UNIVERSIDADE D COIMBRA

Temperature analysis during the drawing of an aluminum cylindrical cup

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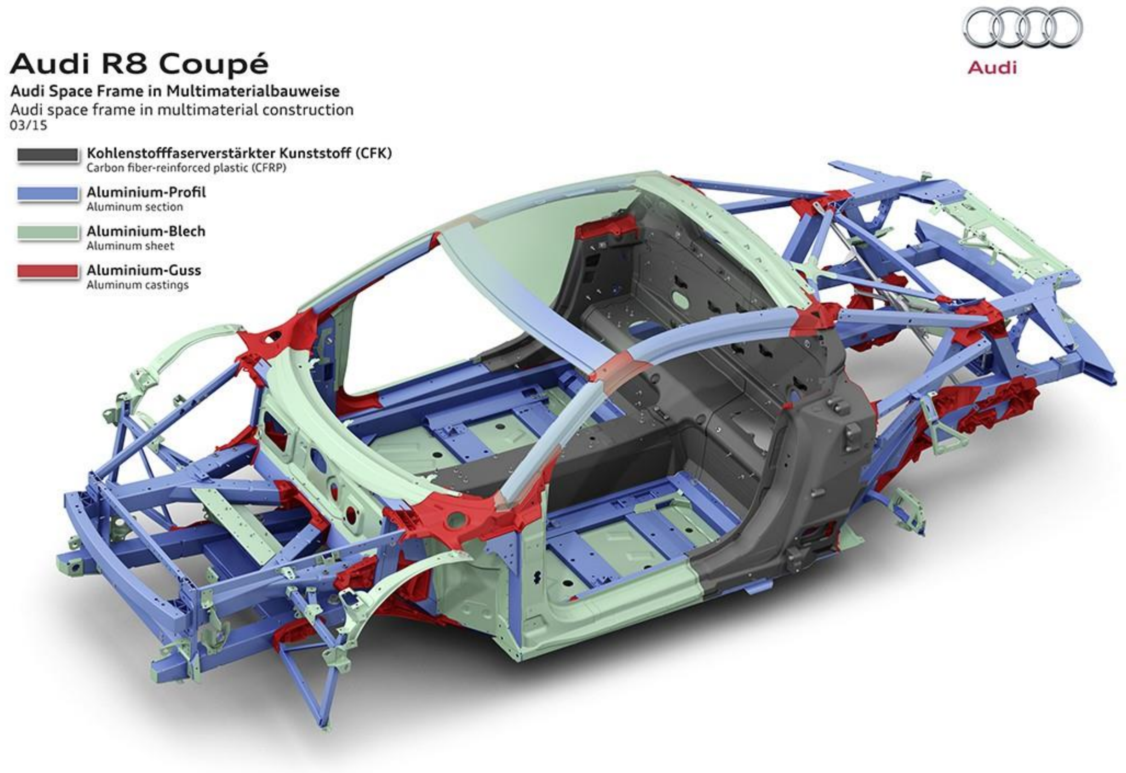
Aluminum alloys

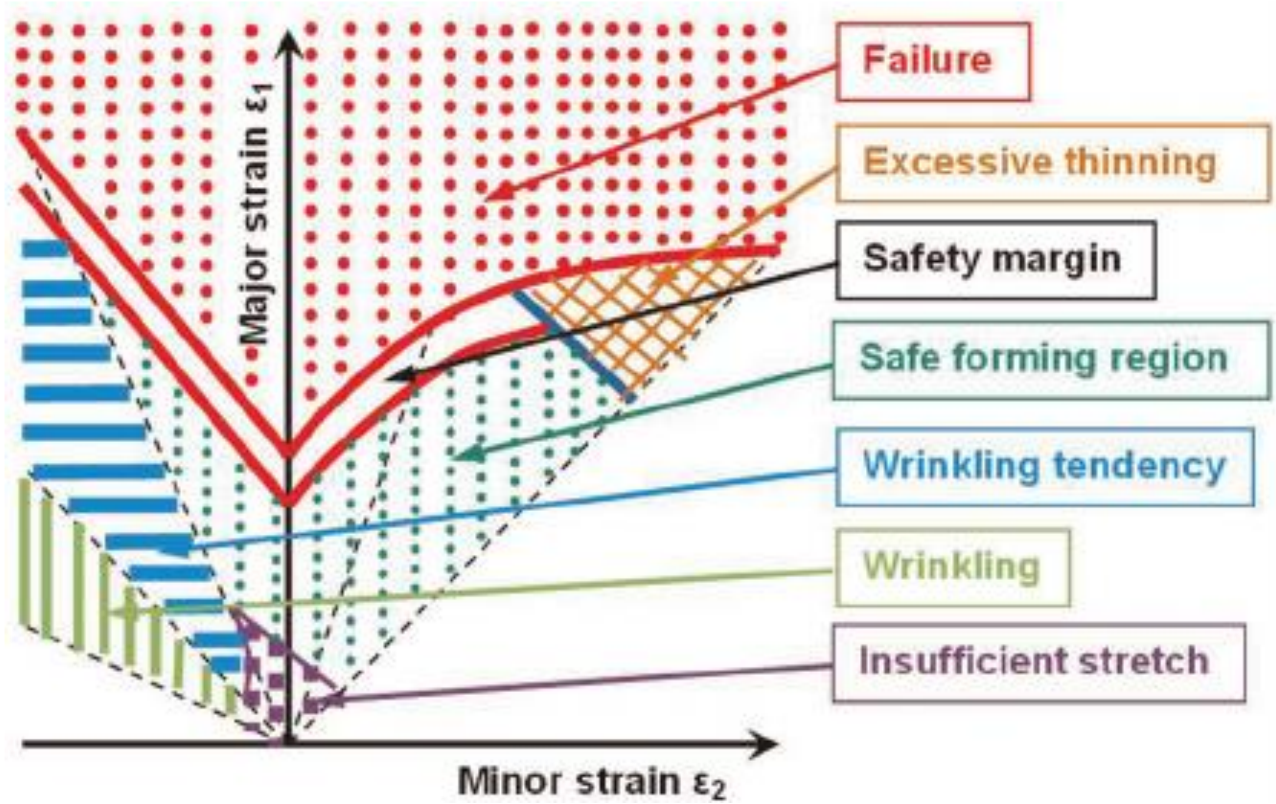
- Increasing use in the **automotive industry** over the past 20 years
- Improve strength and reduce weight of automotive bodies for **safety** and **fuel efficiency**



Introduction

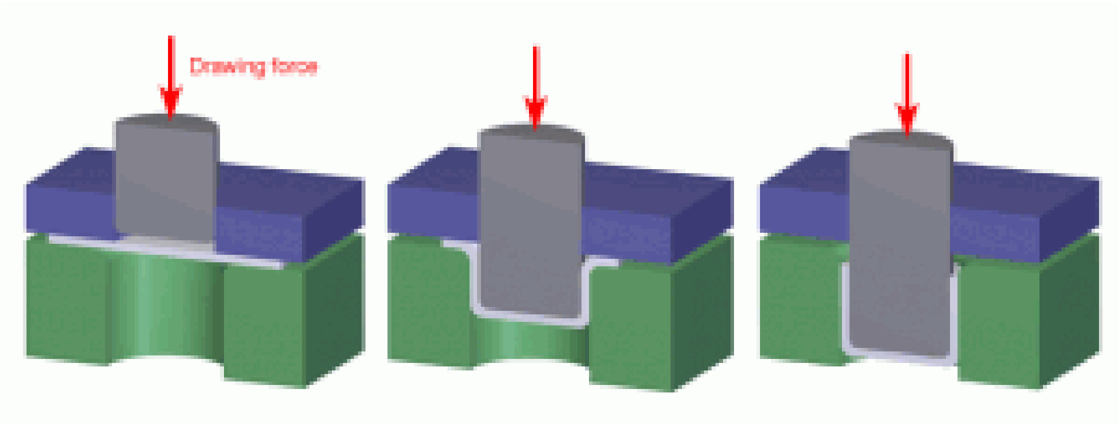
Sheet metal forming processes

- **High levels of plastic deformation** in the components before failure
- High production rates (**short cycle time**)
- **Large friction forces** between sheet and forming tools (high contact pressure)



Heat generated by plastic deformation and friction

- Most of the **plastic work** is converted into heat (about 90%)
- The plastic work is proportional to the **flow stress** of the material
- The presence of **friction forces** in the relative **sliding** generates heat



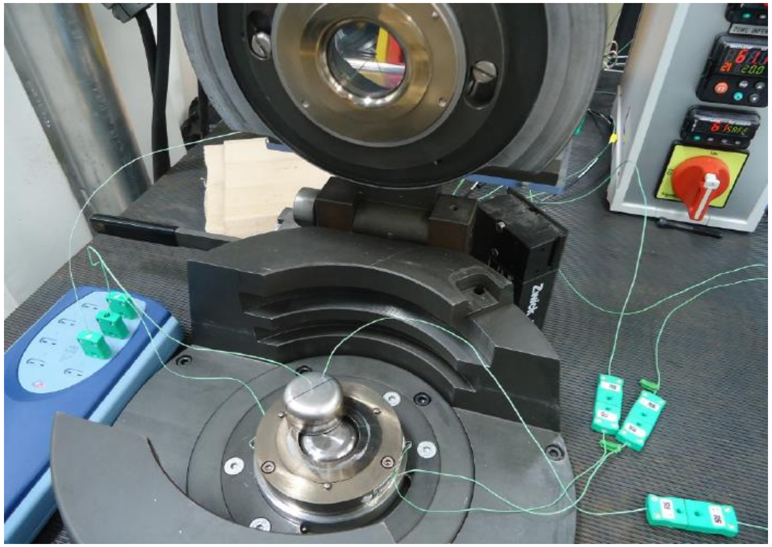
- Significant impact of temperature variations on the **lubricant conditions**

➢ **Objective:** numerical analysis of the **temperature variation** in the forming of an aluminum **cylindrical cup** at room temperature

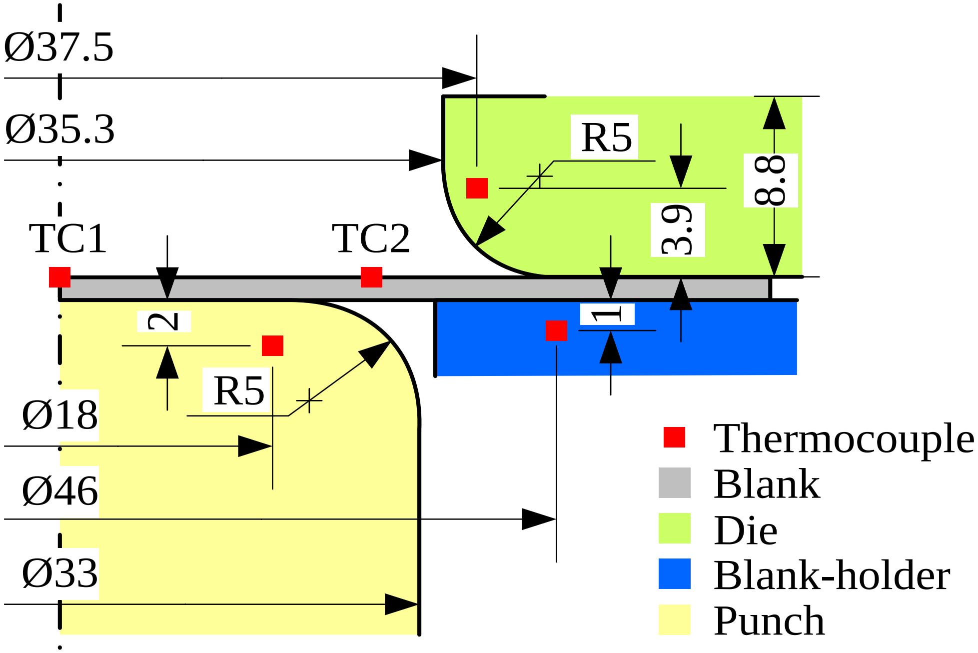
Cylindrical cup forming

Deep drawing of an aluminum cylindrical cup at room temperature

- Temperature monitored by **5 thermocouples** in different localizations
- Circular blank of **AA6016-T4 aluminum alloy** with 1.05 mm thickness
- Different values of **punch speed** (1 mm/s and 10 mm/s)



Experimental apparatus

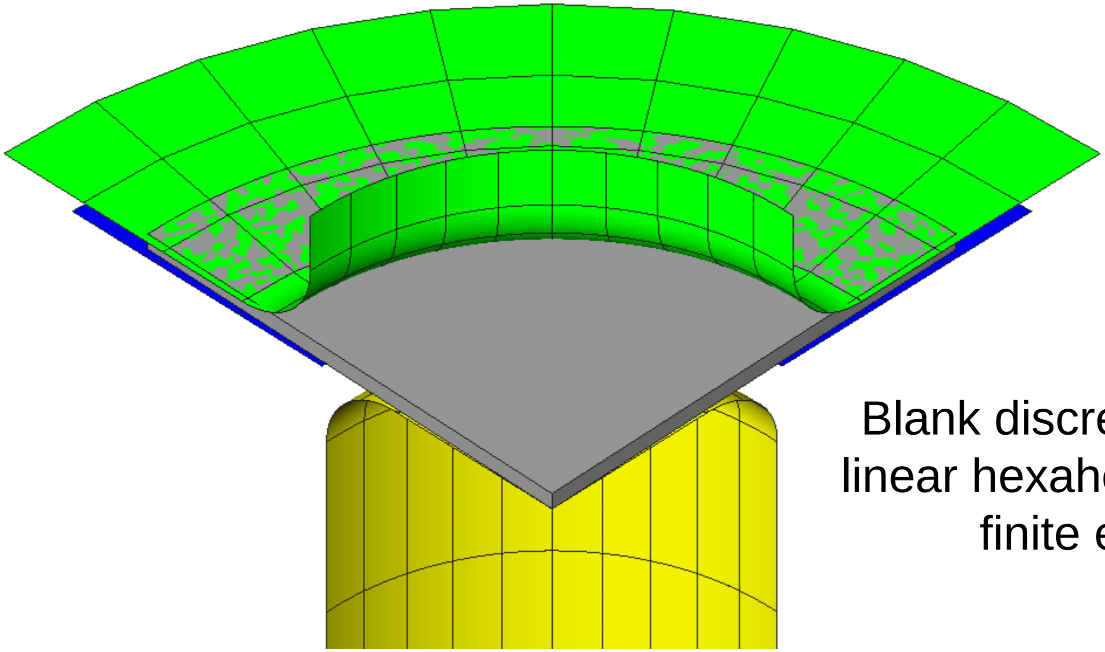


Location of the thermocouples

Cylindrical cup forming

Finite element model

- **Thermo-mechanical** analysis using the **DD3IMP** in-house finite element code
- **1/4 of the model** (symmetry conditions)
- Forming tools are assumed **rigid** and **isothermal** (described by Nagata patches)
- Plastic behavior is assumed **temperature independent**
  - Isotropic work hardening (**Voce law**) and the anisotropic yield criterion (**Barlat'91**)

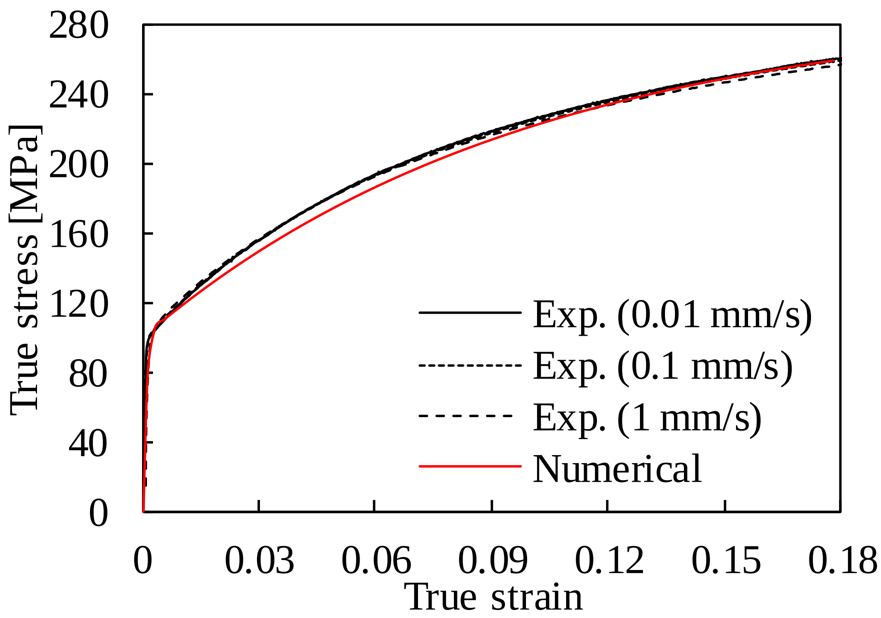


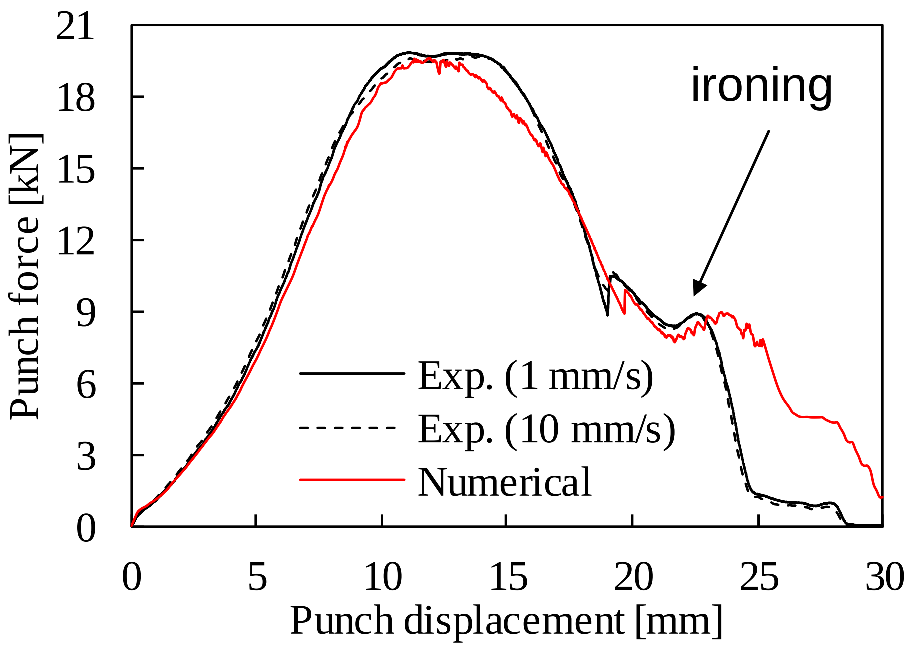
Blank discretized by 5910 linear hexahedral (8-nodes) finite elements

Cylindrical cup forming

Finite element model

- The material is **not strain rate sensitive** at room temperature
  - 3 different values of crosshead velocity in the uniaxial tensile test
- Friction coefficient (μ=0.15) **evaluated by curve fitting** using the experimental punch force evolution

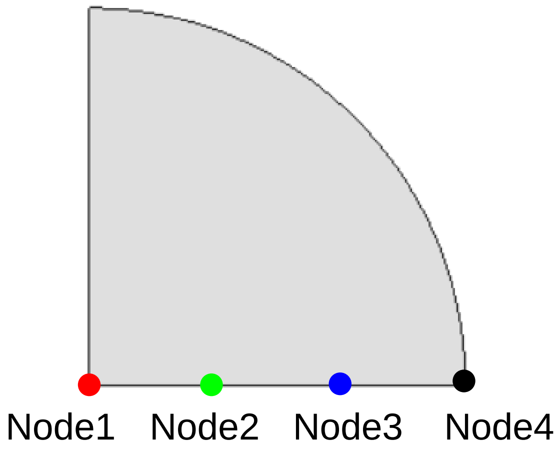




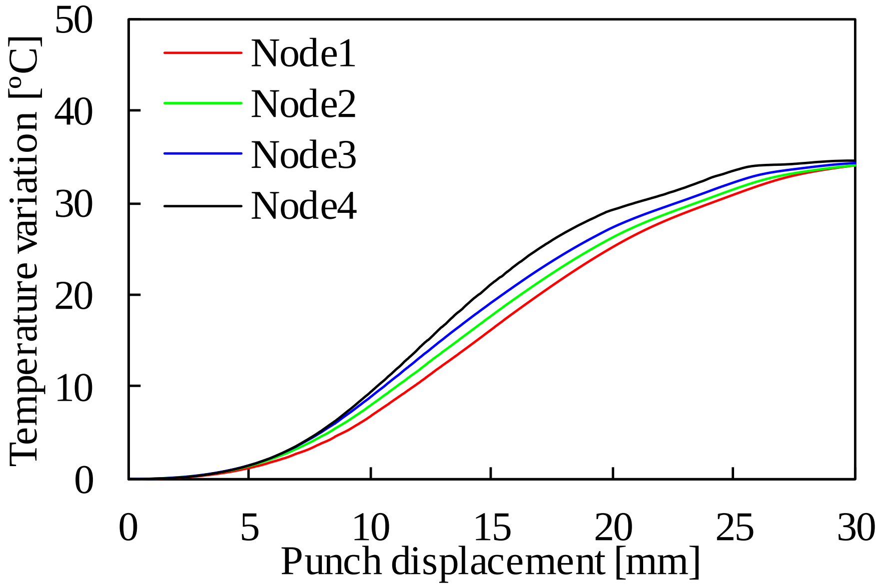
Results and discussion

Isolated thermal conditions for the blank

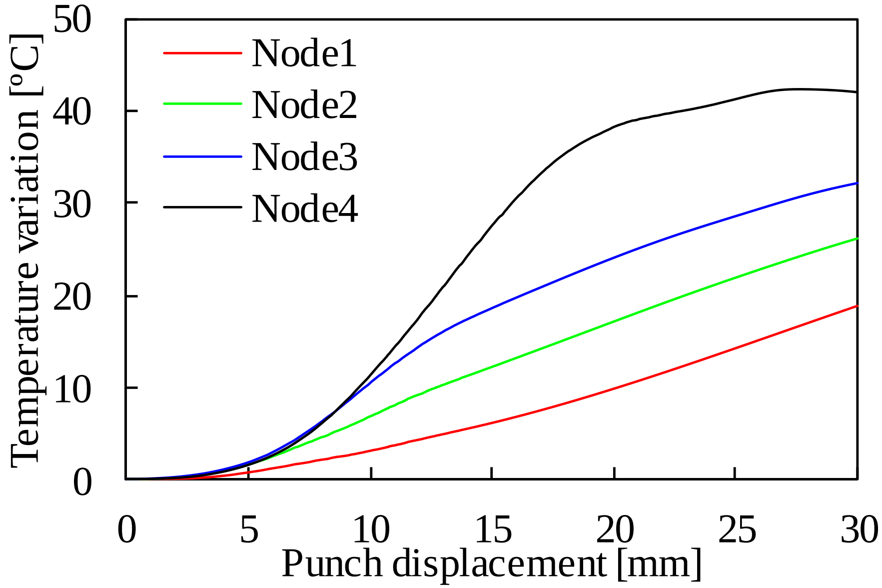
- Temperature increases due to the heat generated both by **plastic deformation** and by the **friction forces**
- Lower punch velocity leads to a temperature homogeneity (**thermal conduction**)



1 mm/s of punch velocity



10 mm/s of punch velocity

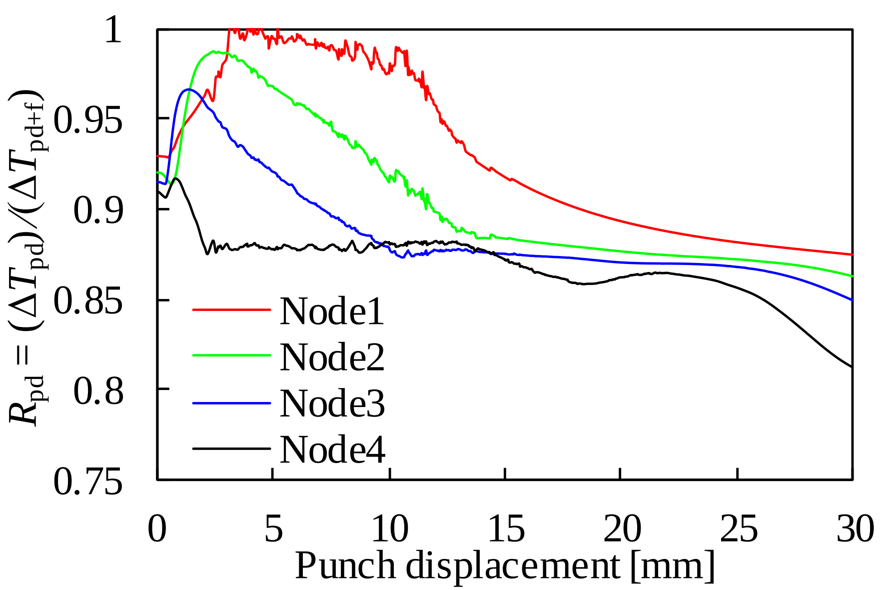


Results and discussion

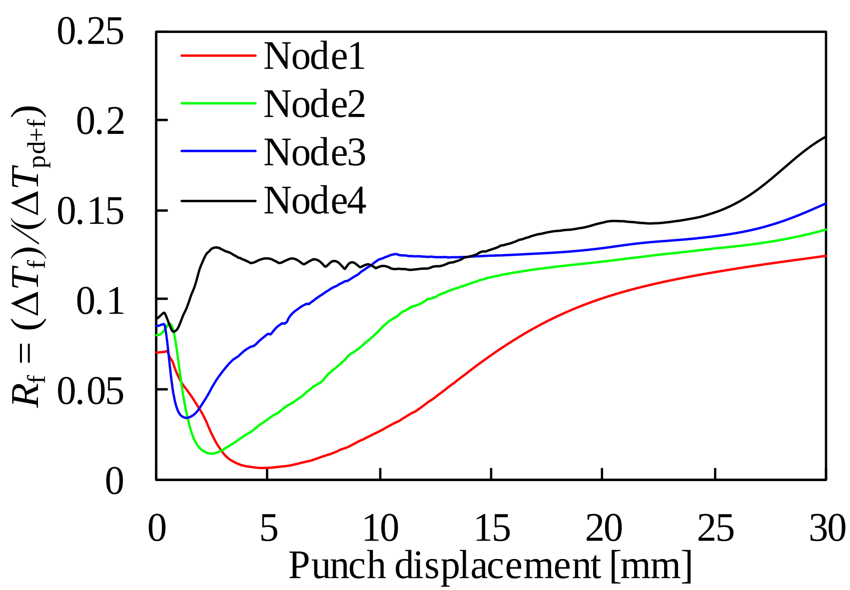
Isolated thermal conditions for the blank

- Quantify the fraction of heat generated by **plastic deformation** and by **friction forces** over the total heat generated (considering 10 mm/s of punch velocity)
- **90%** of the heat generated comes **from plastic deformation** and the remaining 10% arises from the friction forces

Fraction of heat generated by plastic deformation



Fraction of heat generated by friction forces

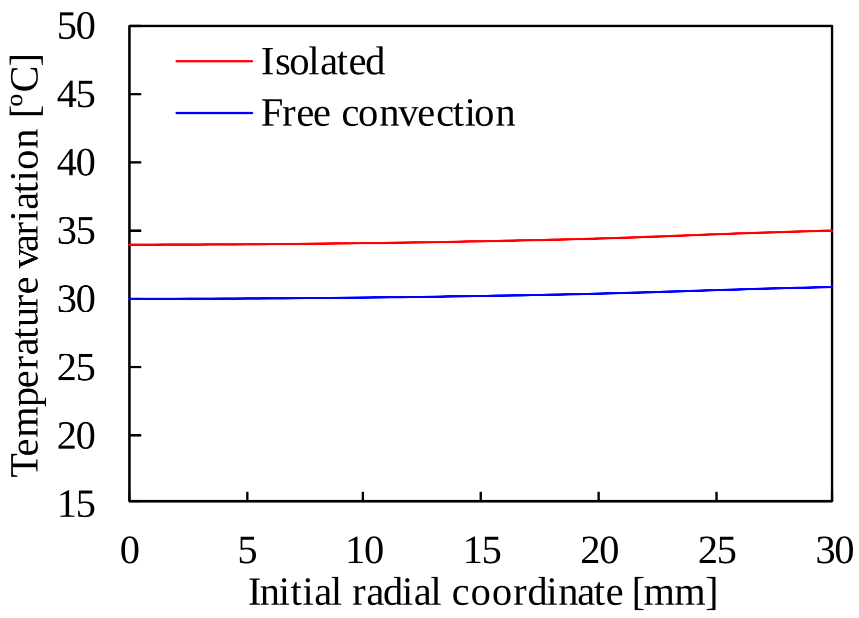


Results and discussion

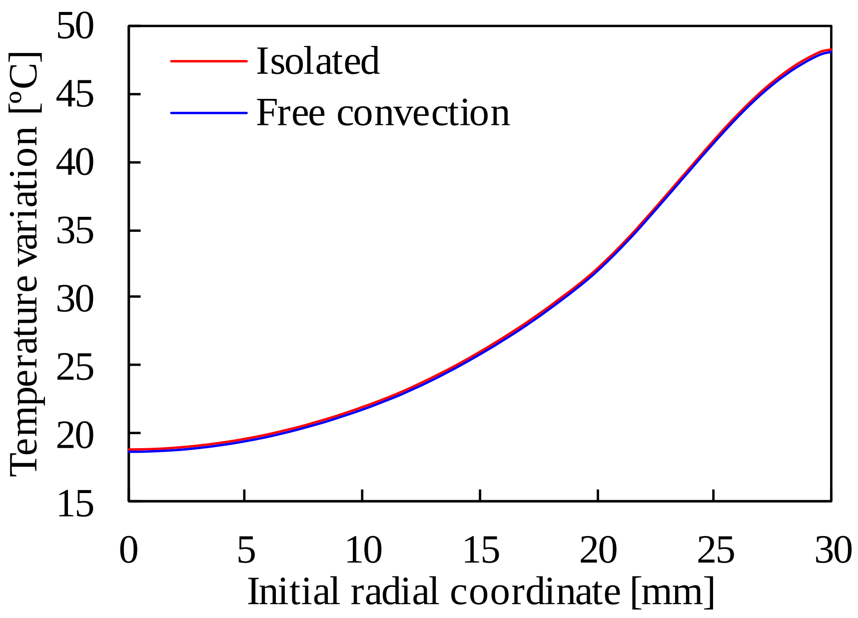
Only free convection to air (h=10 W/m^{2}K)

- Air assumed at **room temperature** (initial blank temperature)
- Almost isothermal for the lower punch velocity
- Free convection is **negligible** for the **highest punch velocity** (lower operation time)

1 mm/s of punch velocity



10 mm/s of punch velocity

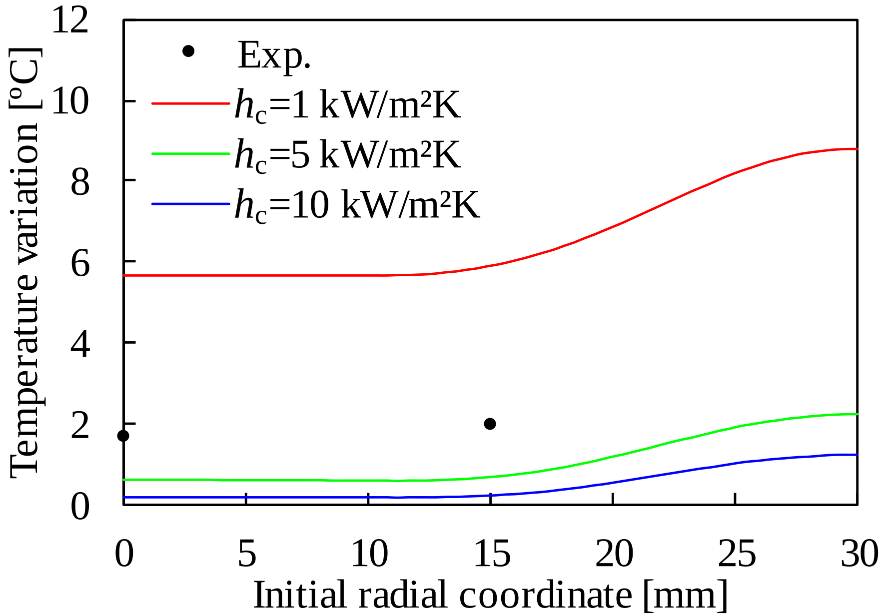


Results and discussion

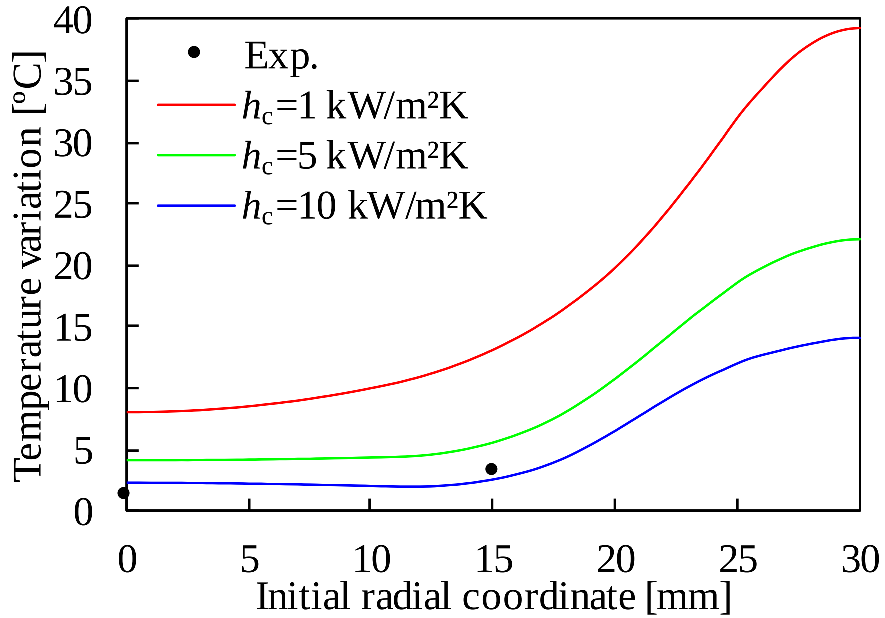
Free convection to air (h=10 W/m^{2}K) and heat loss to the forming tools

- Blank temperature **along the radial direction** at 20 mm of punch displacement
- **Temperature rise strongly reduced** by considering the heat loss to the tools
- Temperature approximately **constant in the cup bottom**, increasing along the cup wall

1 mm/s of punch velocity



10 mm/s of punch velocity

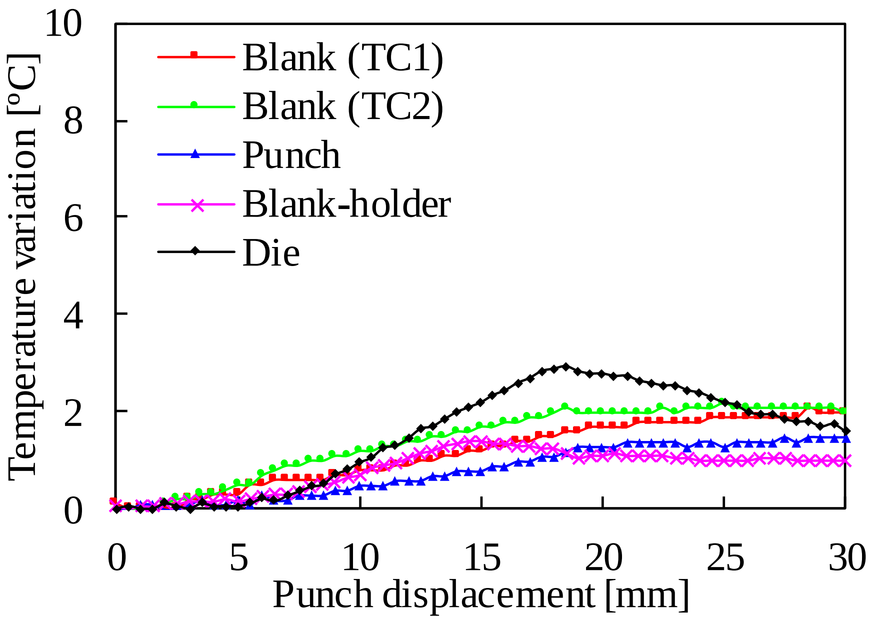


Results and discussion

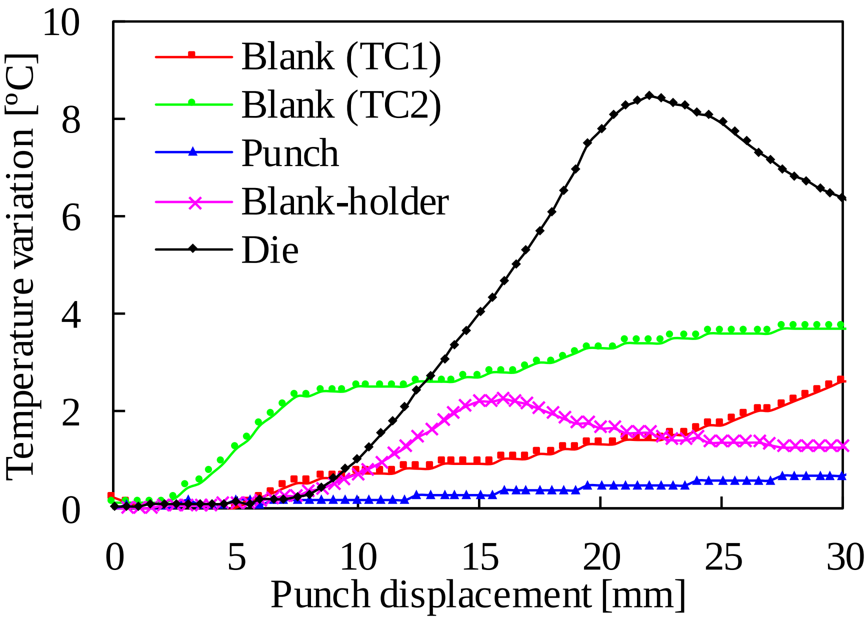
Experimental temperature evolution in the blank and forming tools

- Temperature higher for 10 mm/s of punch velocity, particularly at the die
- Maximum temperature arises close to the **die radius**
  - Most of the plastic deformation (blank) occurs on the flange and die radius
- Minimum temperature arises in the center of the **cup bottom** (TC1)

1 mm/s of punch velocity



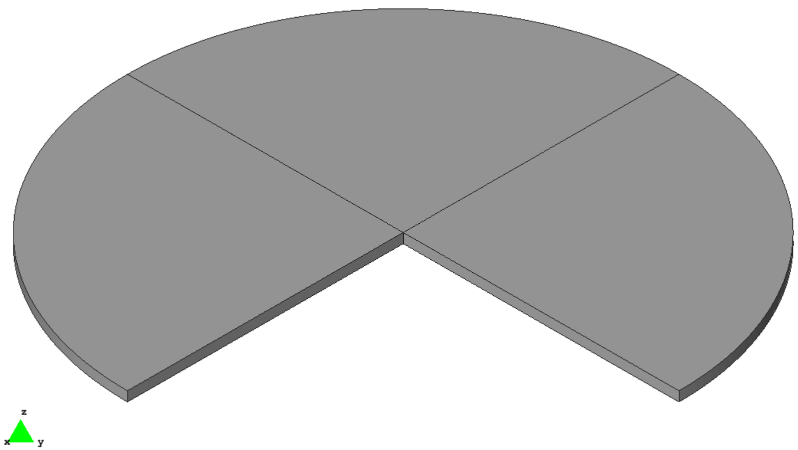
10 mm/s of punch velocity



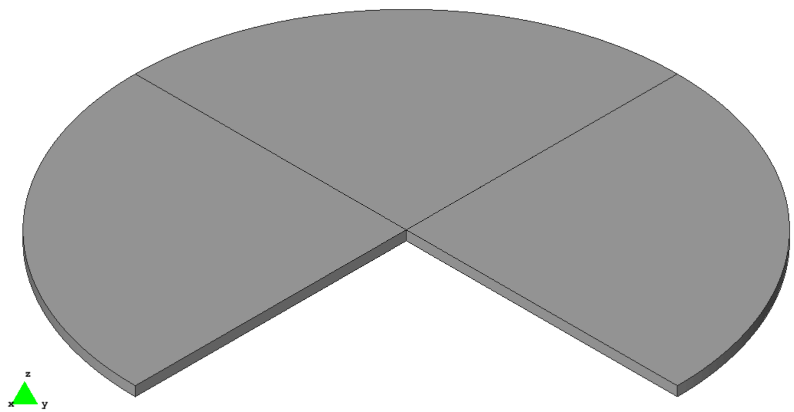
Results and discussion

Predicted temperature in the blank

- Numerical model assumes isothermal conditions for the tools (room temperature)
- Influence of the **punch velocity** in the temperature distribution on the cup



1 mm/s of punch velocity

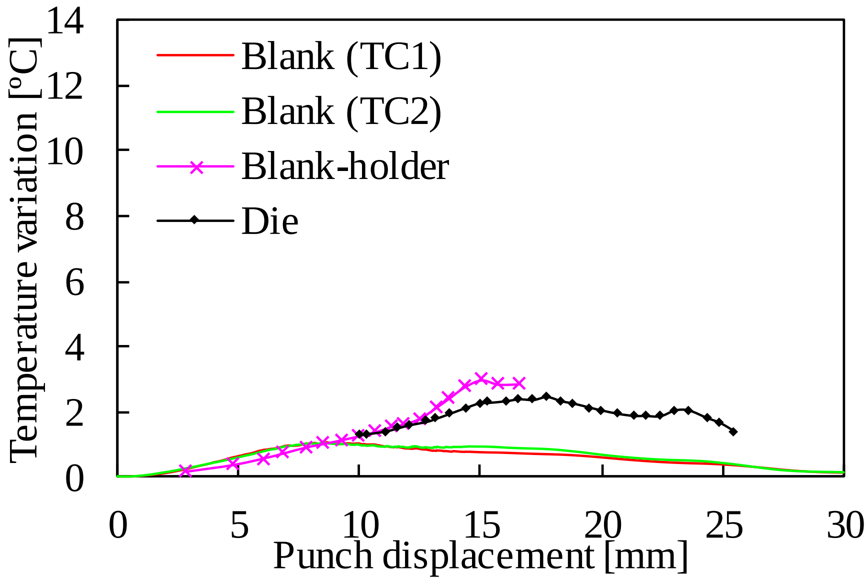


10 mm/s of punch velocity

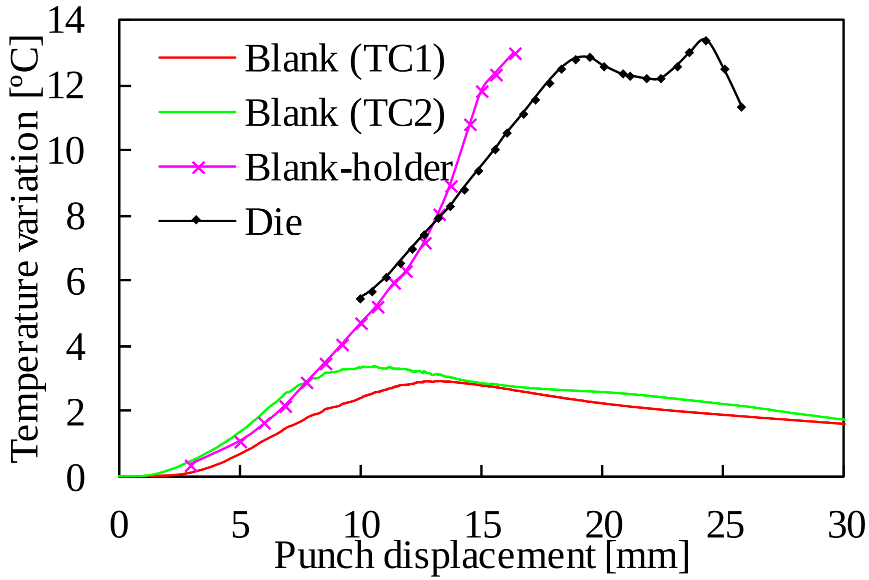
Results and discussion

Predicted temperature evolution in the blank

- Temperature of the tools is evaluated by selecting the **node of the blank closest** to the corresponding thermocouple location (isothermal conditions for the tools)
- The accuracy of the numerical model can be improved by accounting the thermal conduction within the tools



1 mm/s of punch velocity
(h_c=5 kW/m^2K)



10 mm/s of punch velocity
(h_c=10 kW/m^2K)

Conclusions

- Temperature analysis of tools and blank during the deep drawing of an aluminum cylindrical cup
- Heat generated by plastic deformation and friction forces is considered, as well as the heat loss to the environment (air) by natural convection and the heat loss to the tools by contact conductance
- Numerical results show that 90% of the heat generated comes from plastic deformation and the remaining 10% derives from the friction forces
- Increasing the punch speed leads to a global increase of the temperature on the blank and tools (low operation time and consequently less heat loss)
- The experimental temperature rise on the die surface is higher than 9ºC for the punch speed of 10 mm/s
- The accuracy of the numerical model can be improved since the tools are assumed isothermal

Acknowledgements

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Thank you for your attention!