UNIVERSIDADE D COIMBRA

Study of the frictional contact conditions in the hole expansion test

D.M. Neto[1] • P.D Barros[1] • M.C. Oliveira[1] • J.L. Alves[2] • L.F. Menezes[1]

[1]CEMMPRE, Department of Mechanical Engineering, University of Coimbra, Portugal

[2]CMEMS, Department of Mechanical Engineering, University of Minho, Portugal

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Introduction

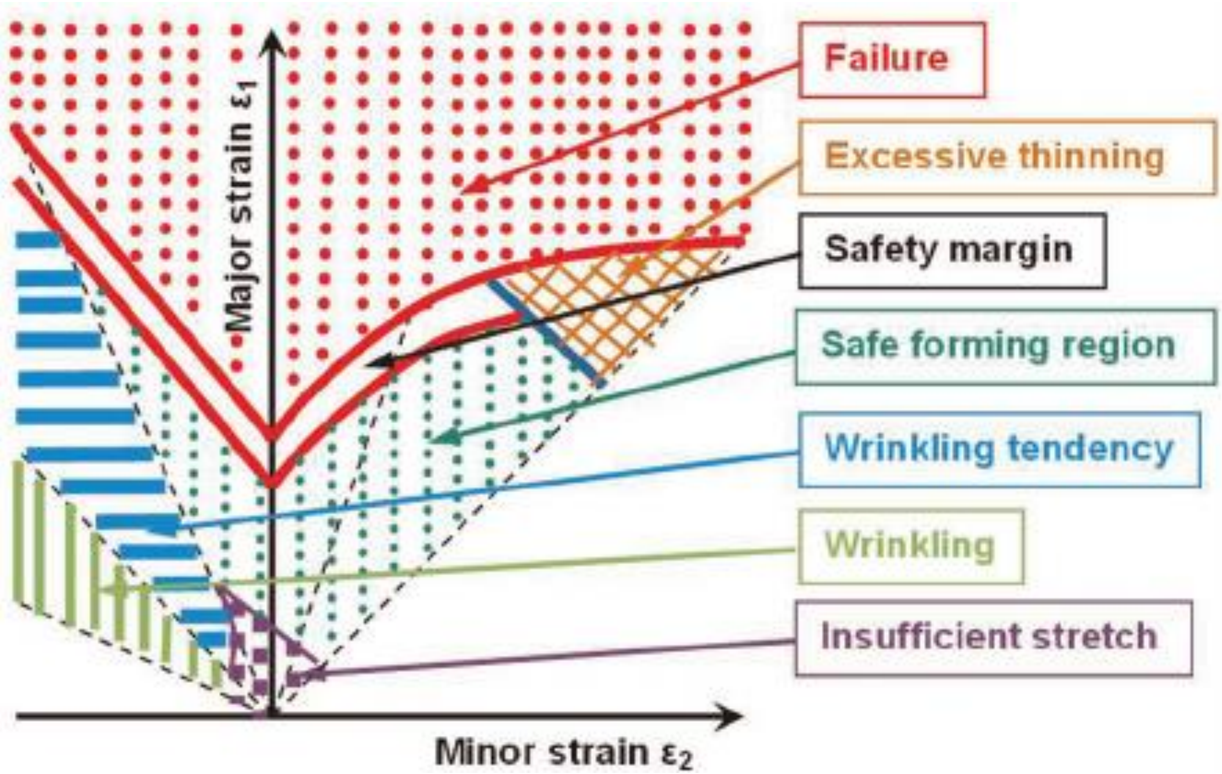
Advanced High Strength Steels (AHSS)

- Increasing use in the **automotive industry** over the past 20 years
- Good combination of **high strength** and **large elongation** (DP, TRIP, TWIP, etc)
- Improve strength and reduce weight of automotive bodies for **safety** and **fuel efficiency**

Volvo XC40

Forming Limit Diagram (FLD)

- Predict a **success or failure** of real sheet forming processes
- High **accuracy** only for **low grade steel sheets**



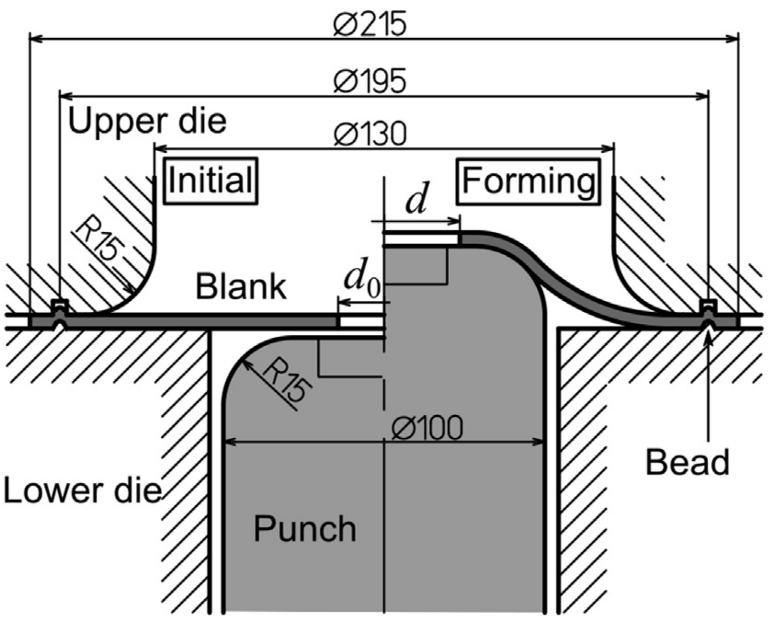
Edge cracking

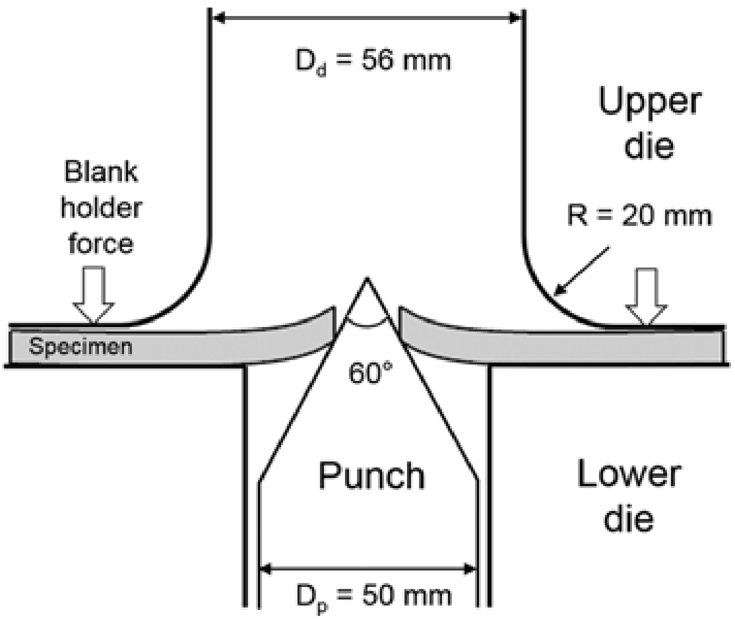
- **Edge cracking** occurring during the stretch-flanging process of **AHSS** cannot be accurately predicted by the FLD

- The **AHSS edge cracking** resistance is commonly evaluated by the **Hole expansion test**

Hole expansion test

- The **sheet specimen** contains a **central hole** and the **tools** are **axisymmetric**
- The **hole expansion ratio** (hole edge crack) defines the edge cracking resistance





Cylindrical punch

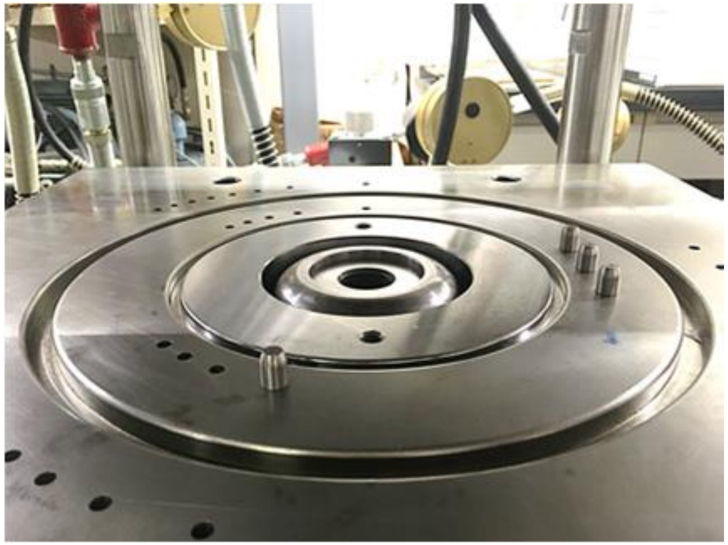
Fractured specimen

Conical punch

Hole expansion test

Influence of the process conditions on the hole expansion ratio

- The cut edge conditions in the hole (punched, water-jet, EDM)
- The friction conditions in contact area (interface punch−specimen)



Punch and blank-holder with bead

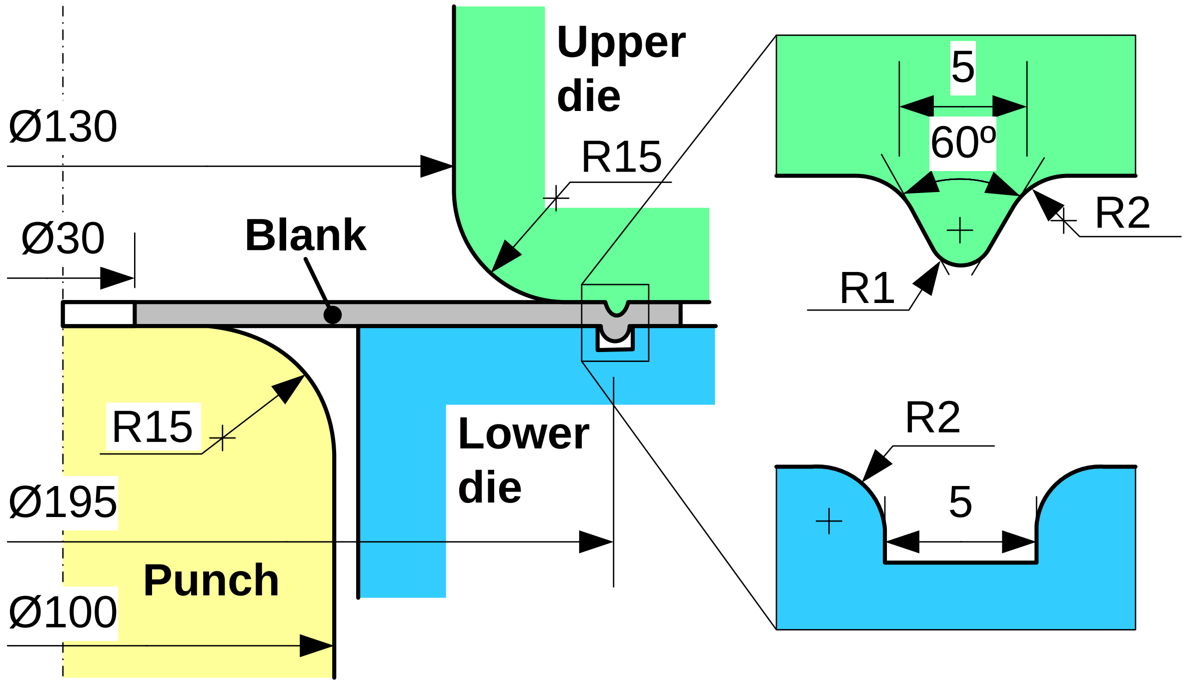
Specimen after the hole expansion

➢ **Objective: numerical analysis of the frictional contact conditions in the hole expansion test**

Hole expansion test

Test conditions from the Benchmark 1: Hole expansion of a high strength steel sheet

- Dual Phase steel (**DP980**) sheet with **1.2 mm of thickness**
- Central hole with **30 mm of diameter**
- Periphery of the blank is clamped using a draw-bead (force about 800 kN)

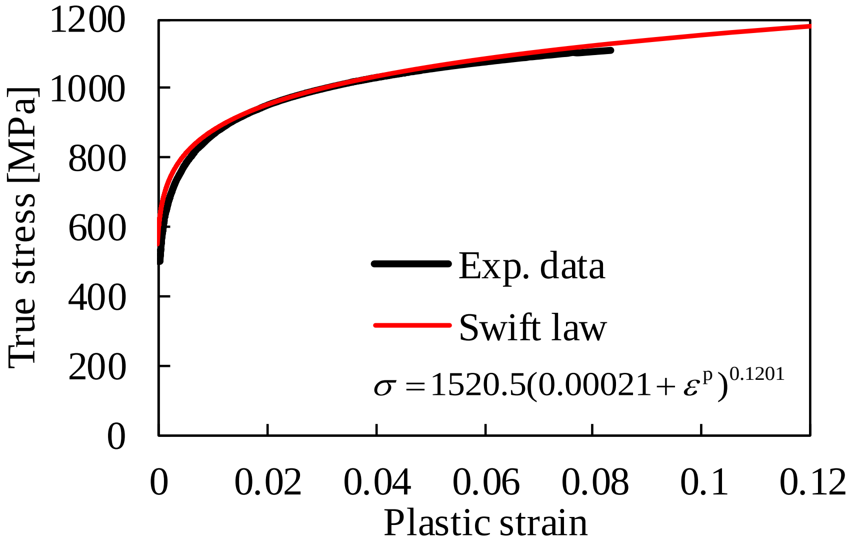


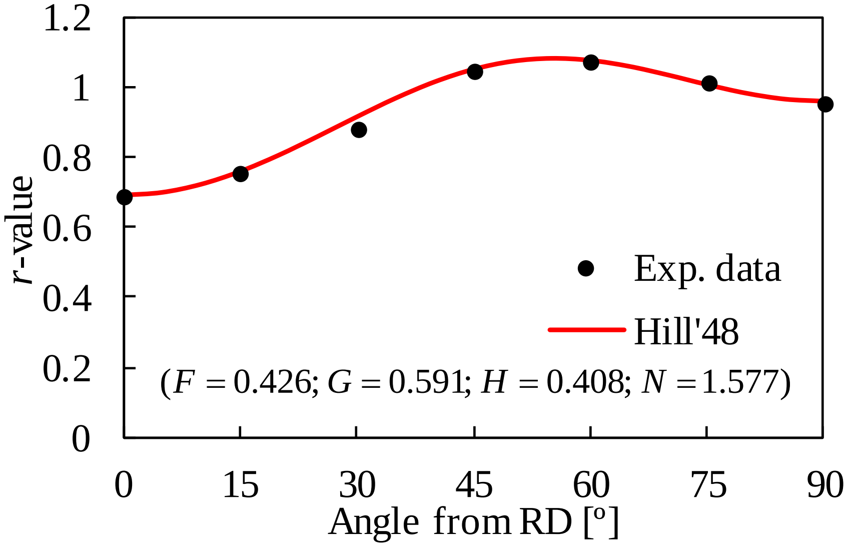
Geometry of the forming tools and specimen used in the hole expansion test

Hole expansion test

Finite element model

- **DD3IMP** in-house finite element code (implicit time integration)
- **1/4 of the model** (symmetry conditions)
- Forming tools are assumed **rigid**
- Plastic behavior of the specimen modelled by the **Swift law** (isotropic work hardening) and the **Hill'48 yield criterion**

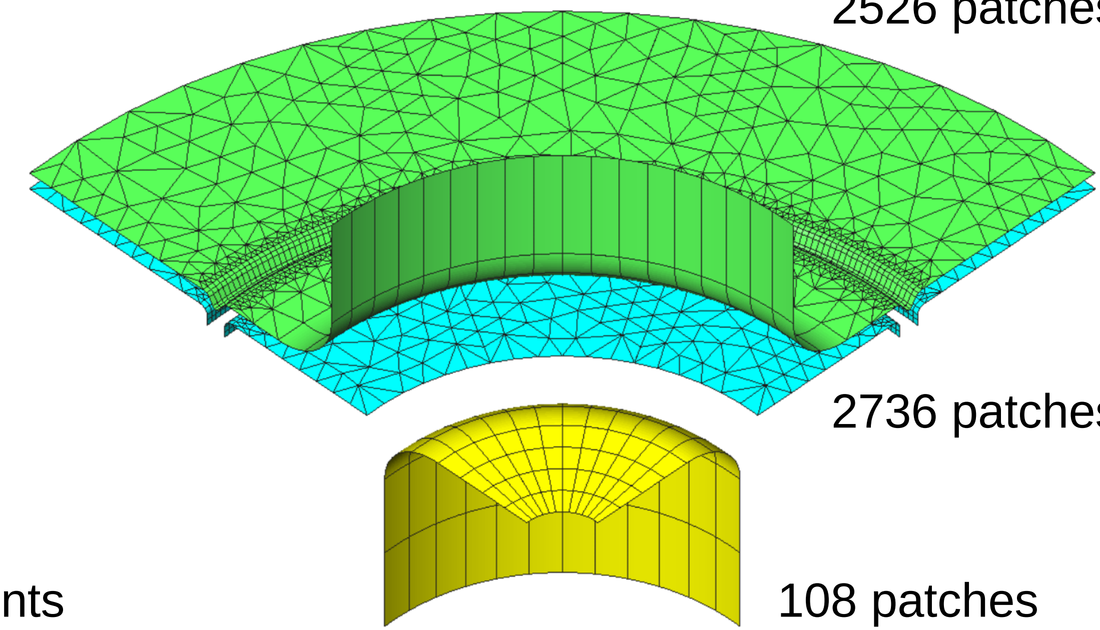




Hole expansion test

Finite element model

- Forming tools discretized by **Nagata patches**
- Blank discretized by **linear hexahedral (8-nodes) finite elements**

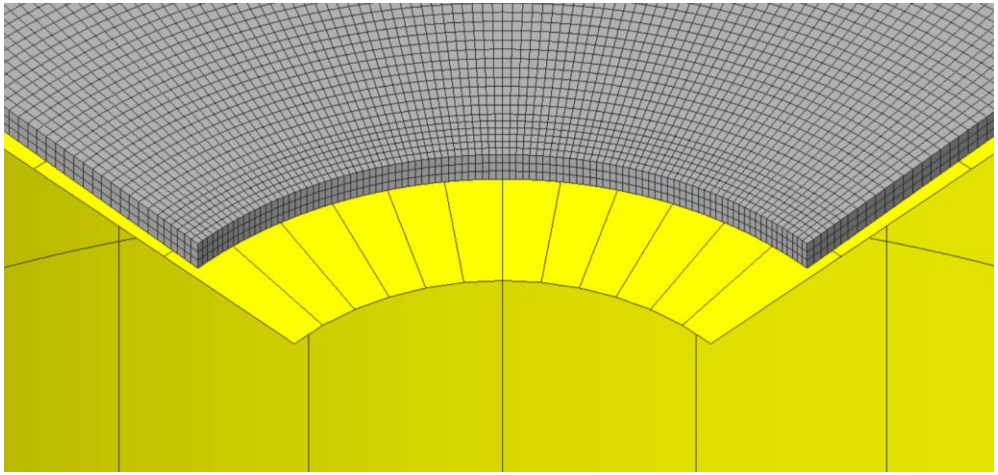


2526 patches

2736 patches

108 patches

64,800 finite elements

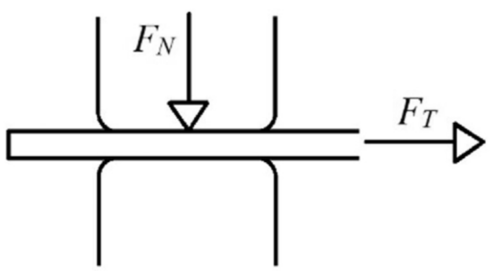


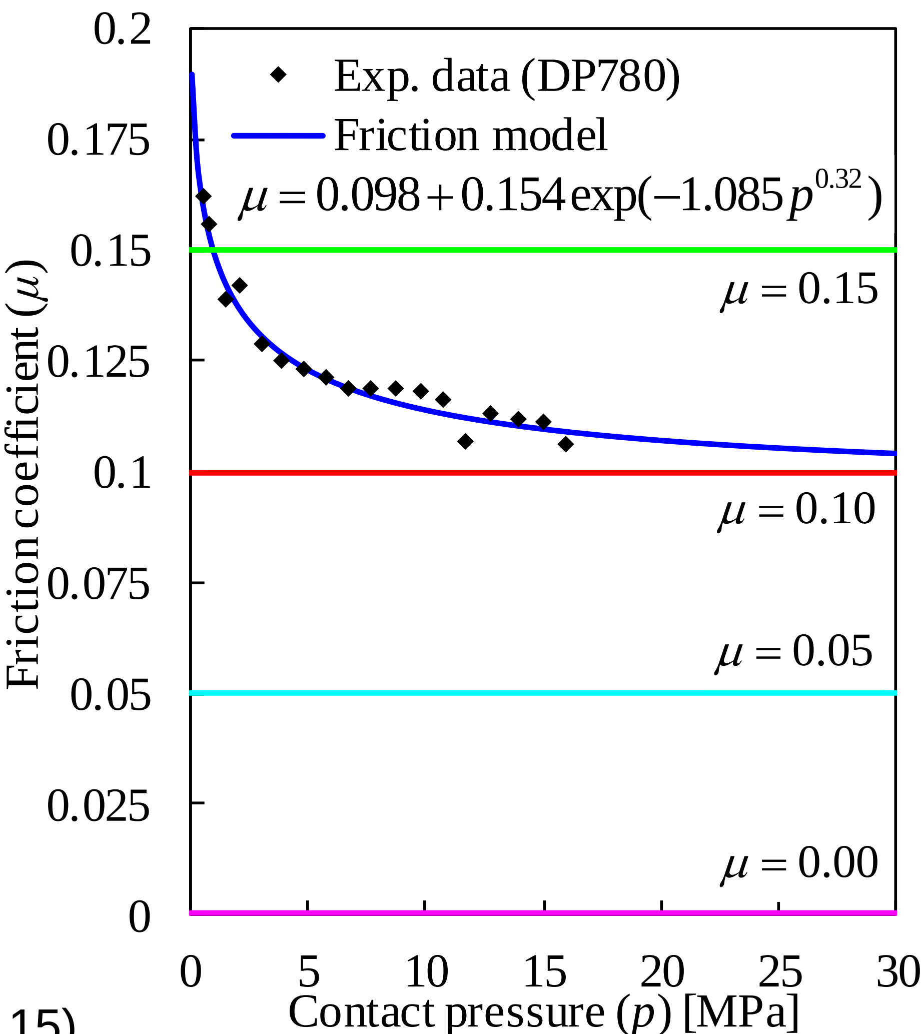
3 layers of finite elements in the thickness direction

100 finite elements in the circumferential direction

Finite element model

- The **Coulomb friction law** is adopted
- Lubricated punch−blank interface
  - 4 **constant** values of friction coefficient
  - **Pressure-dependent** friction coefficient
- Experimental data from *Gil et al (2016)*
  - Strip drawing test





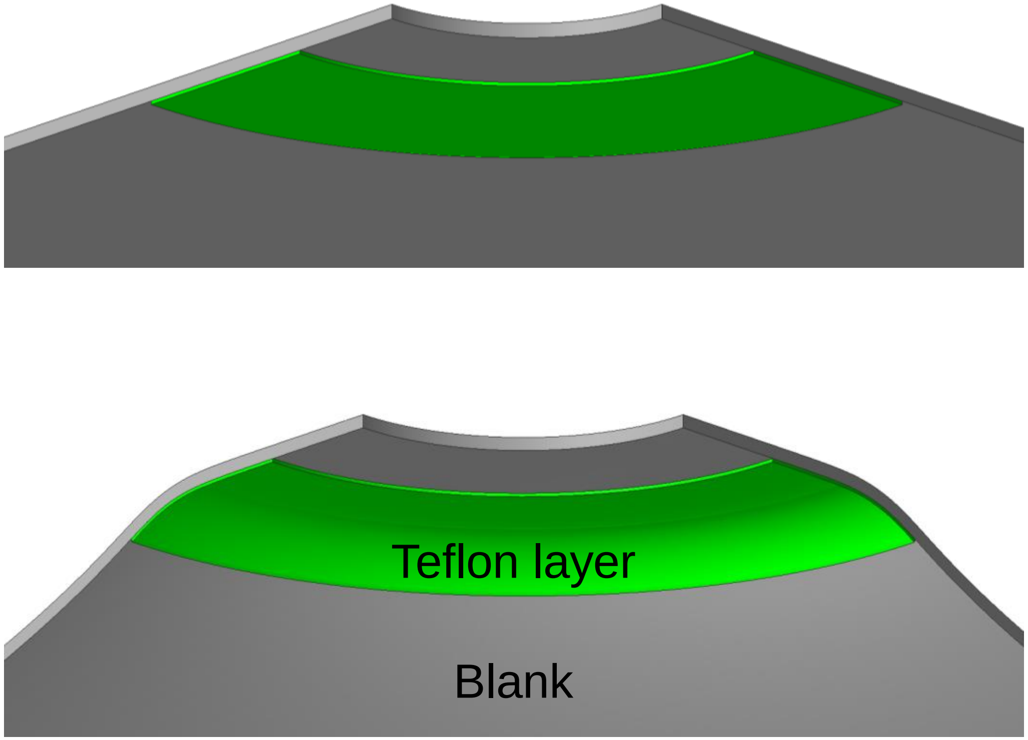
- **No lubricant** on the interfaces between the blank and the upper/lower dies (μ=0.15)

Hole expansion test

Finite element model

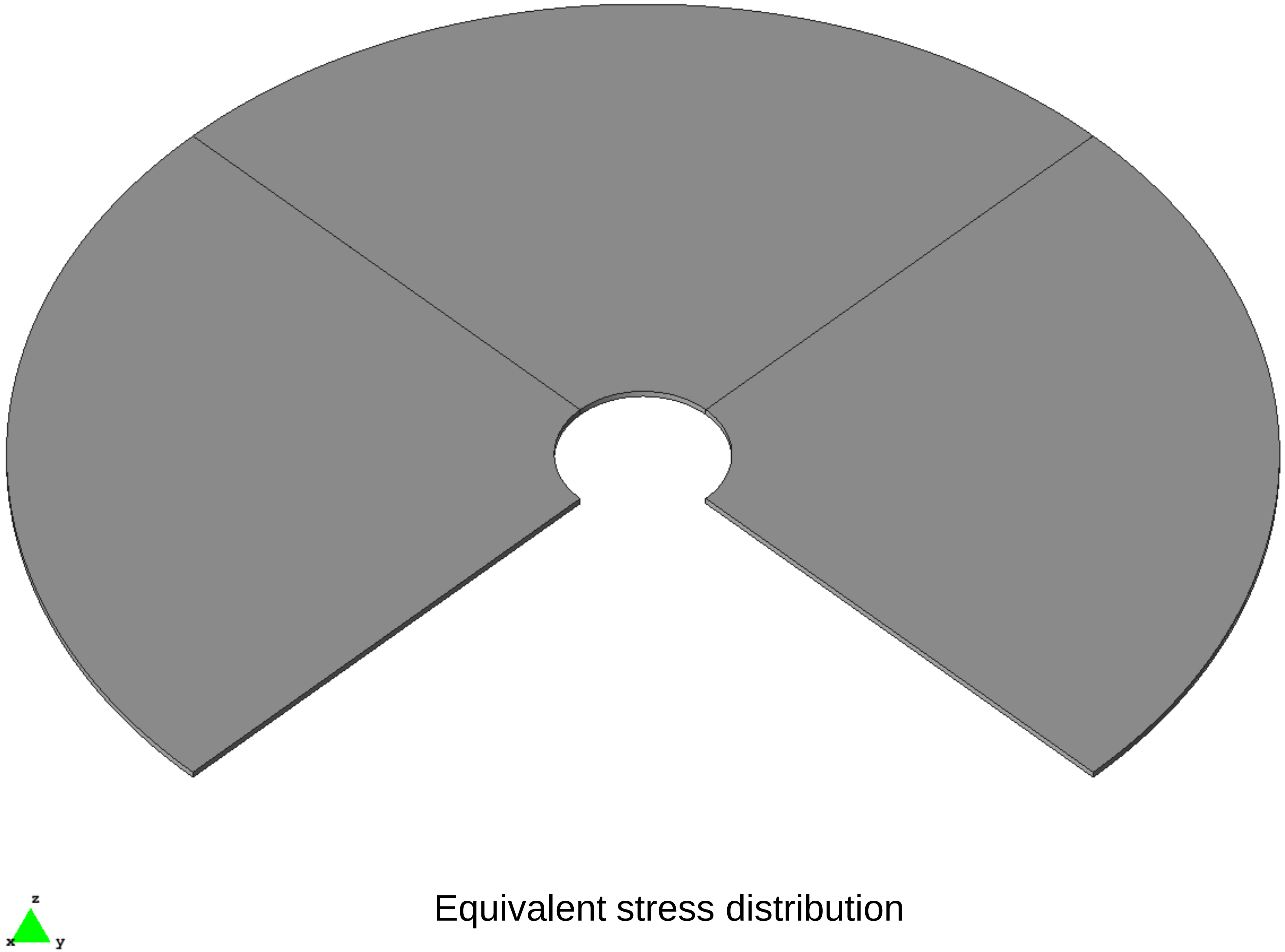
- Inclusion of a **layer of Teflon** (0.3 mm thick) between the blank and the punch head
  - **No sliding** between the blank and the Teflon
  - **No friction** between the Teflon and the punch

- Teflon is assumed **elastoplastic**
  - E=600 MPa and ν=0.4
  - $\sigma=46.8(0.014+\varepsilon^{p})^{0.43}$



Results and discussion

Overview of the hole expansion test simulation

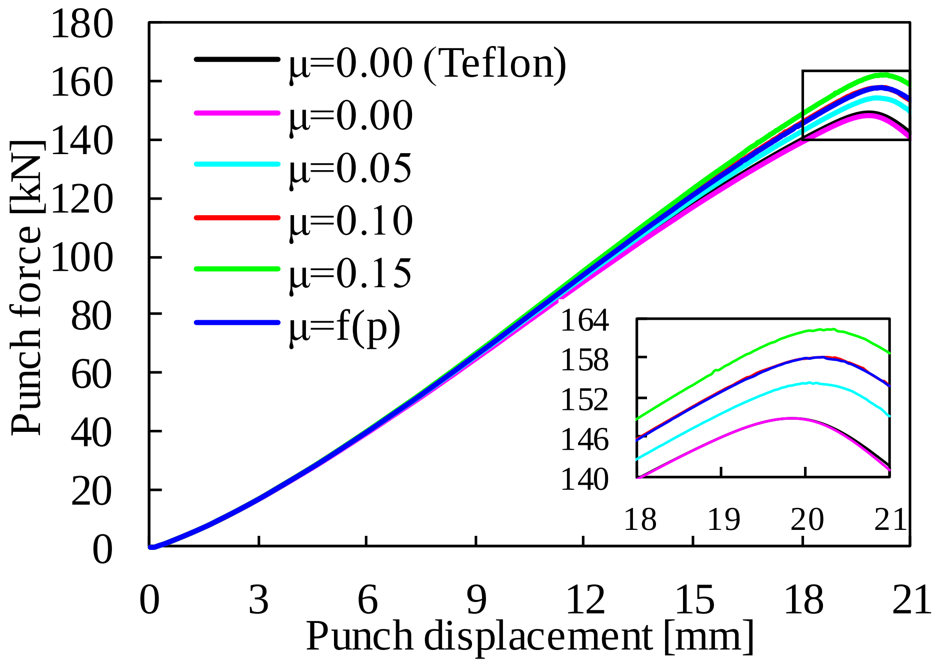


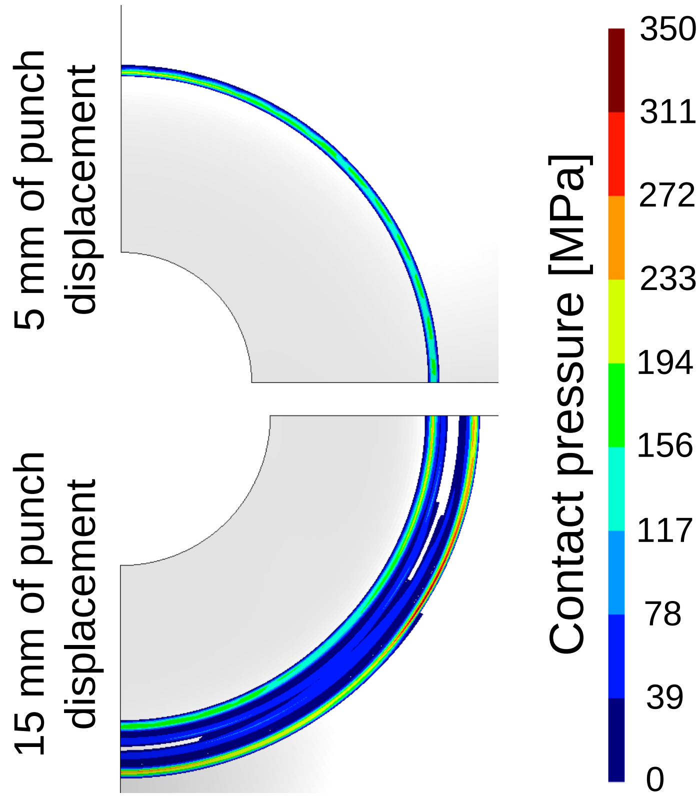
Equivalent stress distribution

Results and discussion

Punch force evolution

- The predicted punch force **increases** with the friction coefficient
- The pressure-dependent friction coefficient provides results identical to μ=0.15
    - Very **high contact pressure** at the punch head
- **Negligible influence** of Teflon layer on the predicted force evolution

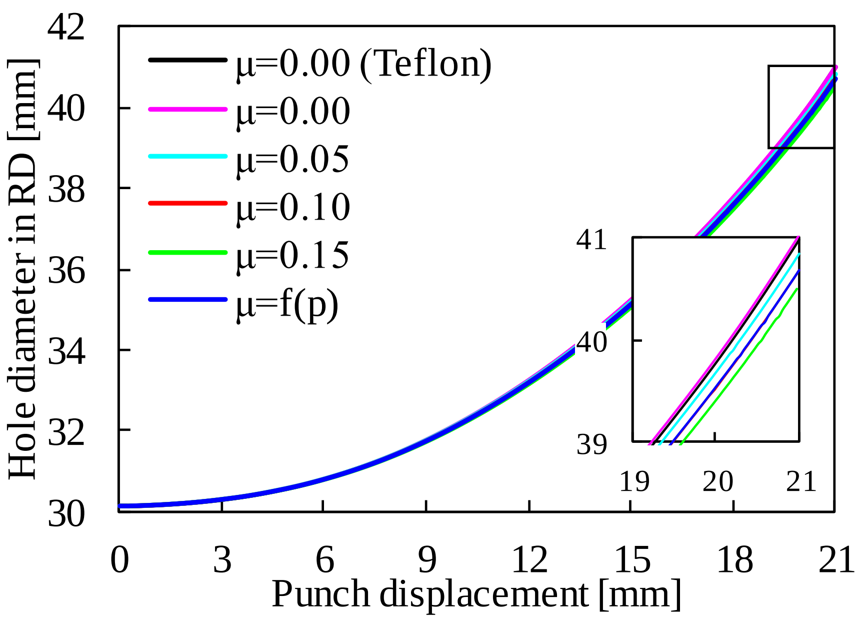




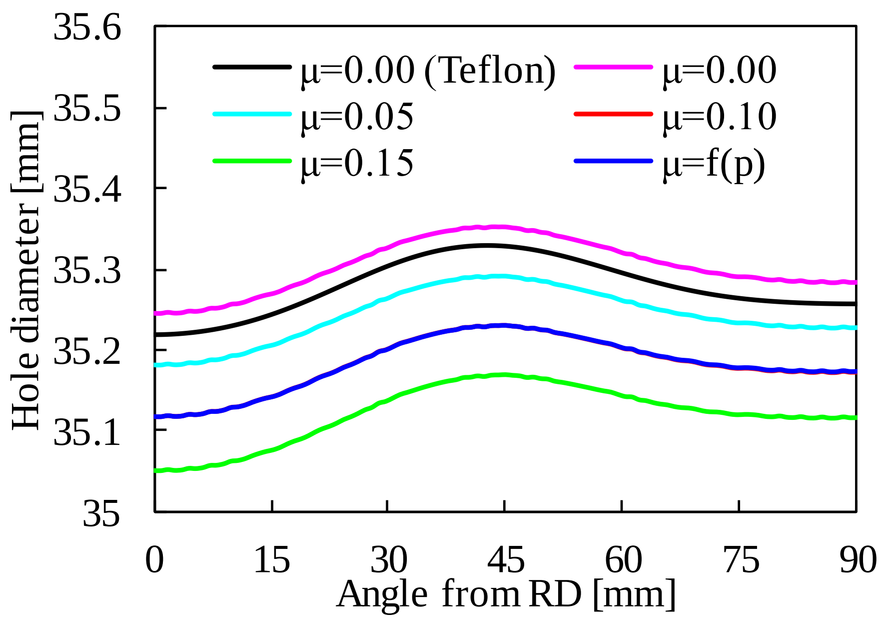
Results and discussion

Hole diameter

- The predicted hole diameter **decreases** with the friction coefficient
  - **Low sliding** between blank and punch head due to the **high friction forces**
- The holes are **not circular** and the shape is affected by the **plastic anisotropy**
  - Hole diameter slightly **larger around the diagonal direction**



exponential growth of the hole diameter

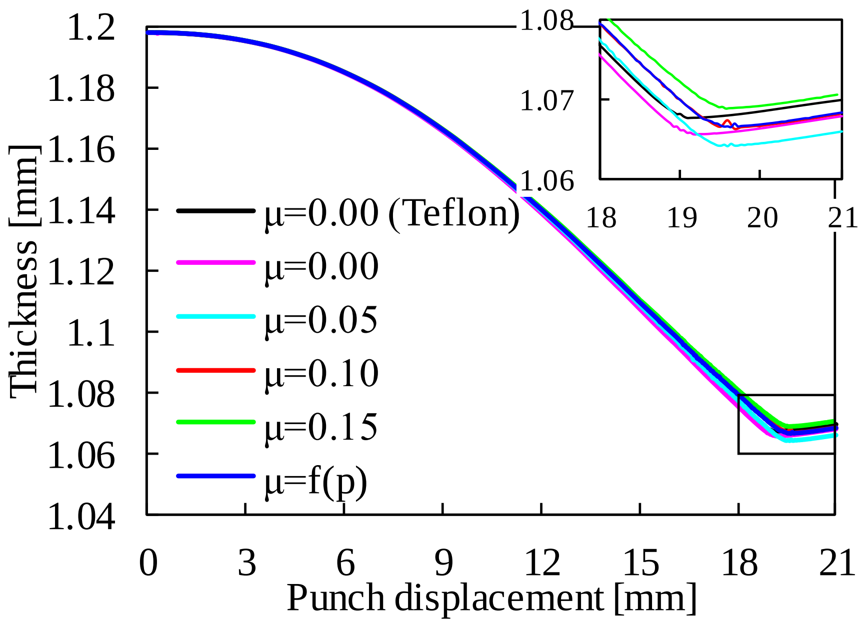


15 mm of punch displacement

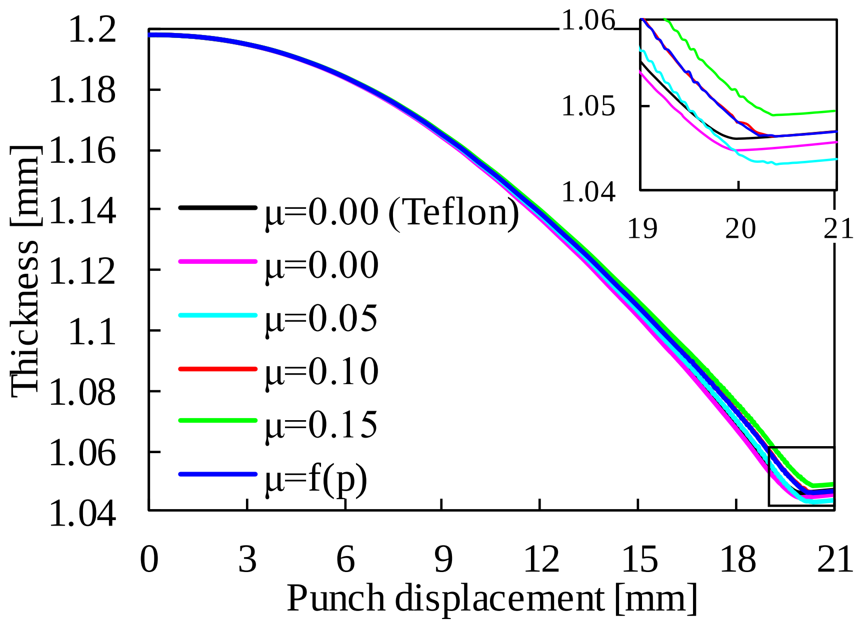
Results and discussion

Thickness evolution

- Thickness reduction **similar for both points** on the hole edge
- More pronounced under **frictionless contact** conditions
- Slight increase due to the **localized necking** near the diagonal direction



Point on the hole edge in the rolling direction

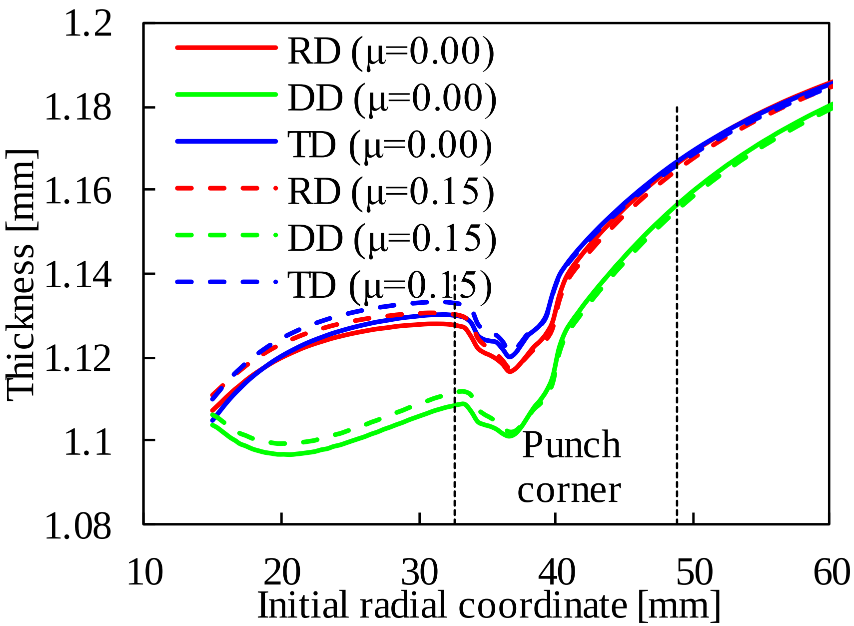


Point on the hole edge in the transverse direction

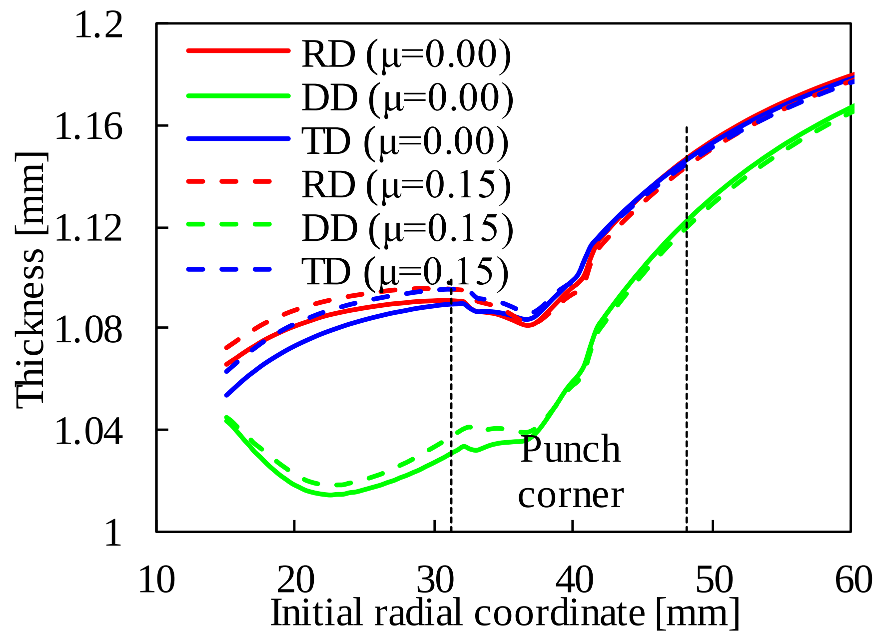
Results and discussion

Thickness distribution

- Thickness distribution evaluated in the 3 different directions (RD, DD and TD)
  - Significantly **lower along the DD** and similar distributions along RD and TD
- The inclusion of **friction** leads to a global **decrease of the thickness strain** in the flat region of the blank



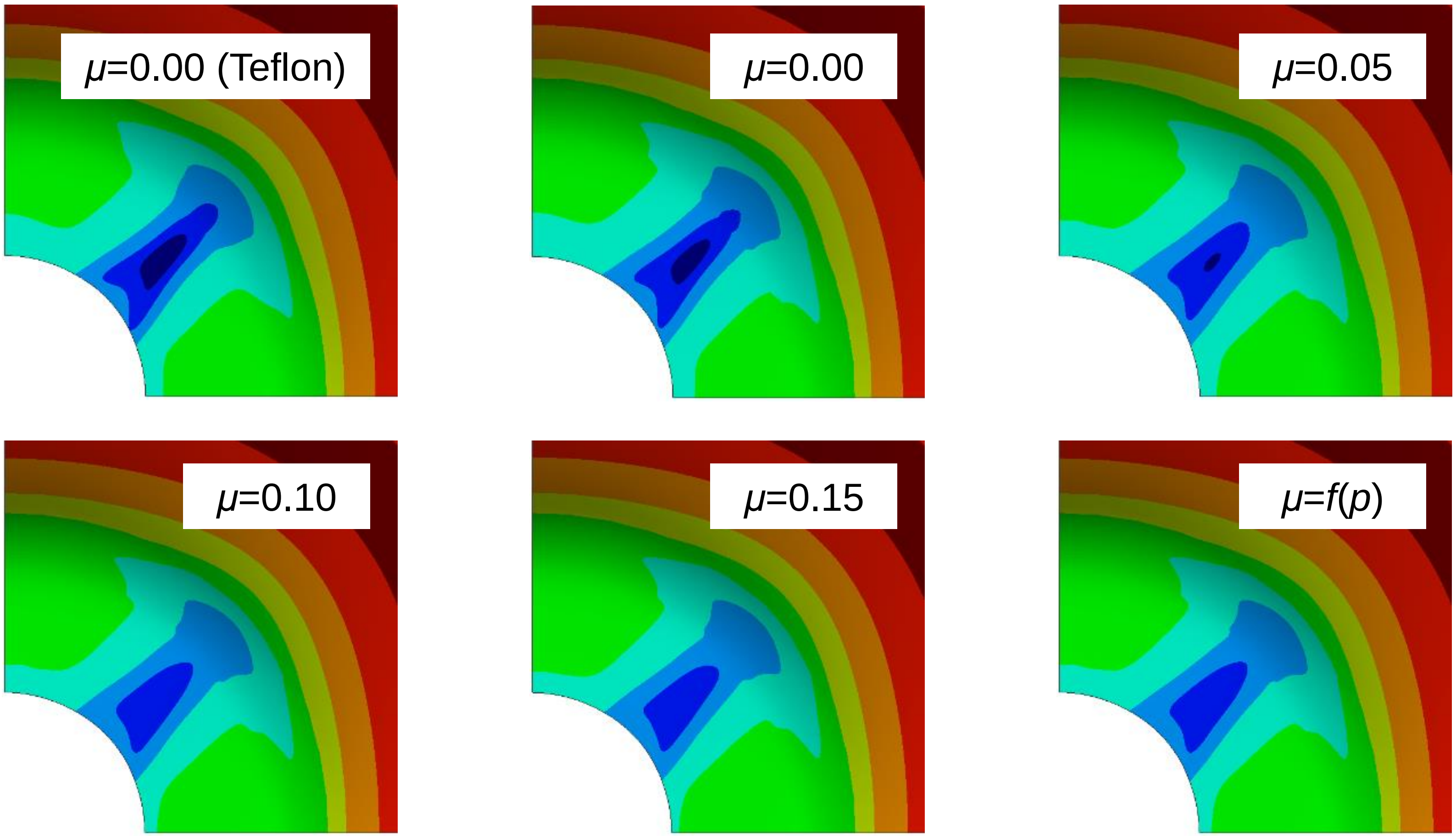
15 mm of punch displacement
(before necking)



19 mm of punch displacement
(after necking)

Thickness distribution after necking (19 mm of punch displacement)

- The **onset of necking** occurs always in the **same localization** but the instant for which it arises depends on the friction coefficient (friction postpones)



Conclusions

- Numerical study of the frictional contact conditions between the blank and the punch head in the hole expansion test
- Coulomb friction law comprising both constant and the pressure-dependent friction coefficients
- Results obtained with the pressure-dependent friction coefficient identical to the ones obtained considering a constant friction coefficient (evaluated at large contact pressure)
- Both the punch force and the hole diameter evolutions are only slightly affected by the friction coefficient
- Necking localization (near the diagonal direction) is independent of the friction coefficient
- Increasing the friction coefficient leads to a global decrease of the thickness strain in the flat region of the blank, postponing the onset of necking

Acknowledgements

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Thank you for your attention!