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Thermomechanical analysis of the draw bead test

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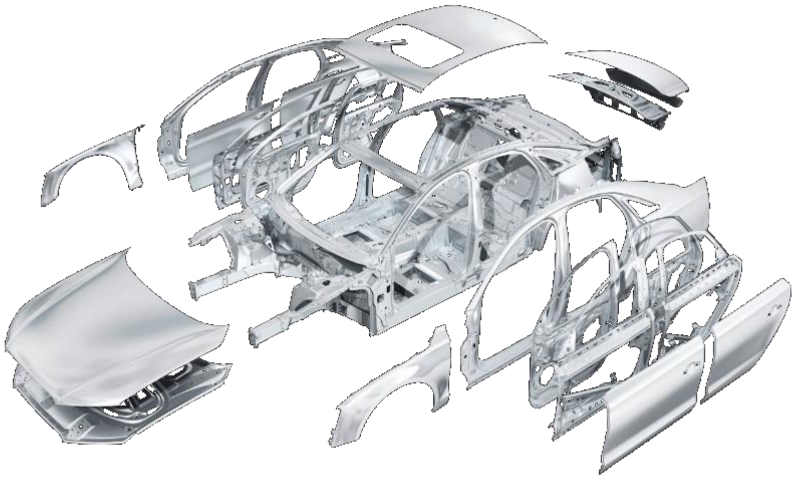
Introduction



Body-in-white

More than 300 sheet metal parts:

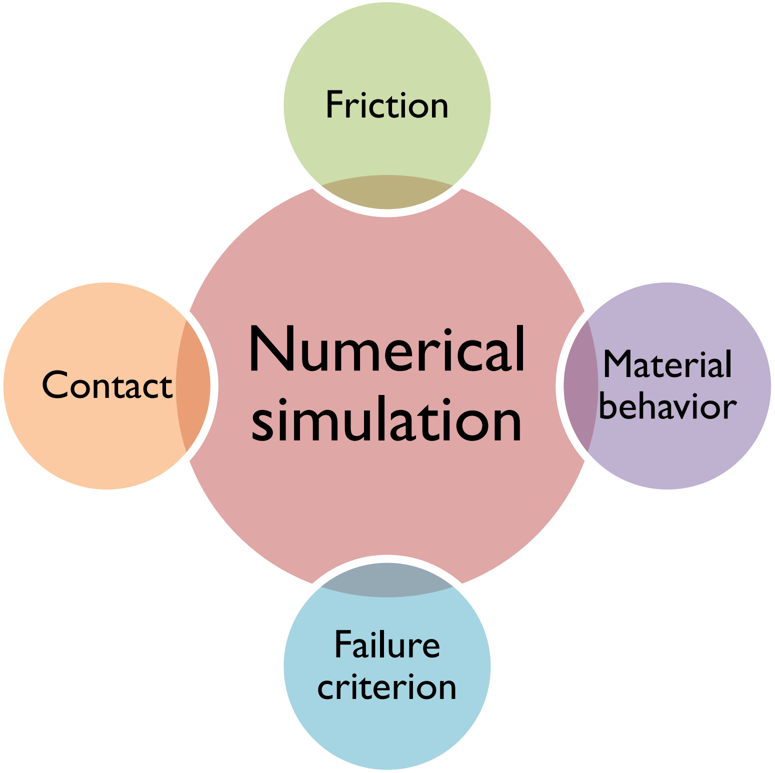
- Closures
- Structural parts
- Reinforcements

Current challenges in the sheet metal forming industry:

- Adoption of new materials (ultra high strength steels, lightweight alloys, etc.)
- Reduced manufacturing cost and lead times
- Shorter product development cycles

Sheet metal forming simulation

- Today the numerical simulation is an **indispensable tool** in the development of new components manufactured by forming
- Simulation is used to **predict formability** issues before going into production



The numerical solution is strongly influenced by the computational models implemented in the FEM code

Heat generation

- Increased adoption of **advanced high strength steels (AHSS)** in the automotive industry
- Large **contact pressures** and consequent frictional forces

- **Heat generated by plastic deformation** (high stress values)
- **Heat generated by frictional contact sliding** (large contact forces)

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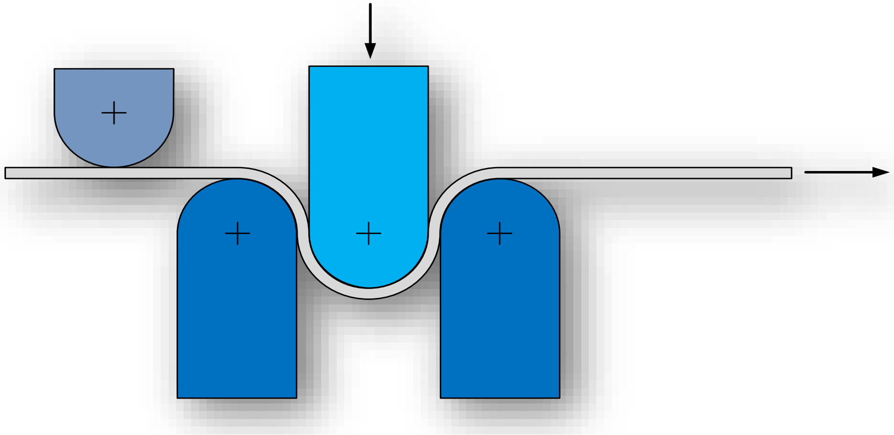
Draw bead test

- Originally developed to evaluate the friction coefficient between the sheet and the tools



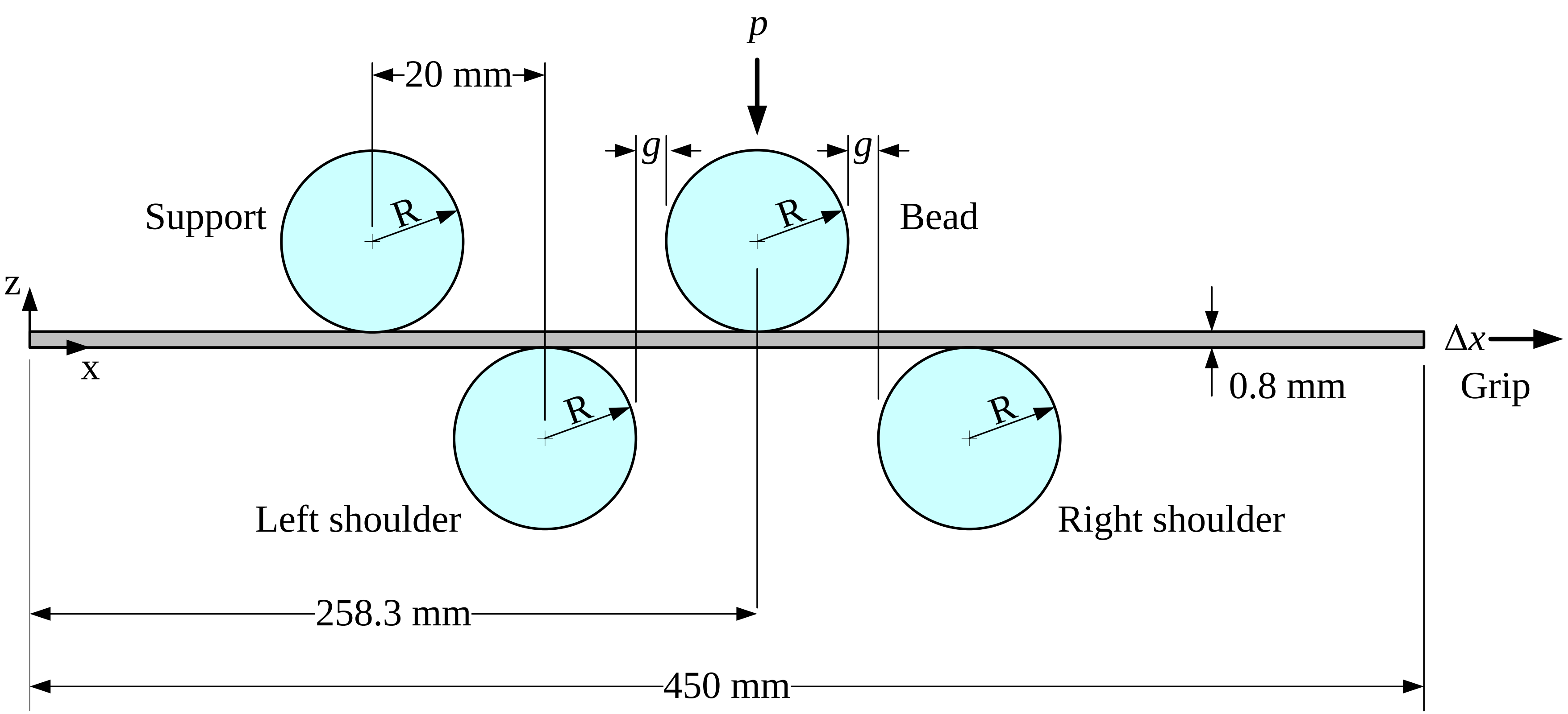
Objective:

Thermomechanical analysis of the draw bead test

- Influence of different factors, namely the bead penetration, the side clearance, the pulling speed and the friction coefficient.

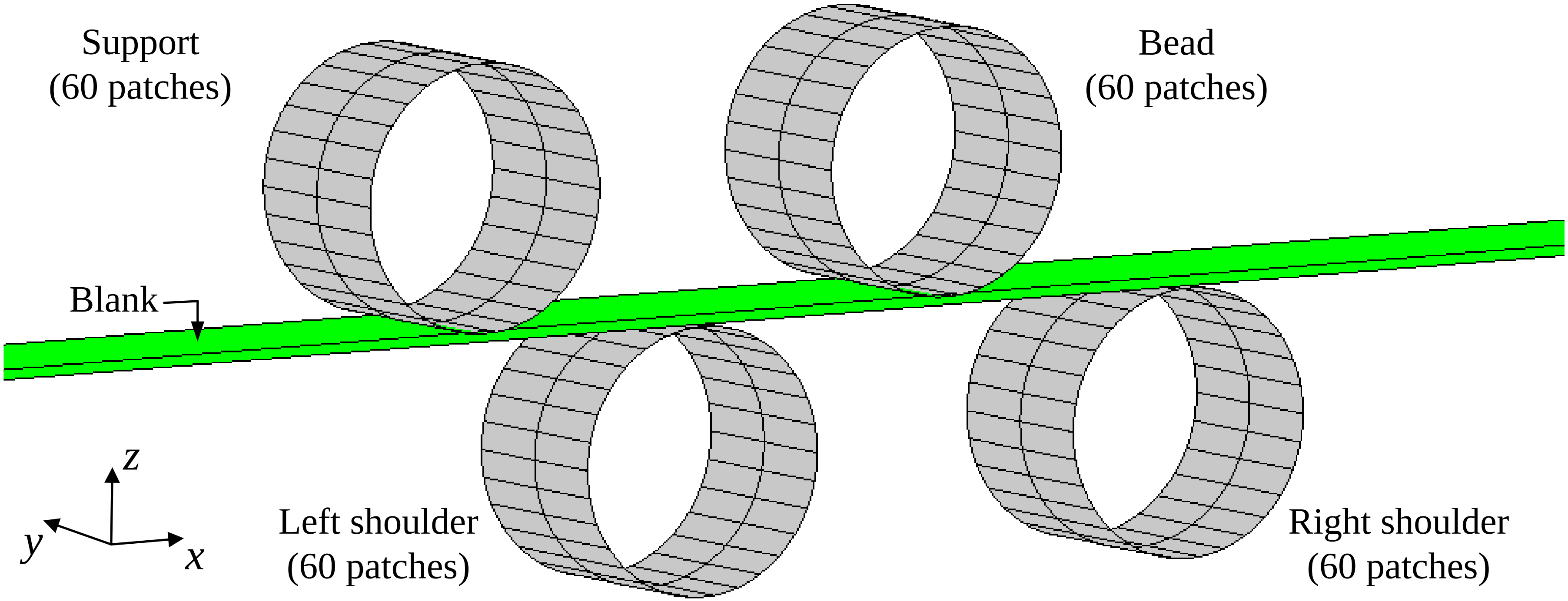
Draw bead test – dimensions

- R=10.5 mm
- Dual phase steel DP780



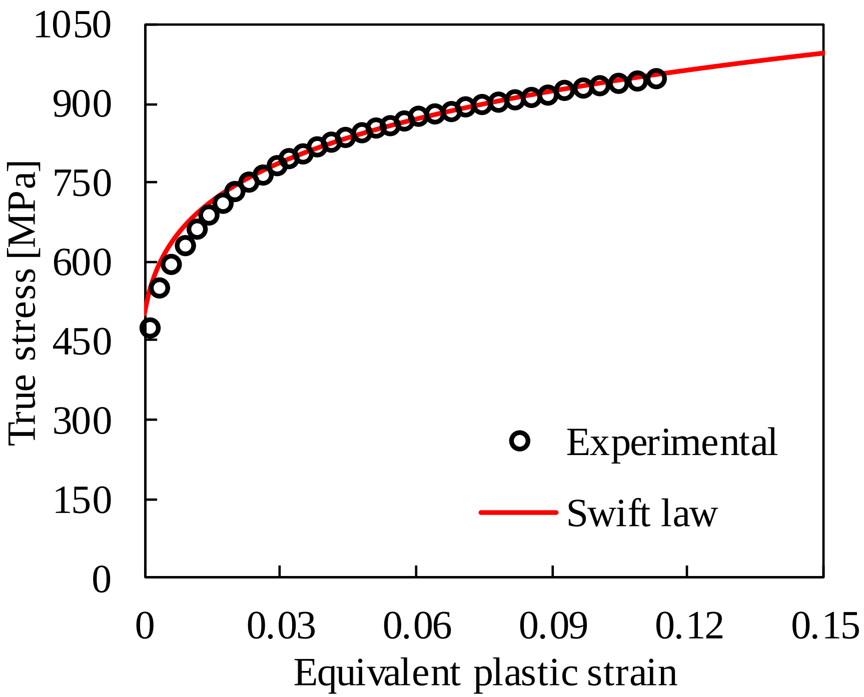
Finite element model

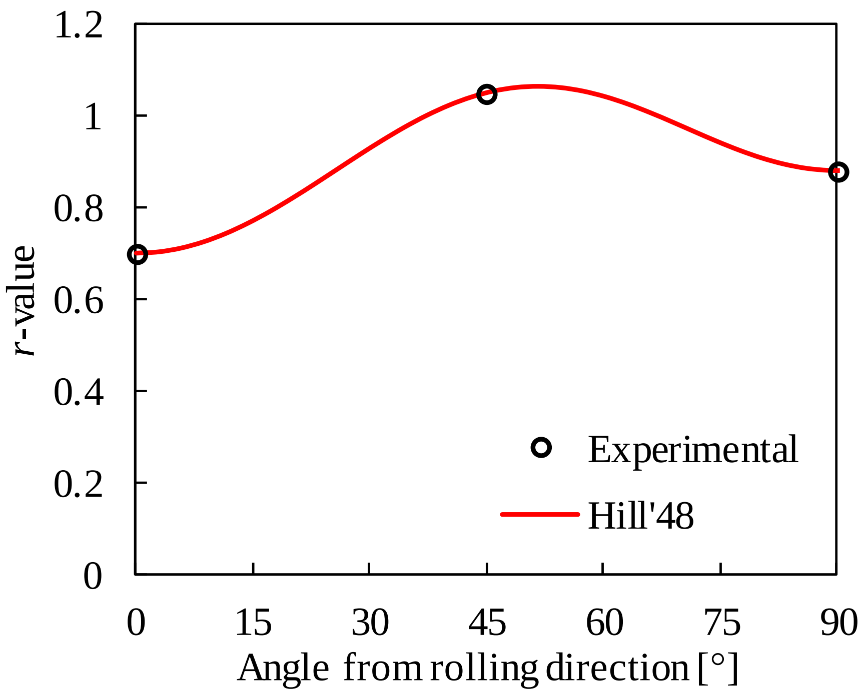
- DD3IMP finite element code
- Cylinders are considered rigid and isothermal (environment temperature)
- Blank discretized with hexahedral finite elements



Material mechanical behavior

- Mechanical behaviour assumed elastoplastic
- Isotropic hardening defined by the Swift law
- Anisotropy described by the Hill'48 yield criterion





Heat transfer

- Differential equation that defines the thermal conduction

$$\rho c \frac{\partial T}{\partial t} - k\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) - \dot{q}_{\mathrm{p}} - \dot{Q}_{\mathrm{f}} = 0$$

- Thermal properties of the dual phase steel DP780

Property	Value
Mass density	7858 kg/m^3
Specific heat capacity	442 J/(kg·K)
Thermal conductivity	42.3 W/(m·K)

Heat generated

- Thermal power generated by plastic deformation

$$\dot{q}_{\mathrm{p}} = \beta \dot{w}^{\mathrm{p}} = \beta(\boldsymbol{\sigma} : \dot{\boldsymbol{\varepsilon}}^{\mathrm{p}})$$

- Thermal power generated by the frictional contact

$$\dot{Q}_{\mathrm{f}} = \eta(\xi \mathbf{t}_{\mathrm{t}} \cdot \dot{\mathbf{g}}_{\mathrm{t}})$$

- Fraction of plastic work converted into heat defined by the Taylor–Quinney factor (β=0.9)
- Fraction of frictional power converted into heat (ξ=1.0)
- Heat generated equality partitioned between the two contacting bodies (η=0.5)

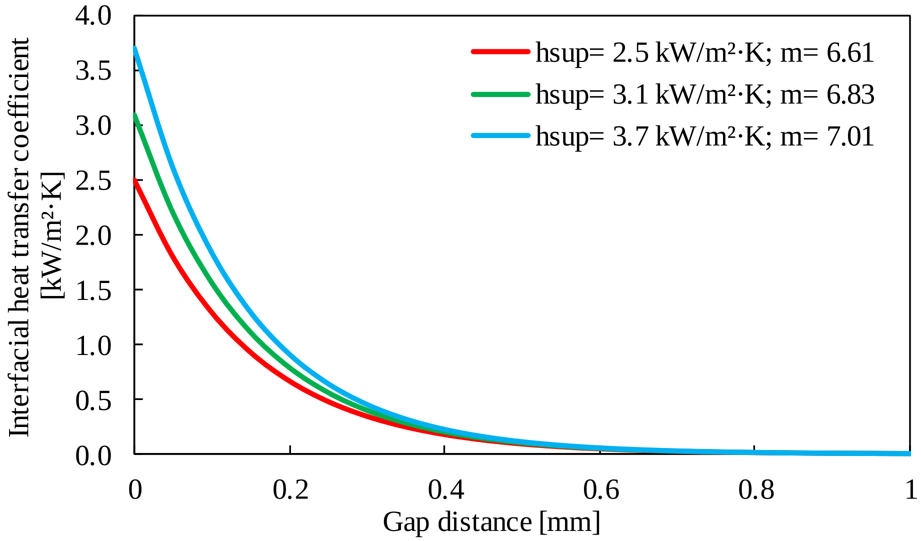
Heat transfer (boundary conditions)

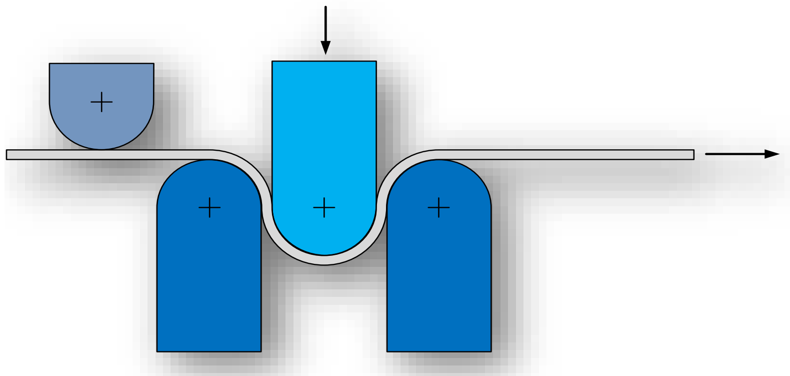
- Boundary condition for free convection (h_{conv}=3.4 W/(m^{2}K))

$$\dot{q}_{\text{conv}} = h_{\text{conv}}(T - T_{\infty})$$

- Boundary condition for contact conductance

$$\dot{q}_{\text{c}} = h_{\text{c}}(T - T_{\text{obs}})$$



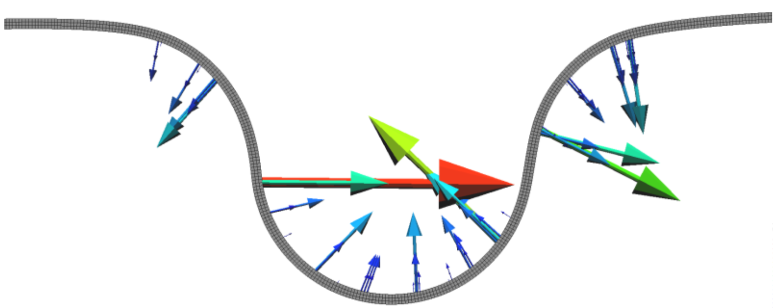


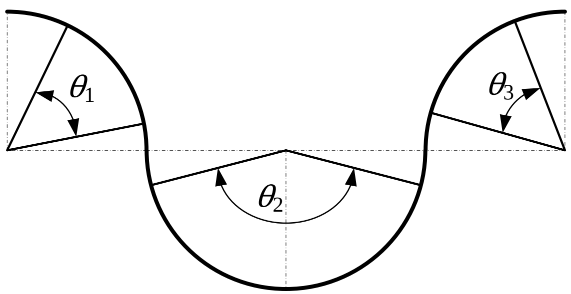
Results

Sensitivity analysis performed considering the reference the model:

- 21.8 mm of bead penetration
- 1.2 mm of side clearance
- 1 mm/s of pulling speed
- 0.15 of friction coefficient

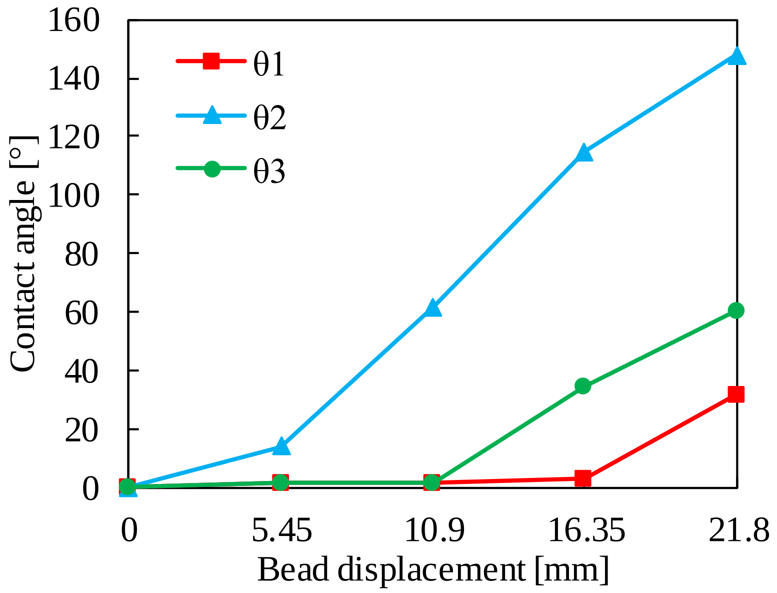
- Definition of the contact angles:

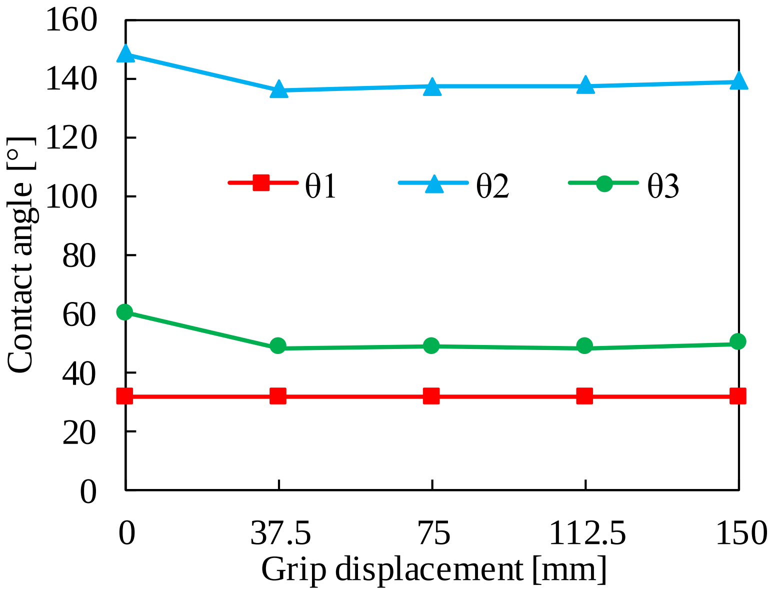




Results – bead penetration

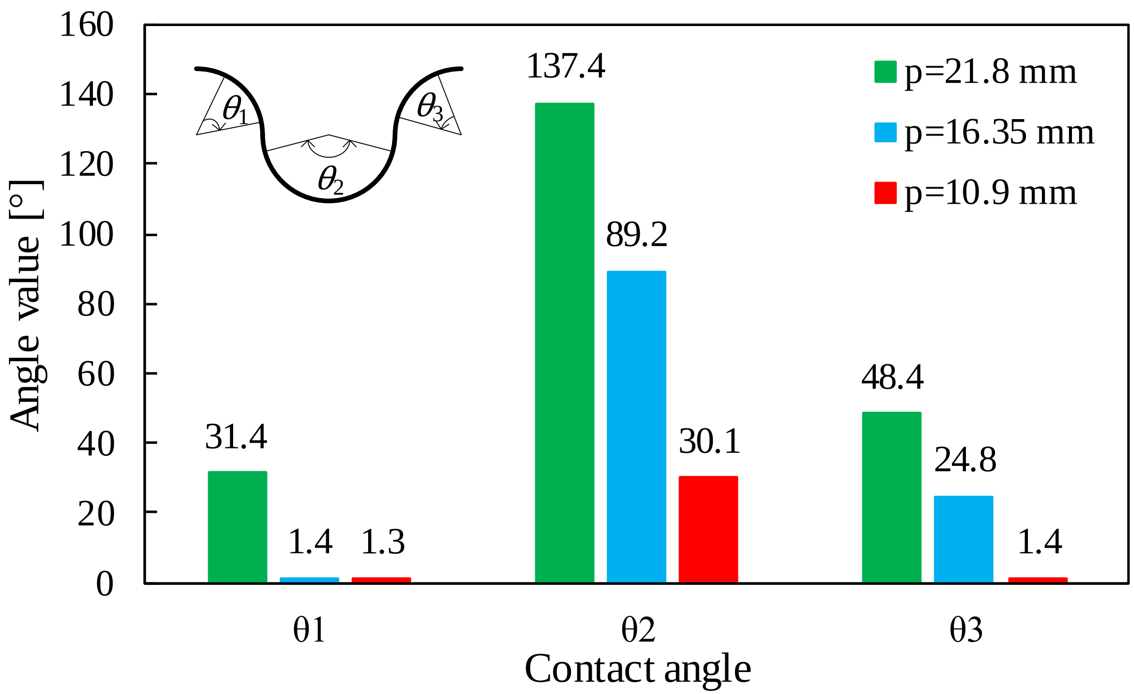
- Increase of the contact angles with the bead penetration and stabilization during the pulling stage
- Different contact angles between left and right shoulders ($\theta_1 \neq \theta_3$)





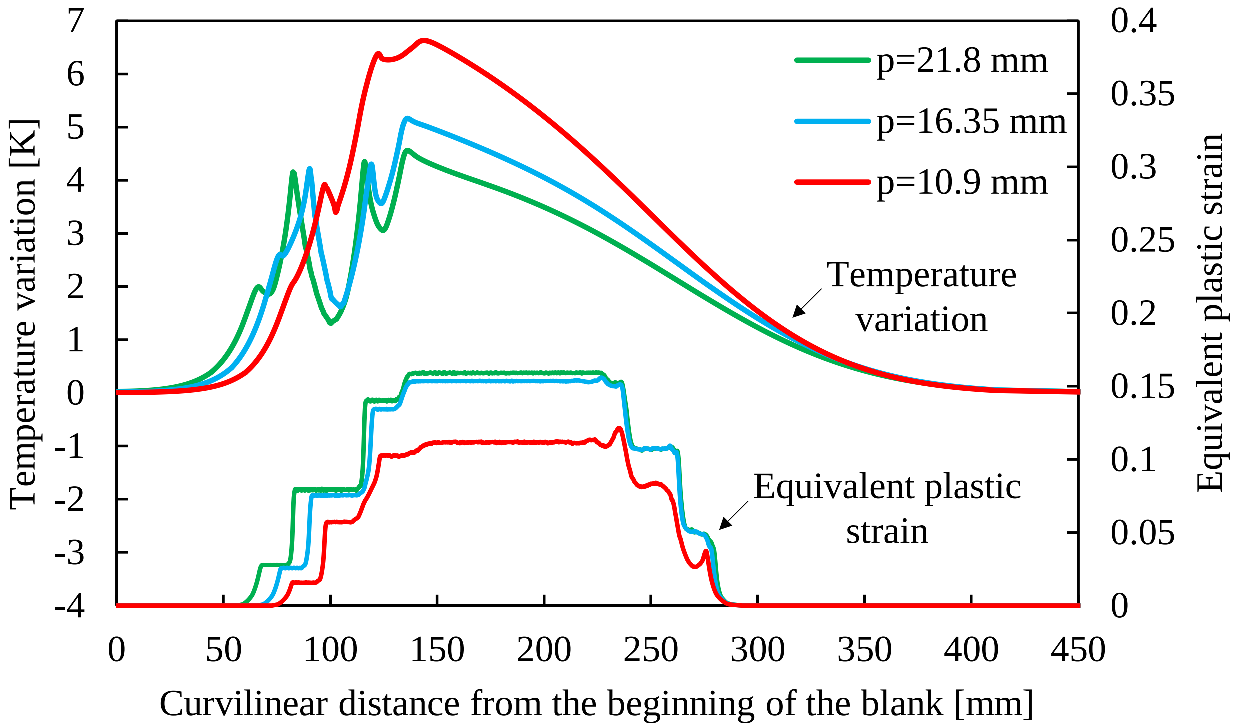
Results – bead penetration

- Influence of the bead penetration on the contact angles (steady state regime): **large impact!**
- Reduction of the heat losses to the environment and to the cylinders



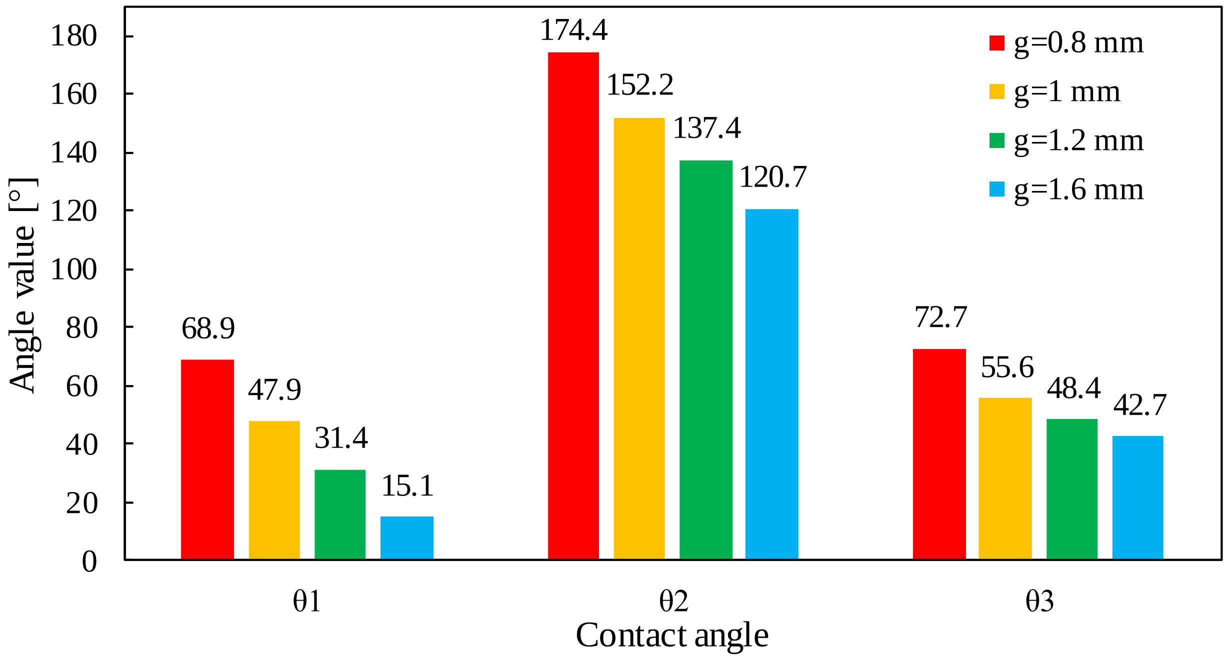
Results – bead penetration

- Influence of the bead penetration on the temperature rise
- Low contact areas leads to large values of temperature rise (low heat losses through contact conductance)



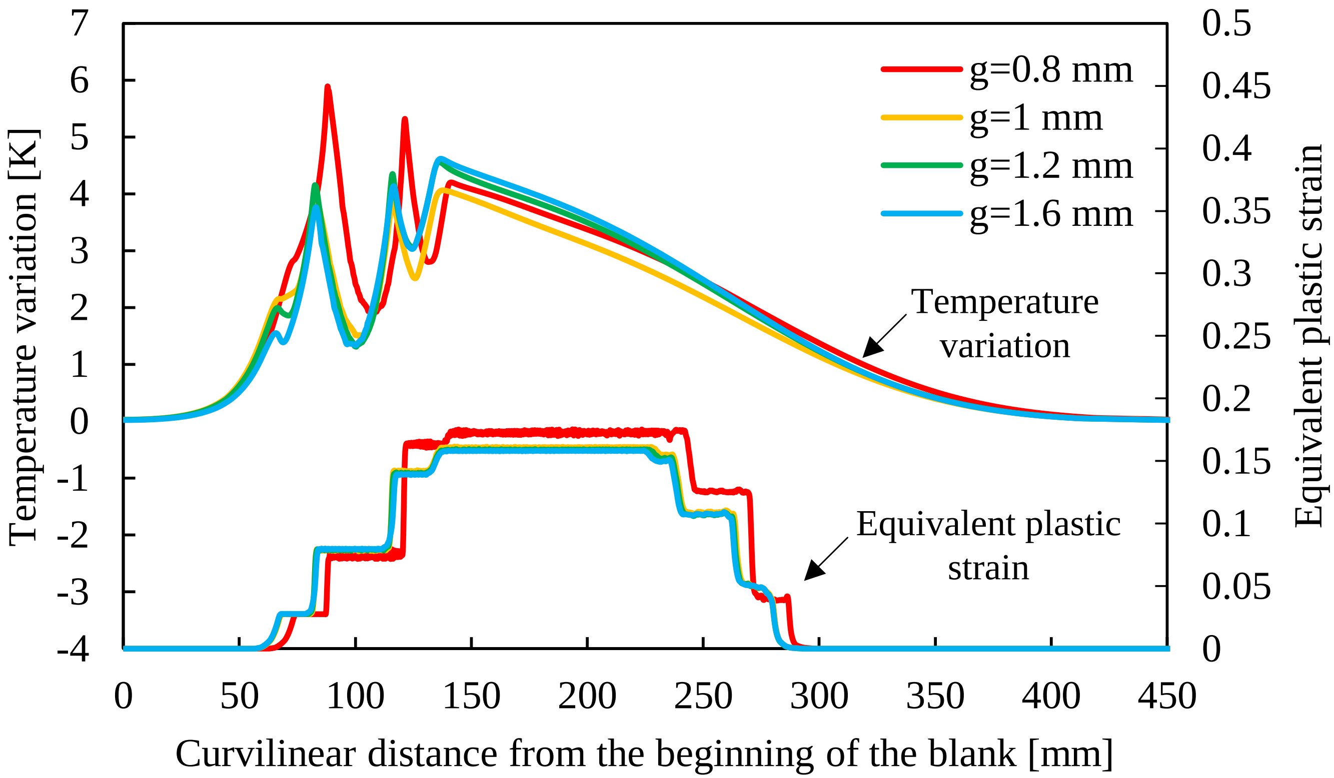
Results – side clearance

- Influence of the side clearance on the contact angles (steady state regime)
- Increasing the side clearance leads to the reduction of the contact area



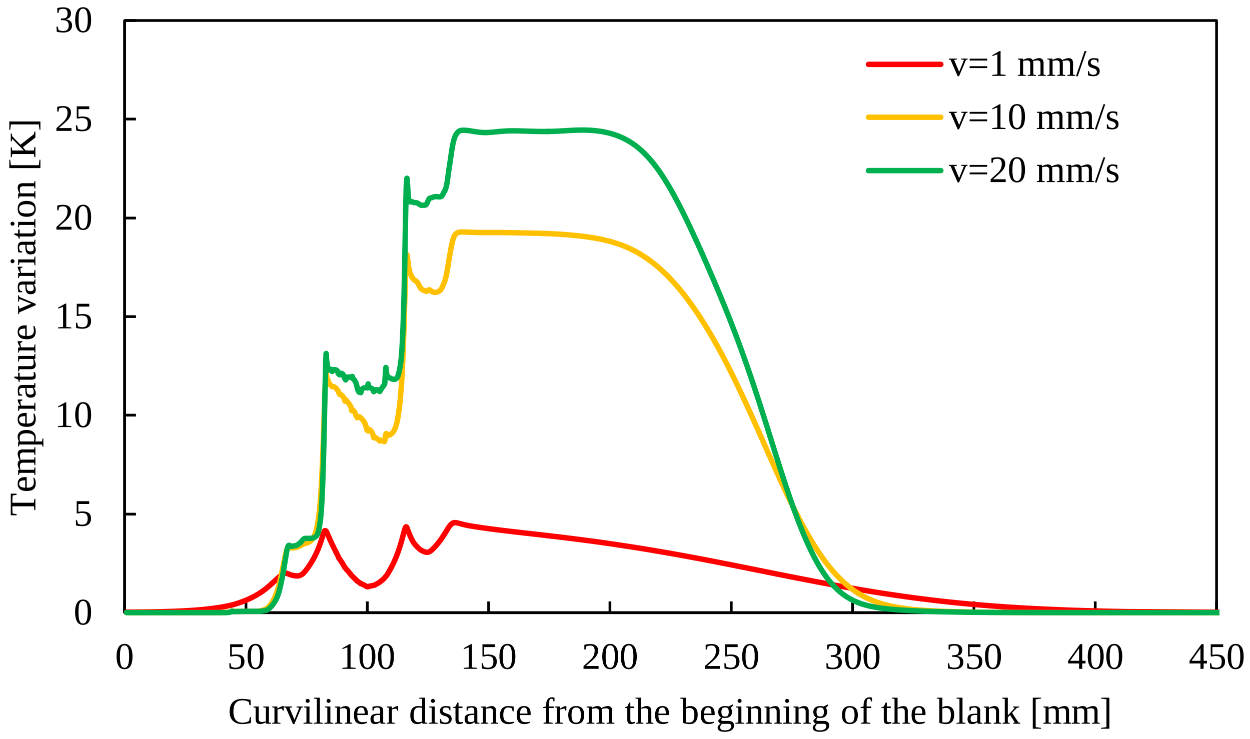
Results – side clearance

- Influence of the side clearance on the temperature distribution
- Reduction rs



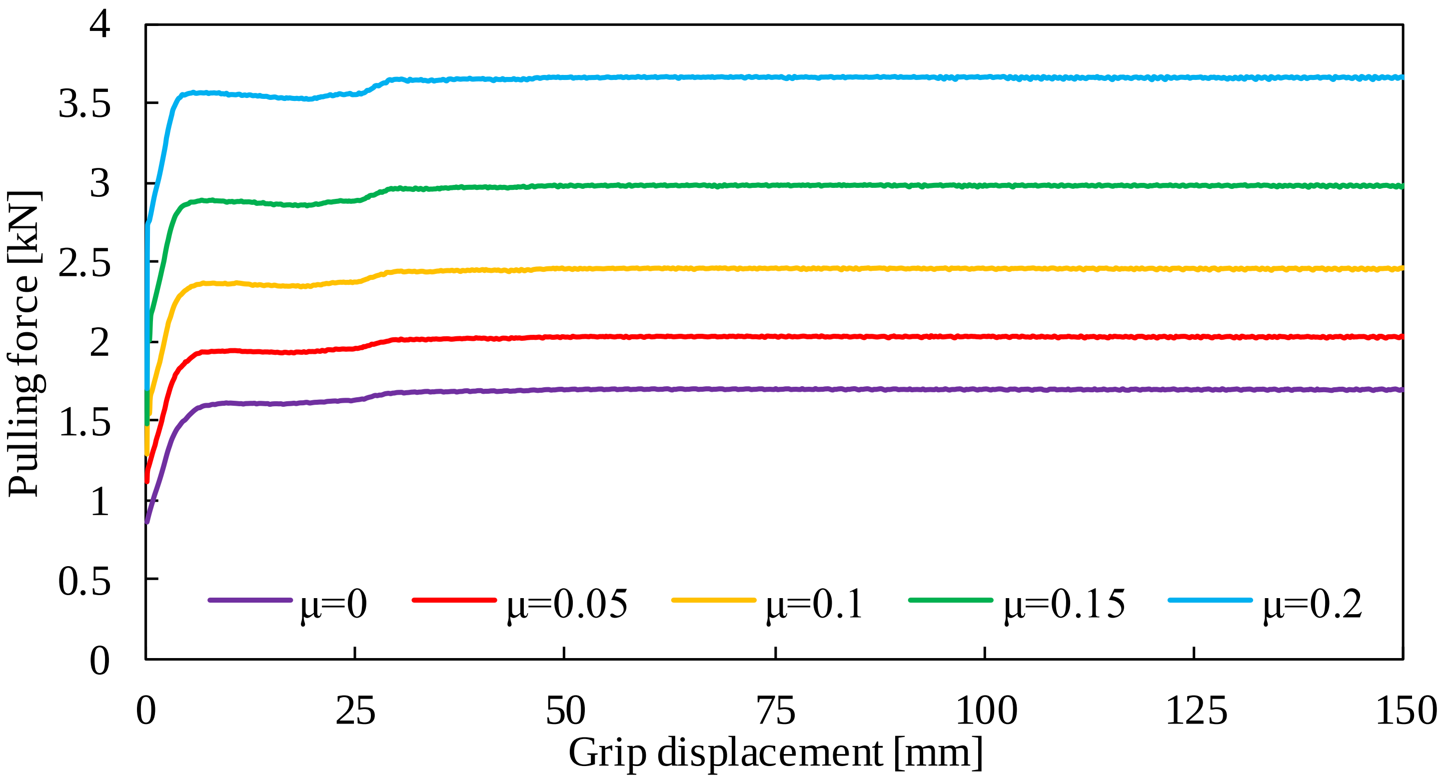
Results – pulling speed

- Influence of the pulling speed on the temperature distribution: **large impact!**
- Reduction of the heat losses to the environment and to the cylinders



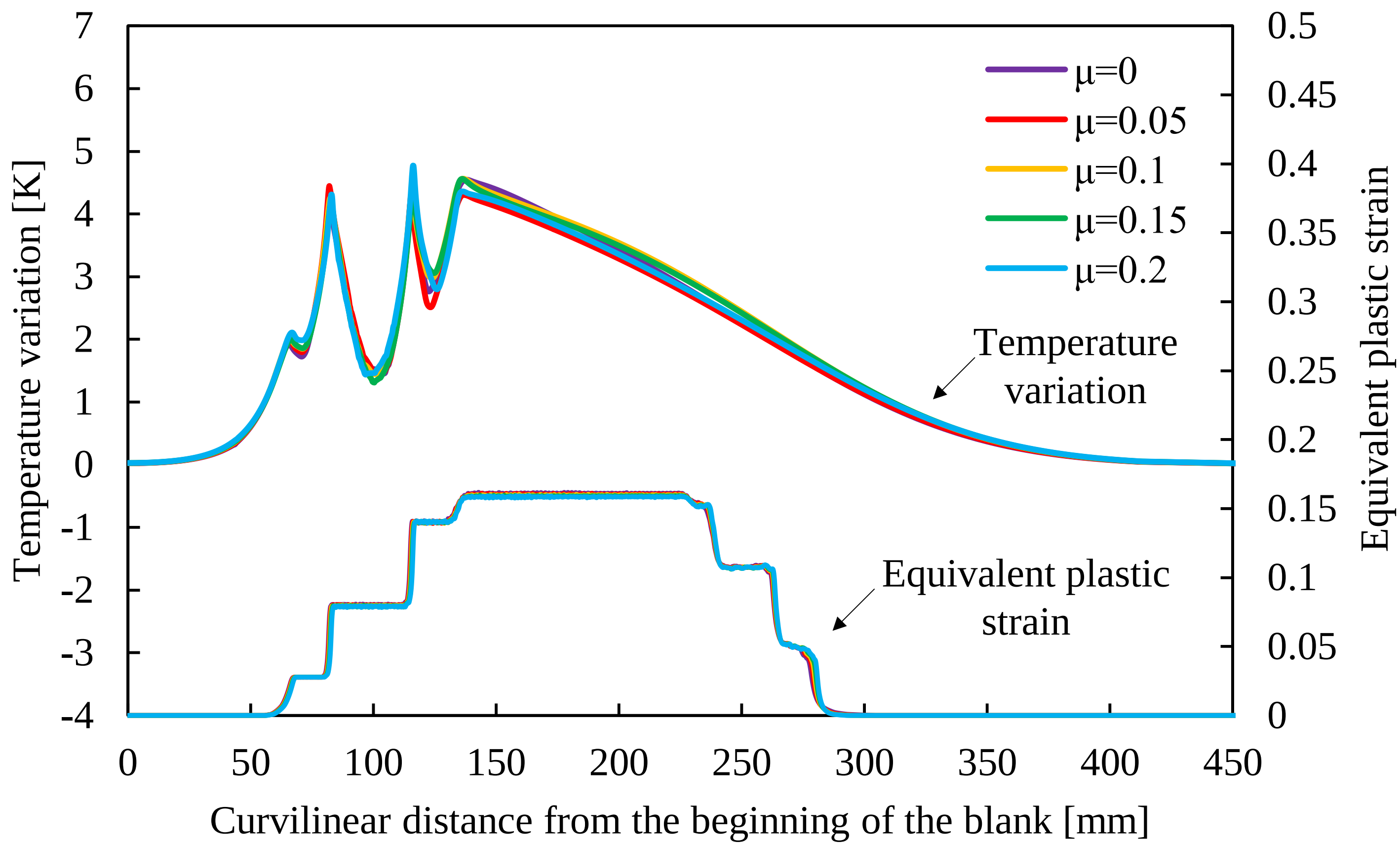
Results – friction coefficient

- Influence of the friction coefficient on the pulling force evolution: **large impact!**



Results – friction coefficient

- Influence of the friction coefficient on the temperature rise: **negligible!**
- Equivalent plastic strain distribution similar for all cases



Conclusions

- The proposed finite element model takes into account both the heat generated by plastic deformation and friction, as well as the heat losses to the environment by free convention and the contact conductance with the forming

- Both linear elastic and elastic-perfectly plastic material behaviour
- Roughness
- Although the contact forces are strongly influenced by the coefficient of friction, its influence on the temperature rise is negligible
- The temperature rise is predominantly influenced by pulling speed, which is unimportant for low values of pulling speed

Acknowledgements

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Thank you for your attention!