_{11})\sigma_{22}^2 \\ & - (1/9)[(b_1-b_2+b_4)\sigma_{11}+(b_1-b_3+b_4)\sigma_{22}]\sigma_{33}^2 \\ & + (2/9)(b_1+b_4)\sigma_{11}\sigma_{22}\sigma_{33} \\ & - \left(\sigma_{13}^2/3\right)[2b_9\sigma_{22}-b_8\sigma_{33}-(2b_9-b_8)\sigma_{11}] \\ & - \left(\sigma_{12}^2/3\right)[2b_{10}\sigma_{33}-b_5\sigma_{22}-(2b_{10}-b_5)\sigma_{11}] \\ & - \left(\sigma_{23}^2/3\right)[(b_6-b_7)\sigma_{11}-b_6\sigma_{22}-b_7\sigma_{33}] + 2b_{11}\sigma_{12}\sigma_{23}\sigma_{13} \end{aligned}$$

Anisotropy parameters identified with DD3MAT code

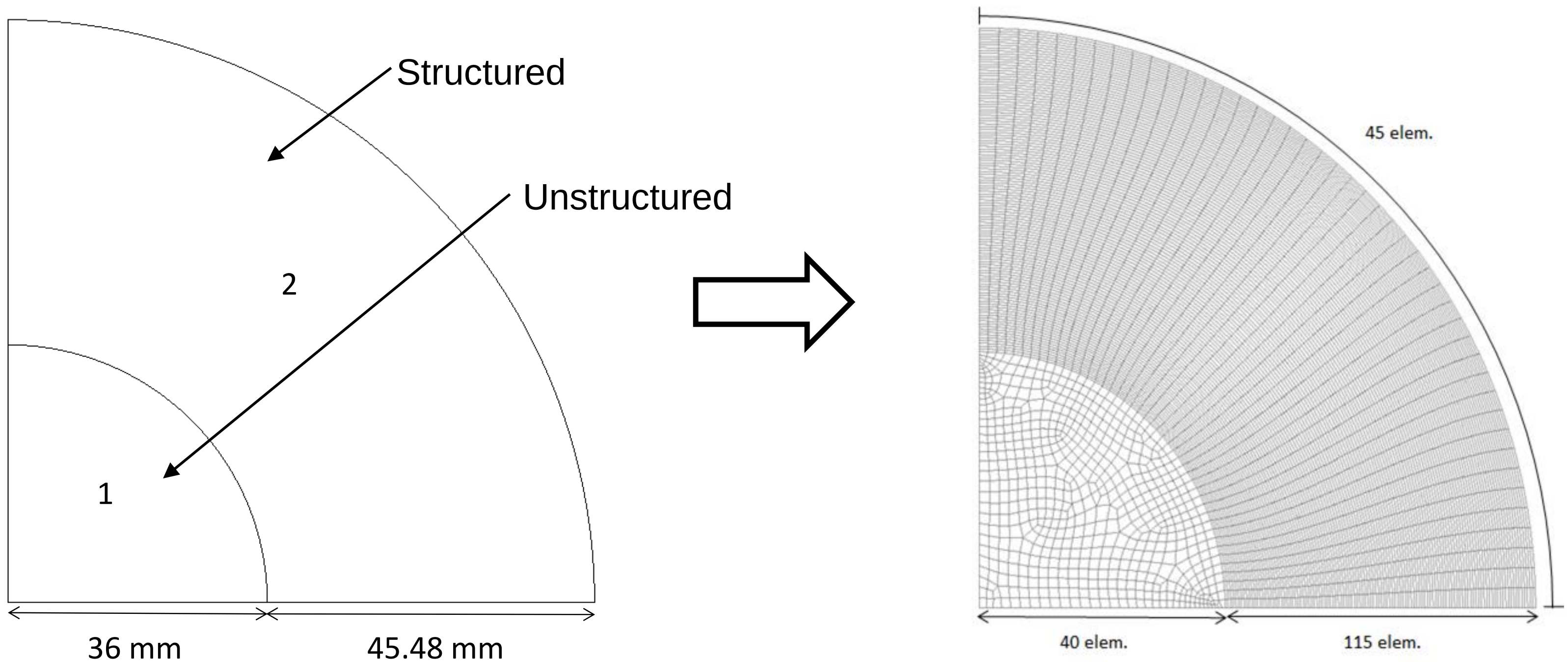
## **Material mechanical behavior –** AA5352

- Set 1 – original experimental data fit
- Set 2 – lower *r*-value at 90º
- Set 3 – *r*-values "best fit"



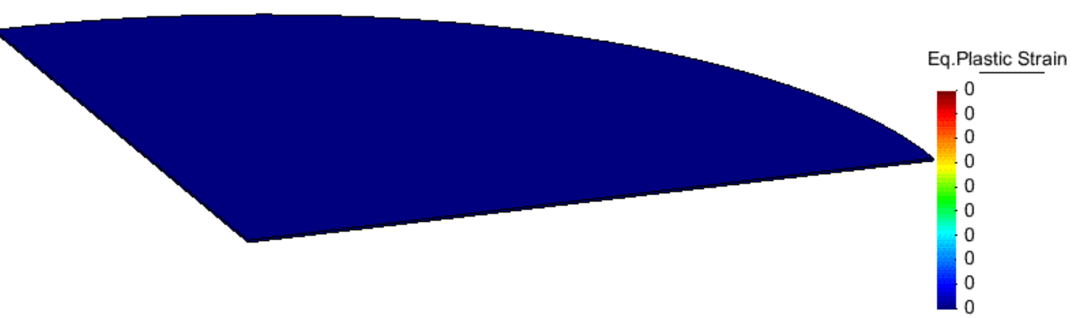
## Blank discretization

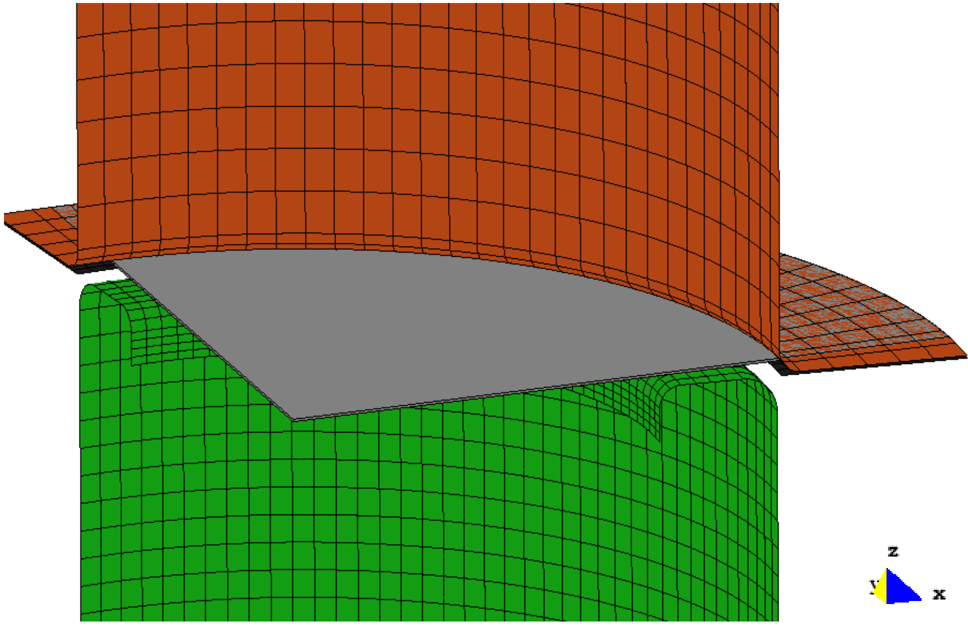



- 8-node solid hexahedral finite elements;
- Total of 17844 finite elements.

**Tools discretization -** Drawing

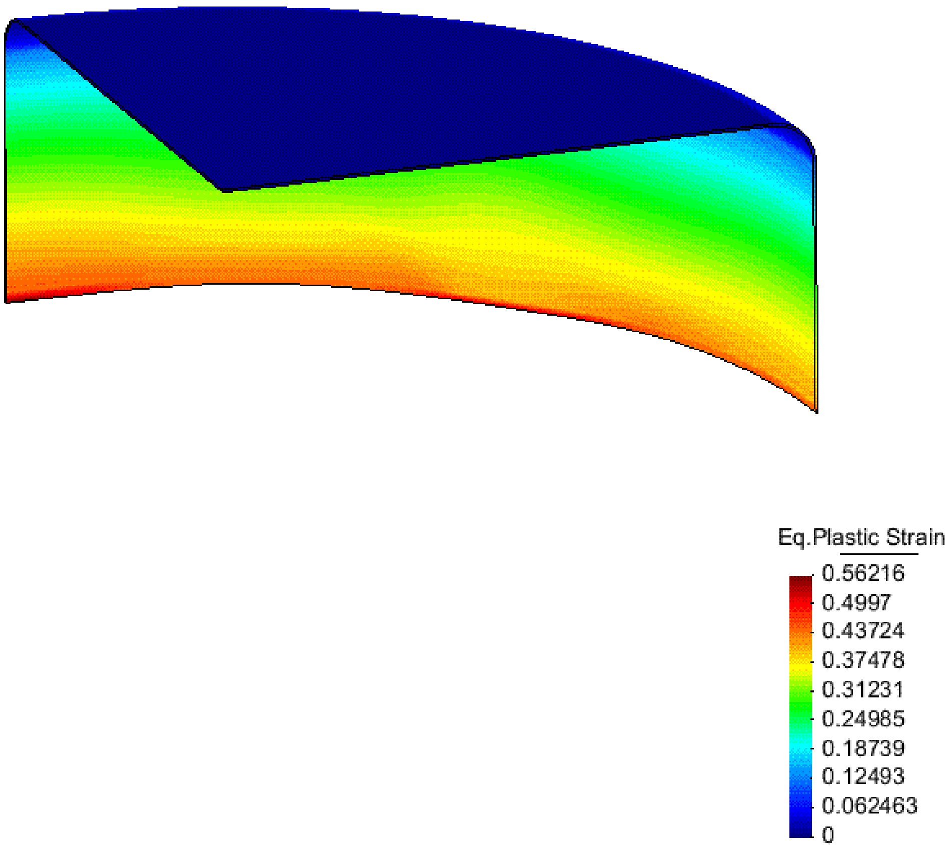
Simulations performed with DD3IMP

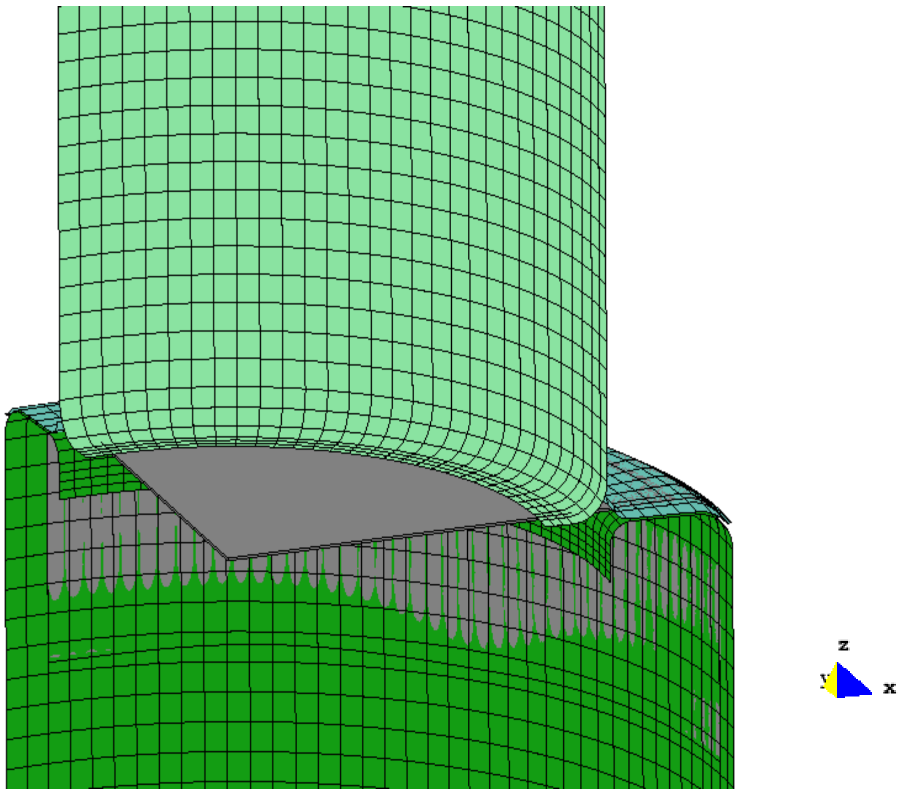


**Tools discretization -** Redrawing

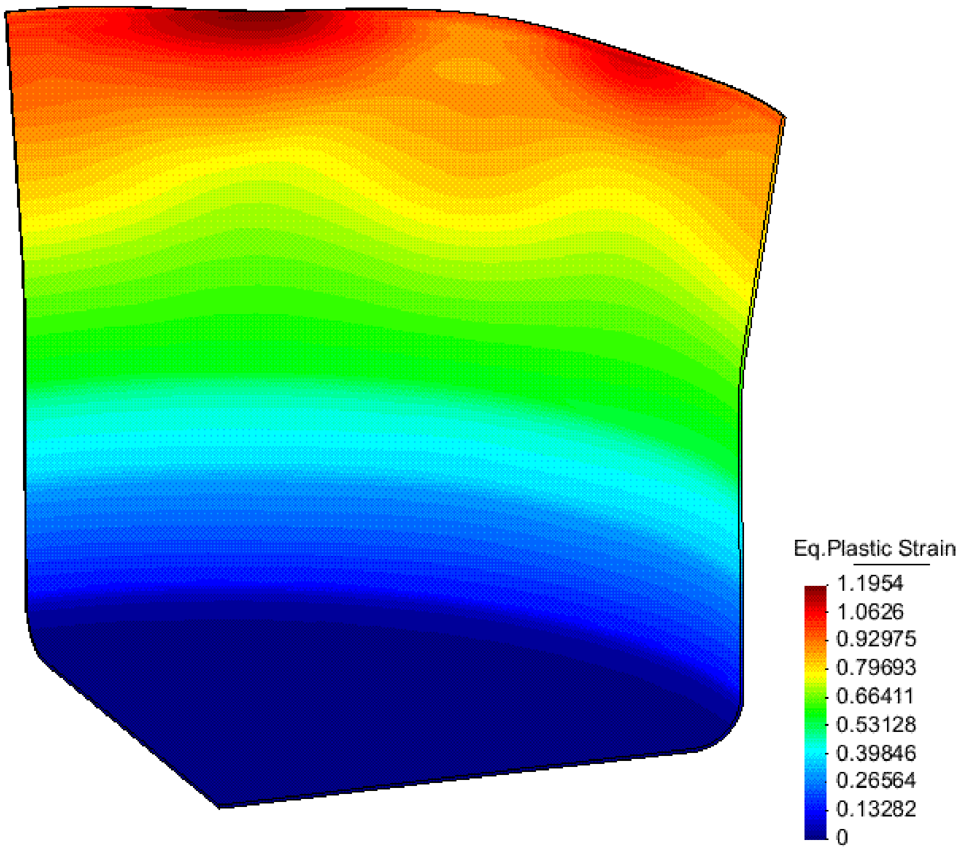
Simulations performed with DD3IMP

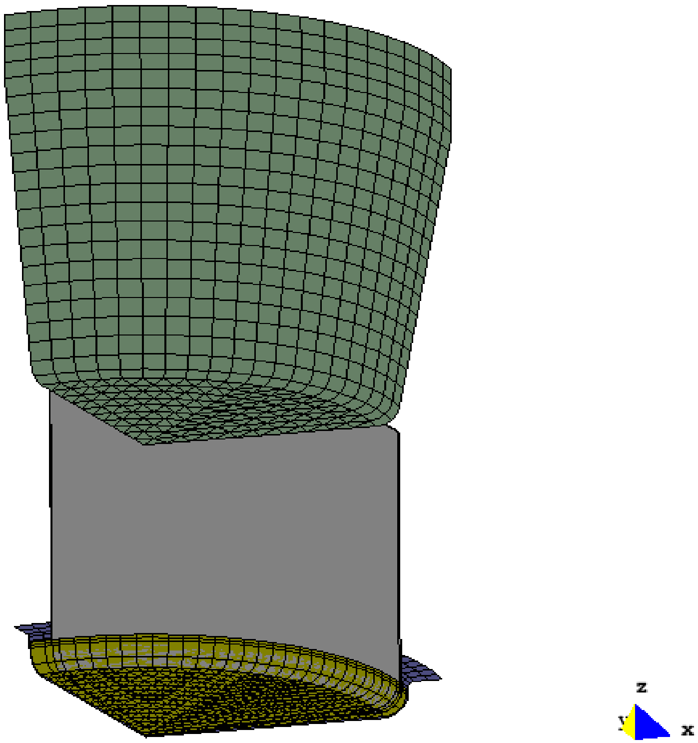


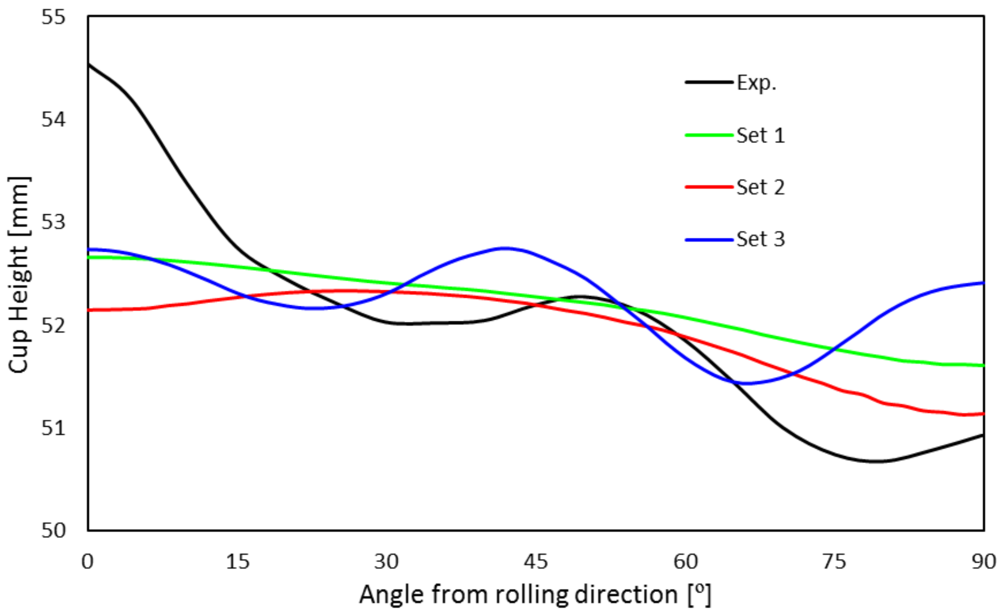
**Tools discretization -** Expansion

Simulations performed with DD3IMP



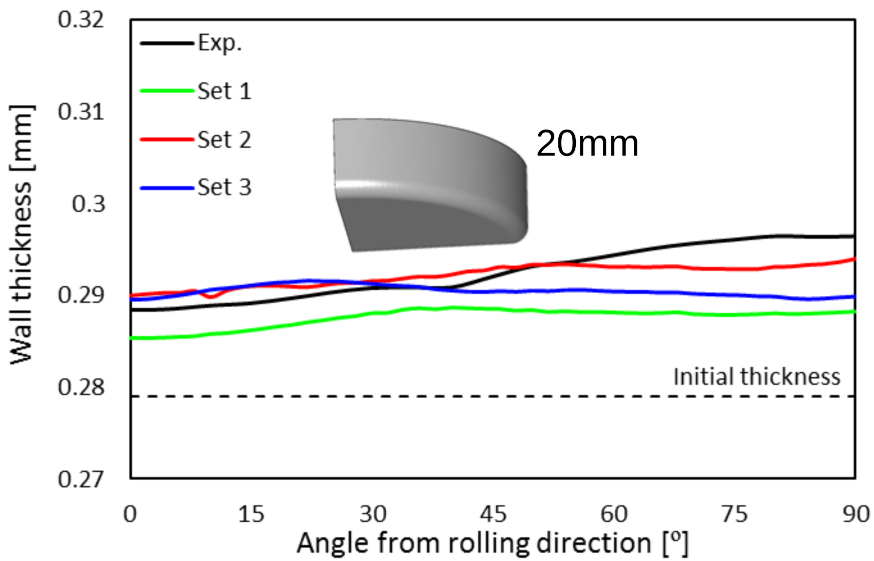



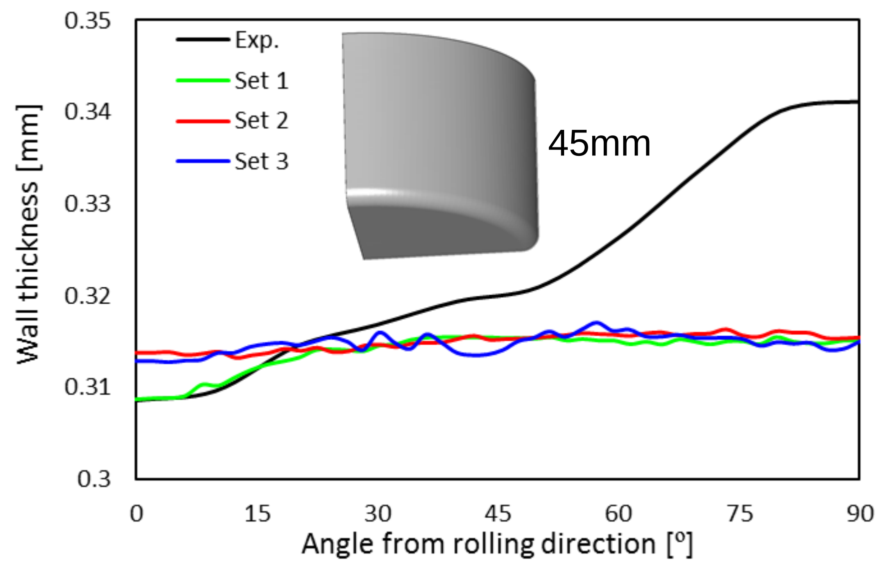
## **Earing profile –** after redraw operation




- Pinching effect for 0º with rolling direction

## **Thickness distribution –** after redraw operation

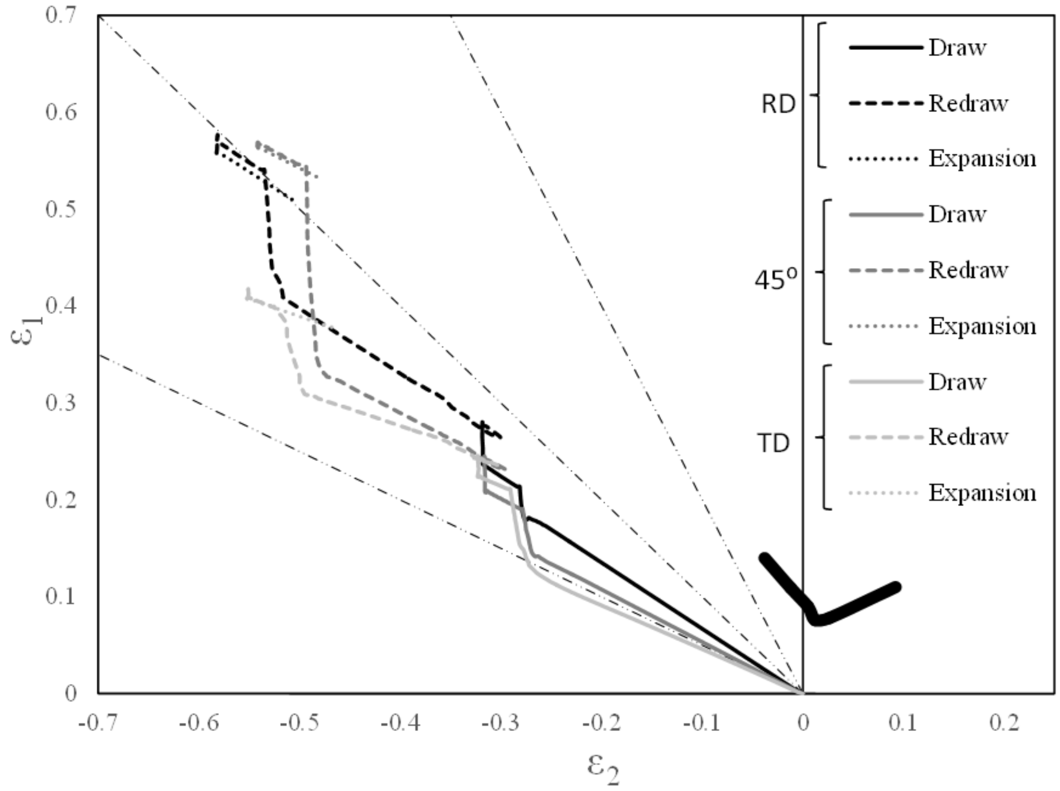



- Set 1 lower thickness for 0º due to higher *r*-value (45mm cup height)

**Fracture location –** during expansion

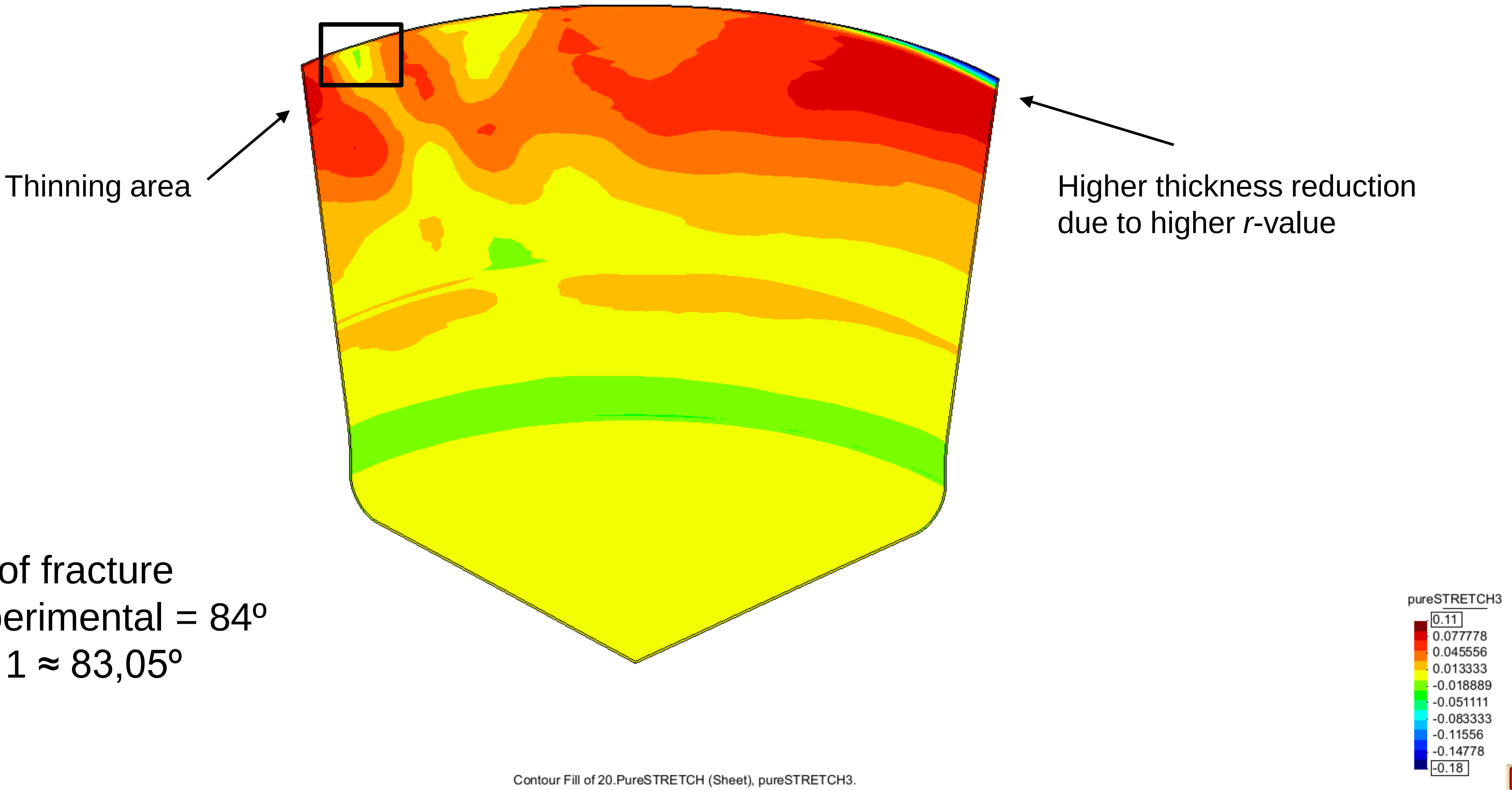
Considering given FLC




- Strain path does not cross given FLC

**Fracture location –** during expansion

Considering thinning

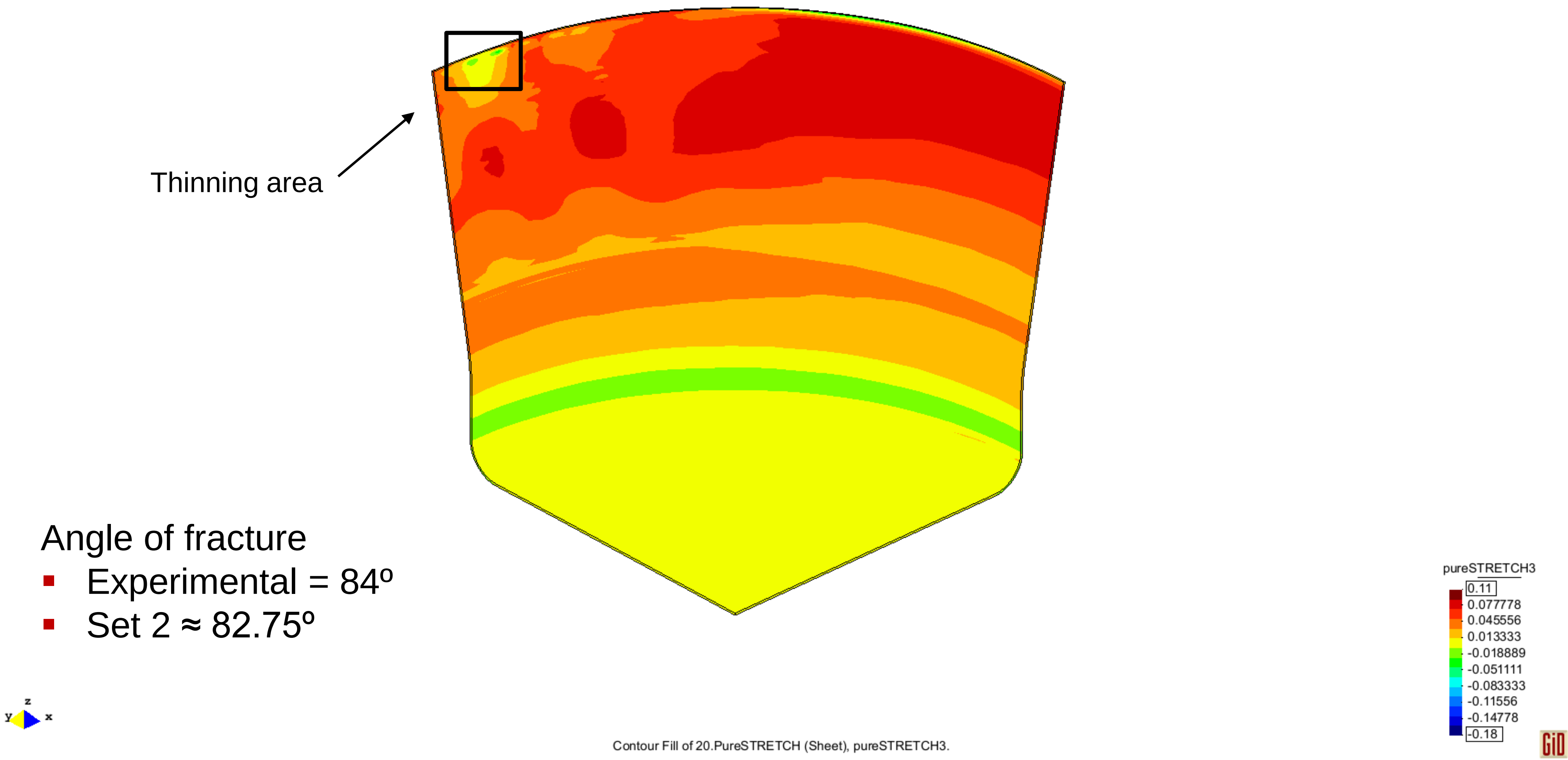



Angle of fracture

- Experimental = 84º
- Set 1 ≈ 83,05º

**Fracture location –** during expansion

Considering thinning



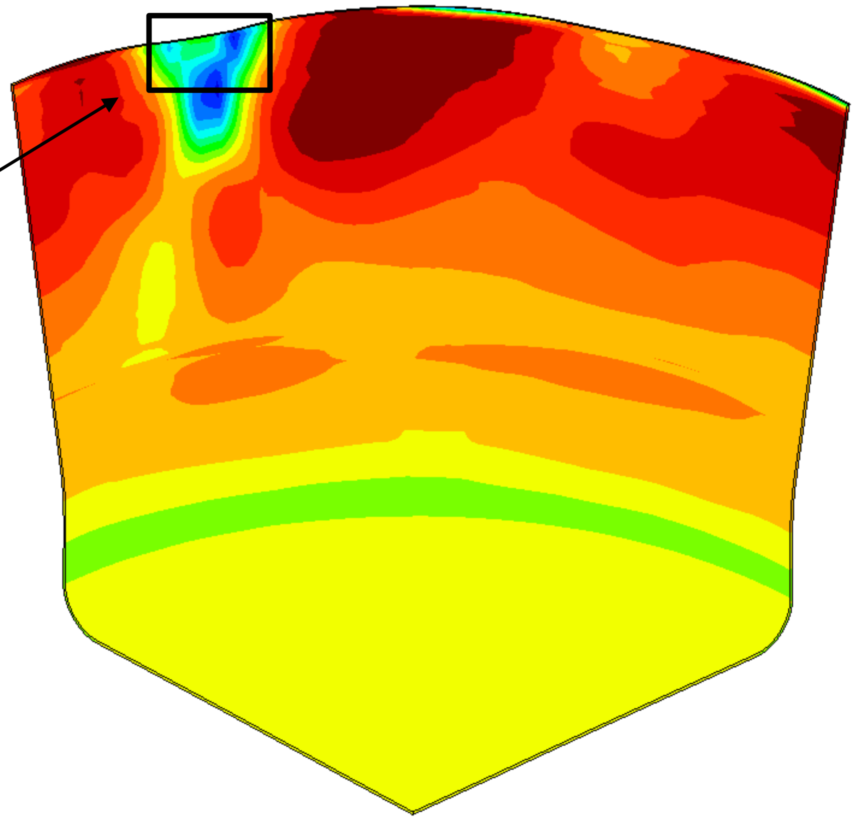

Angle of fracture

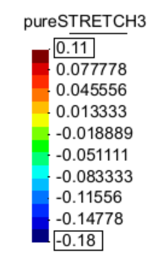
- Experimental = 84º
- Set 2 ≈ 82.75º

**Fracture location –** during expansion

Considering thinning

Thinning area






Angle of fracture

- Experimental = 84º
- Set 3 ≈ 66,55º

- The accurate prediction of the material's mechanical behaviour is crucial for the evaluation of the material flow;
- … which is dependent on the yield criterion flexibility;
- Slight variations of the *r*-values lead to a considerable difference of both earing and thickness predictions;
- The failure location is influenced by the modelling of the material's mechanical behavior;
- Reliable experimental data is mandatory for the prediction of stamping defects.

The authors gratefully acknowledge the financial support of the Portuguese Foundation for Science and Technology (FCT) under projects with reference PTDC/EMS-TEC/0702/2014 (POCI-01- 0145-FEDER-016779) and PTDC/EMS-TEC/6400/2014 (POCI-01-0145-FEDER-016876) by UE/FEDER through the program COMPETE 2020. The first author is also grateful to the FCT for the PhD grant SFRH/BD/98545/2013.

COMPETE 2020 | PORTUGAL 2020 | UNIÃO EUROPEIA Fundo Europeu de Desenvolvimento Regional | FCT Fundação para a Ciência e a Tecnologia MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR

# Formability assessment of a cup drawing under complex nonlinear strain paths

**P.D. Barros**[1], **R.R. Amaral**[2], **M.C. Oliveira**[1], **A.D. Santos**[2,3], **J.L. Alves**[4] **and L.F. Menezes**[1]

[1]CEMMPRE, Centre for Mechanical Engineering, Materials and Processes, University of Coimbra
[2]INEGI, Institute of Science and Innovation in Mechanical and Industrial Engineering, Porto
[3]FEUP, Faculty of Engineering, University of Porto
[4]CMEMS, Center for Microelectromechanical Systems, University of Minho