Universidade de Coimbra

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Prediction of wrinkling and springback in sheet metal forming

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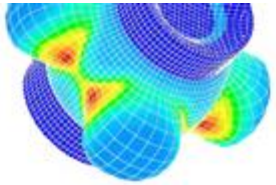
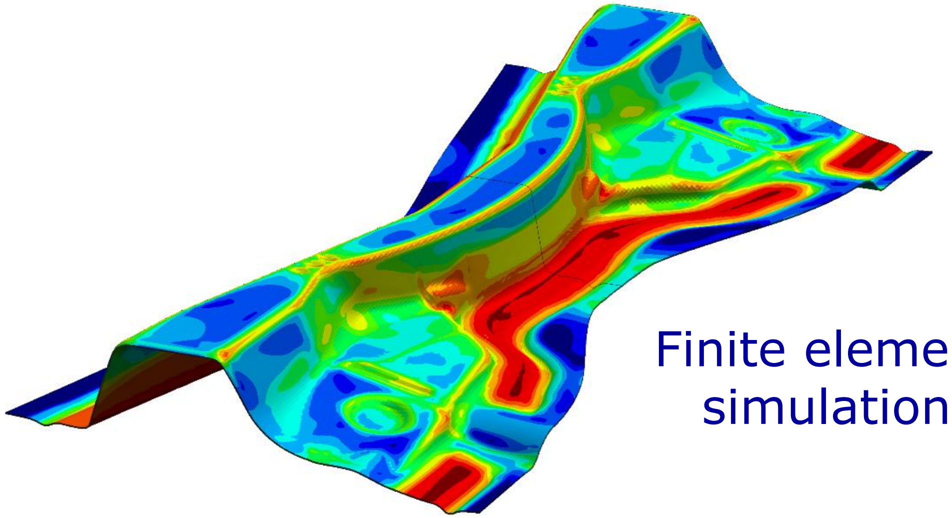


NUMIFORM 2016
The 12th International Conference
on Numerical Methods in Industrial Forming Processes

Introduction

- Sheet metal forming processes are widely used in the automotive industry
- Major concerns are the environmental protection and the safety specifications
- Adoption of new materials such as high-strength steels and aluminum alloys
- The numerical simulation allows the shortening of development cycles

Benchmark 2 - Numisheet 2005

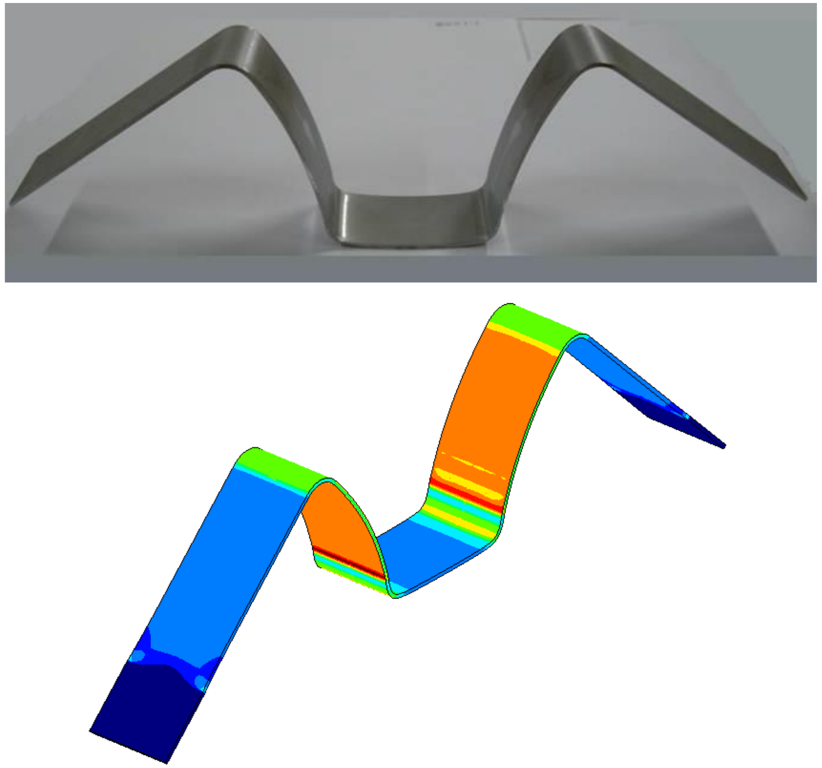


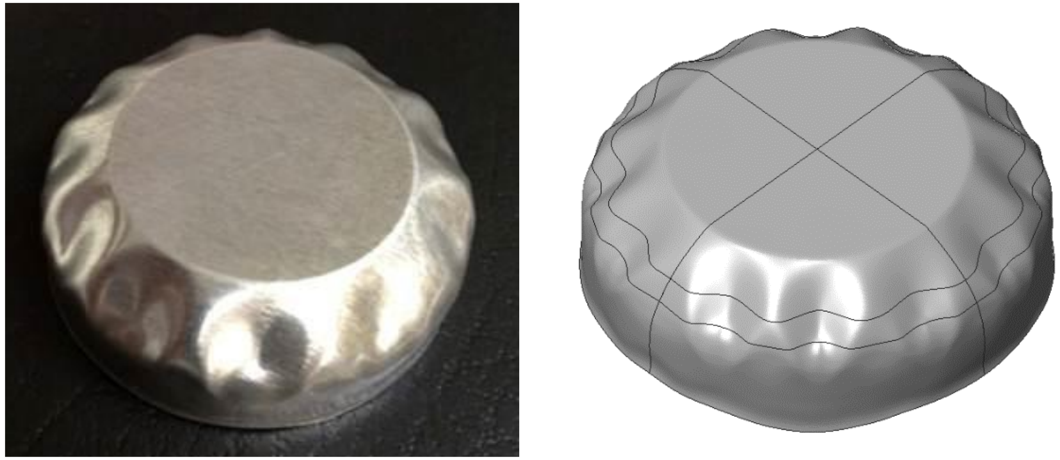
Finite element simulation

Forming defects

New materials are more prone to develop forming defects:

- Springback
- Wrinkling and buckling
- Necking and fracture
- Surface marks





Benchmark 4 - Numisheet 2014

Benchmark 4 - Numisheet 2011

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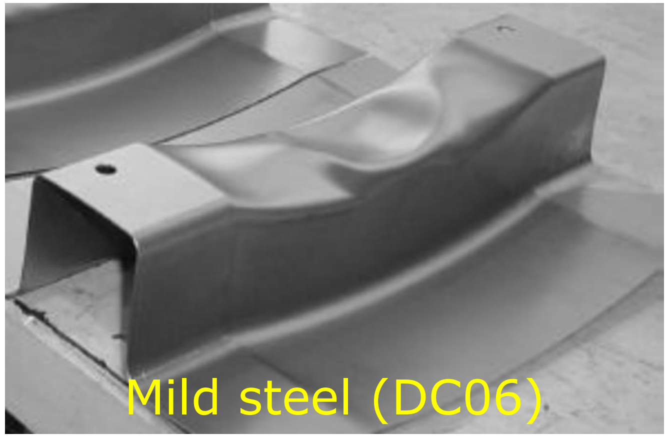
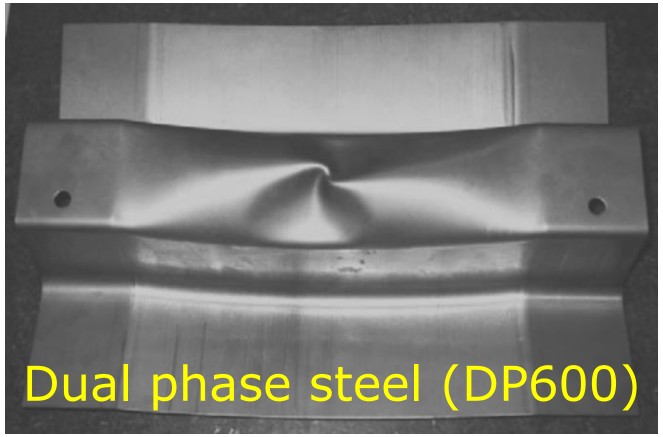
Experimental procedure

Sheet metal forming of a rail prone to 2D springback and wrinkling

- Clamping the blank (300x300x1mm) between the die and the blank-holder with 90 kN, using six nitrogen gas springs connected
- Punch stroke of 60 mm, while increasing the blank-holder force from 90 to 130 kN



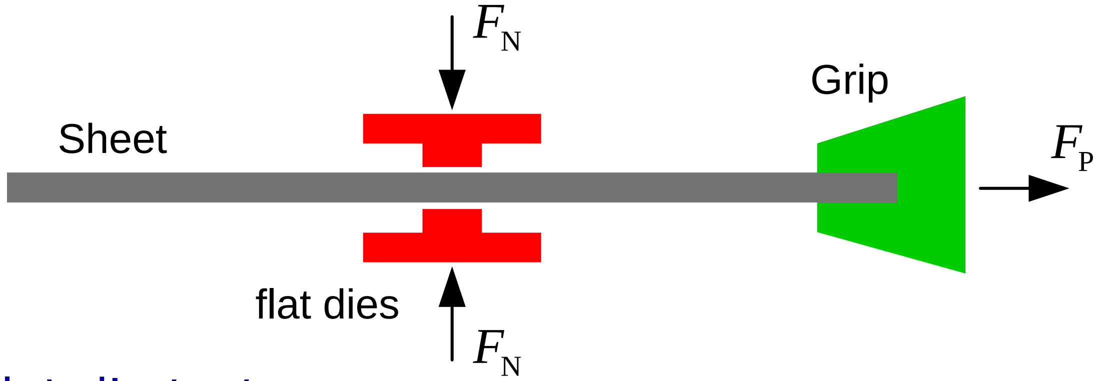
Mild steel (DC06)



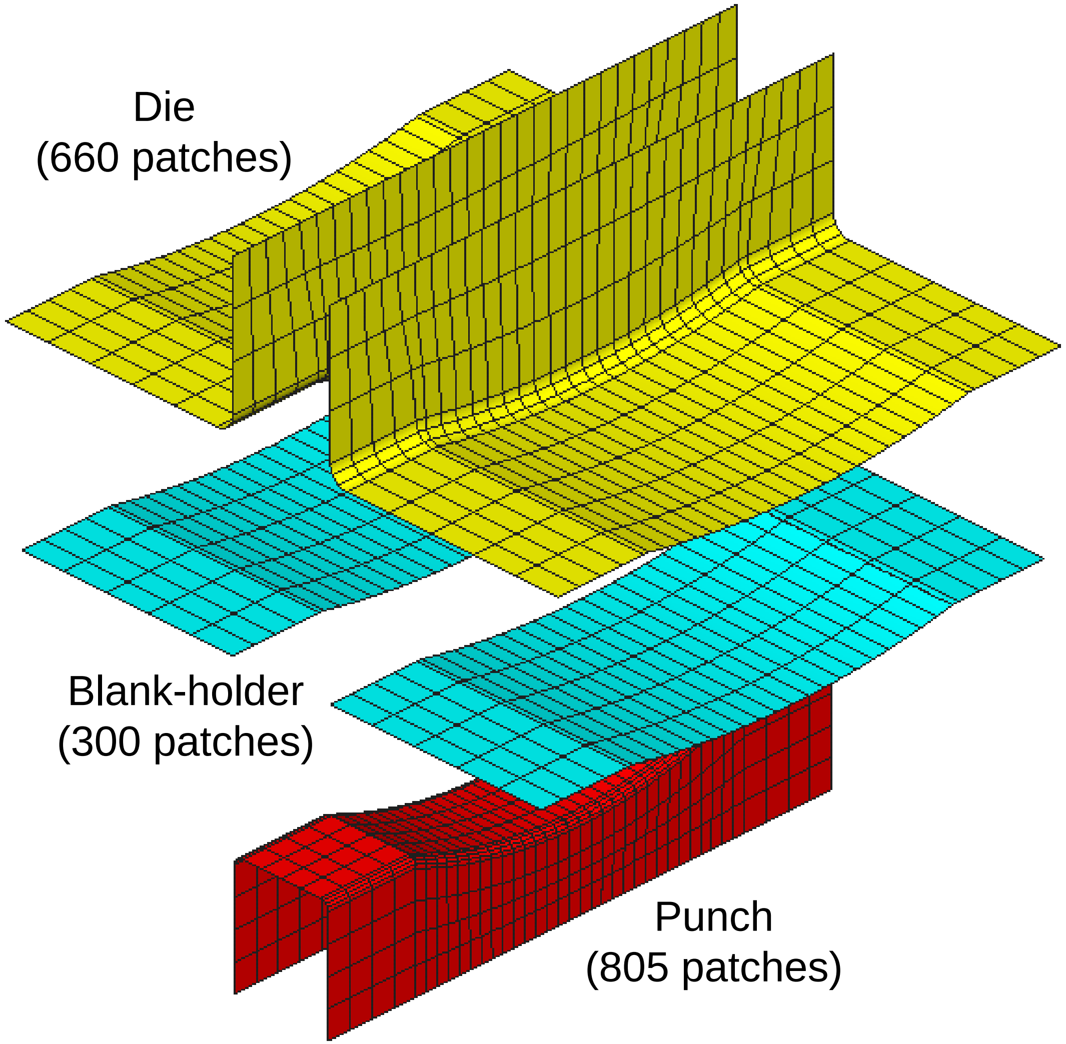
Dual phase steel (DP600)

Finite element model

- In-house static implicit finite element code DD3IMP
- Geometry of the forming tools (rigid) modelled by Nagata patches
- Friction coefficient dependent of the normal contact pressure



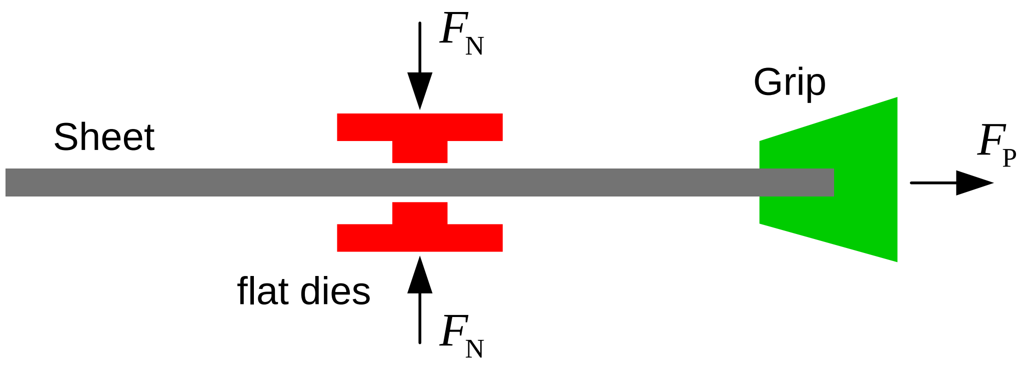
Flat die test

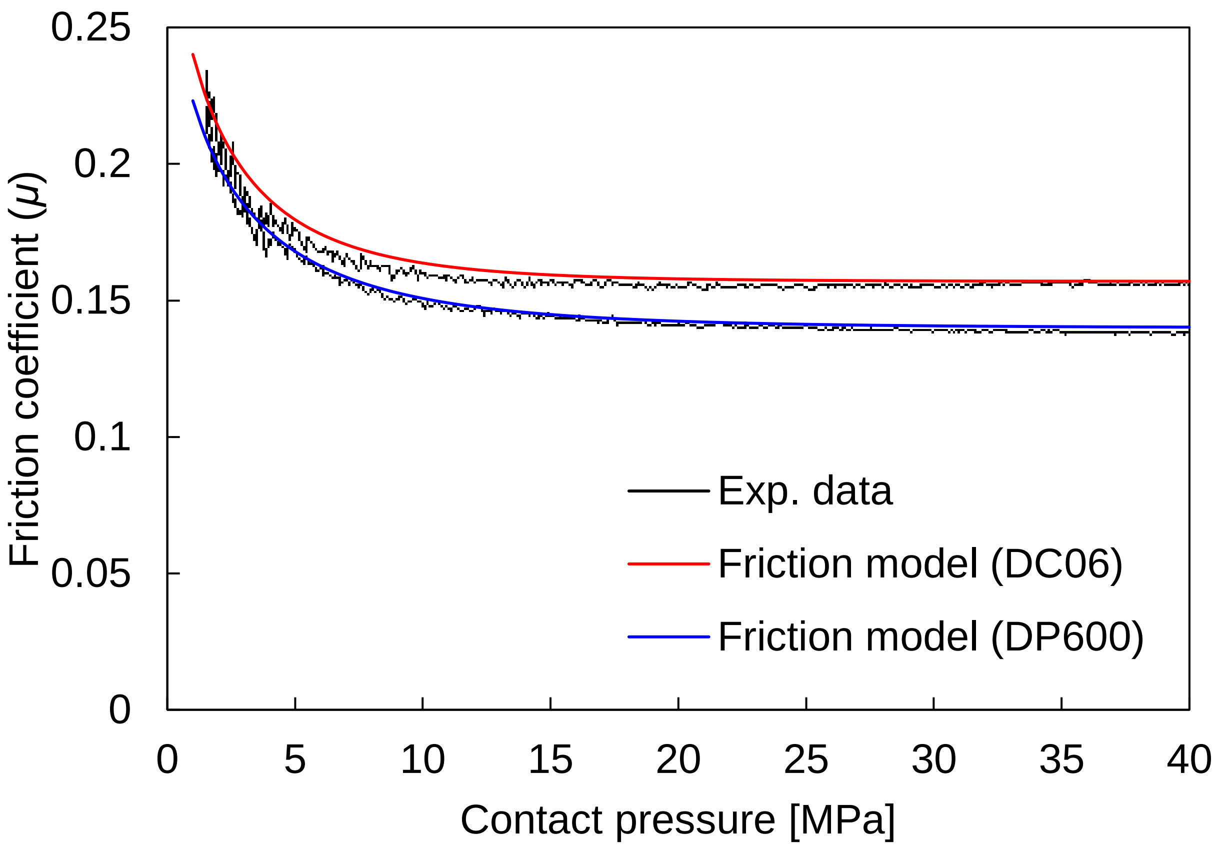


Forming tools described by Nagata patches

Finite element model

- Fitting the numerical model to experimental data from the flat-die tests
- The value of the friction coefficient decreases with the increase of the contact pressure





$$\mu = B - (B - A)\exp(-mP^n)$$

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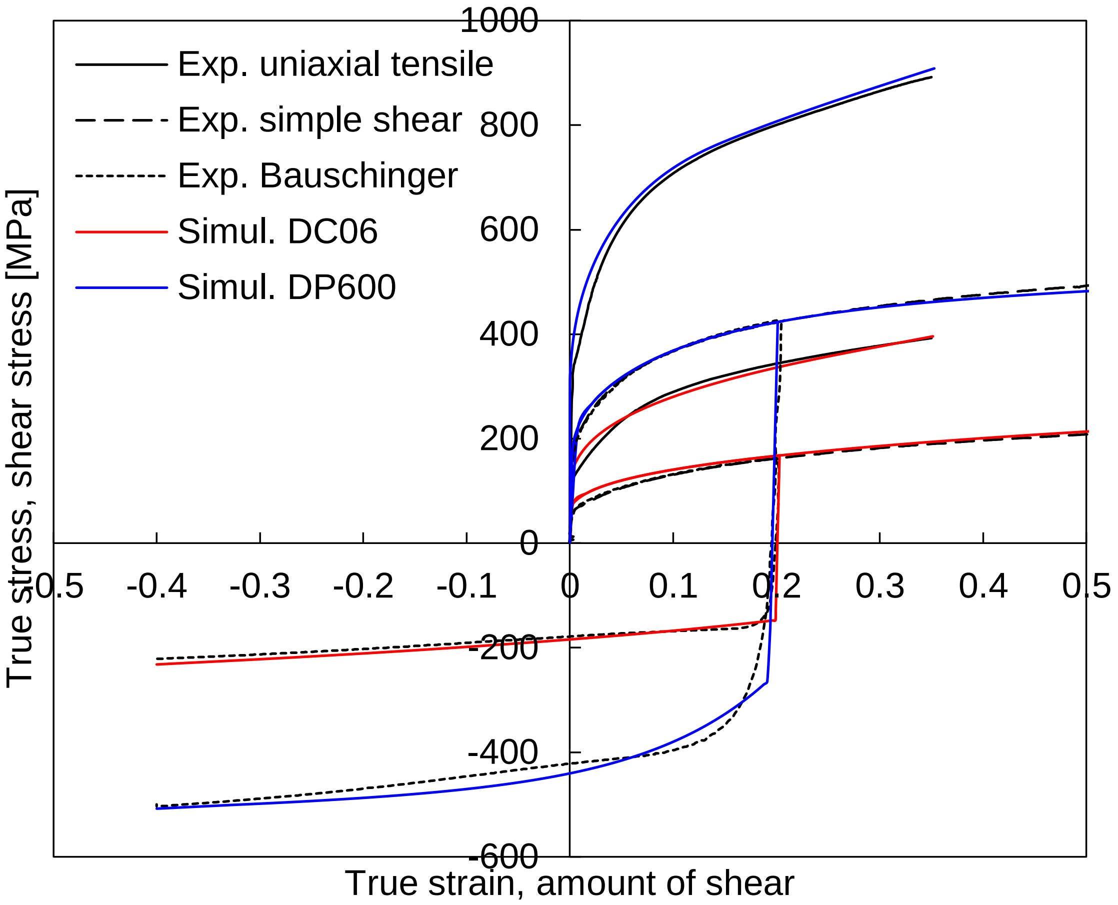
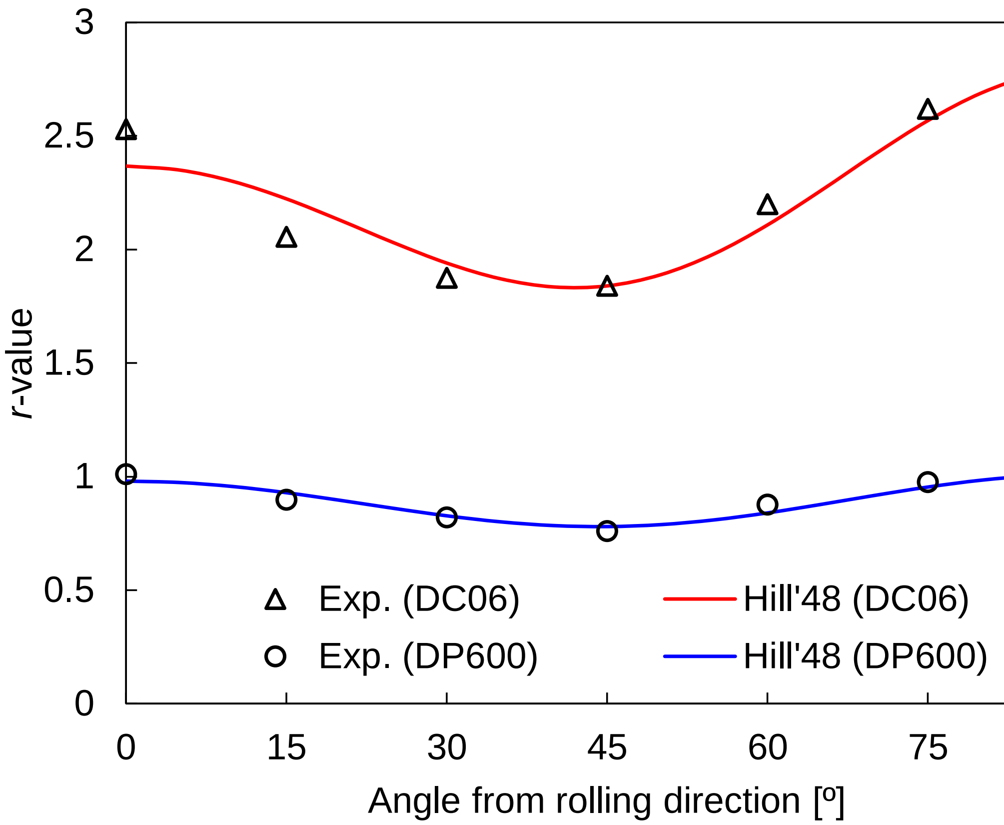
Finite element model

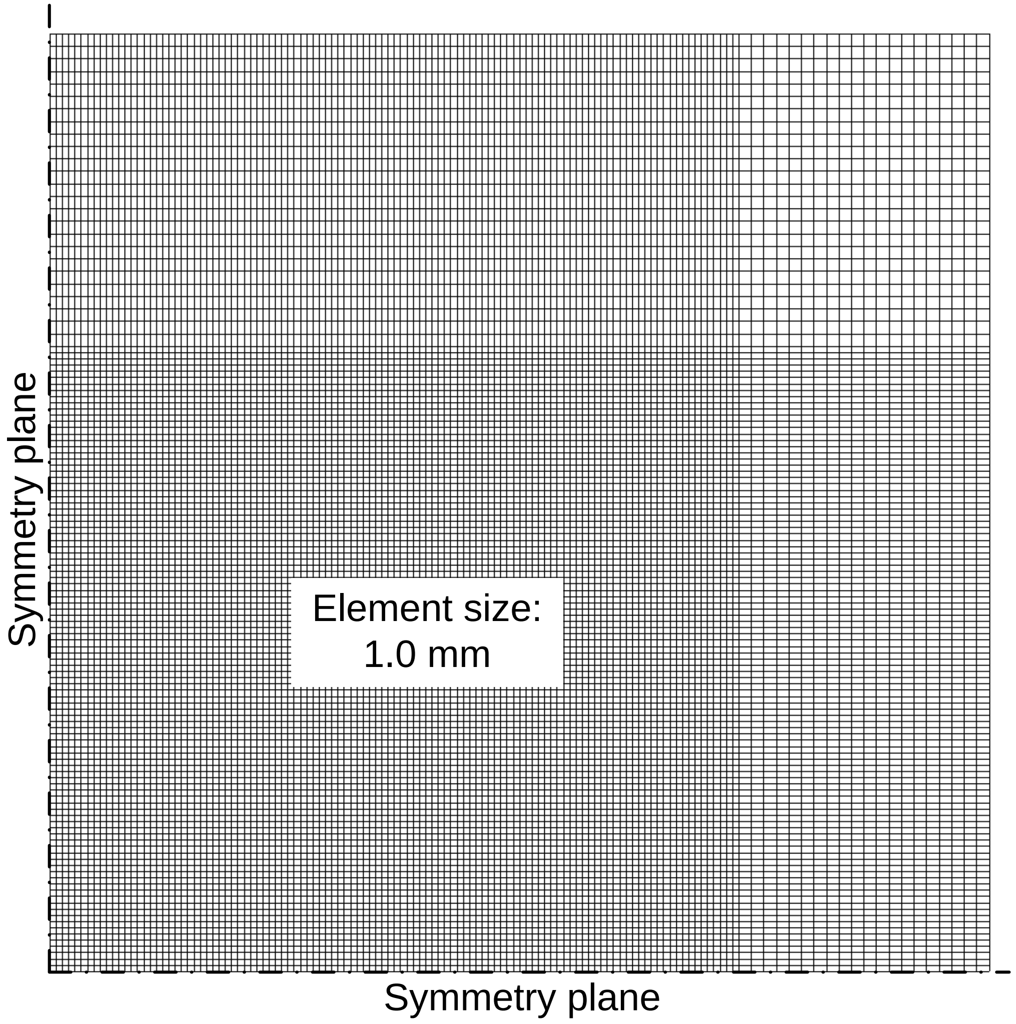
- Hardening behavior described by the Swift law with kinematic hardening (A-F)
- Plastic anisotropy described by the Hill 1948 yield criteria





Finite element model

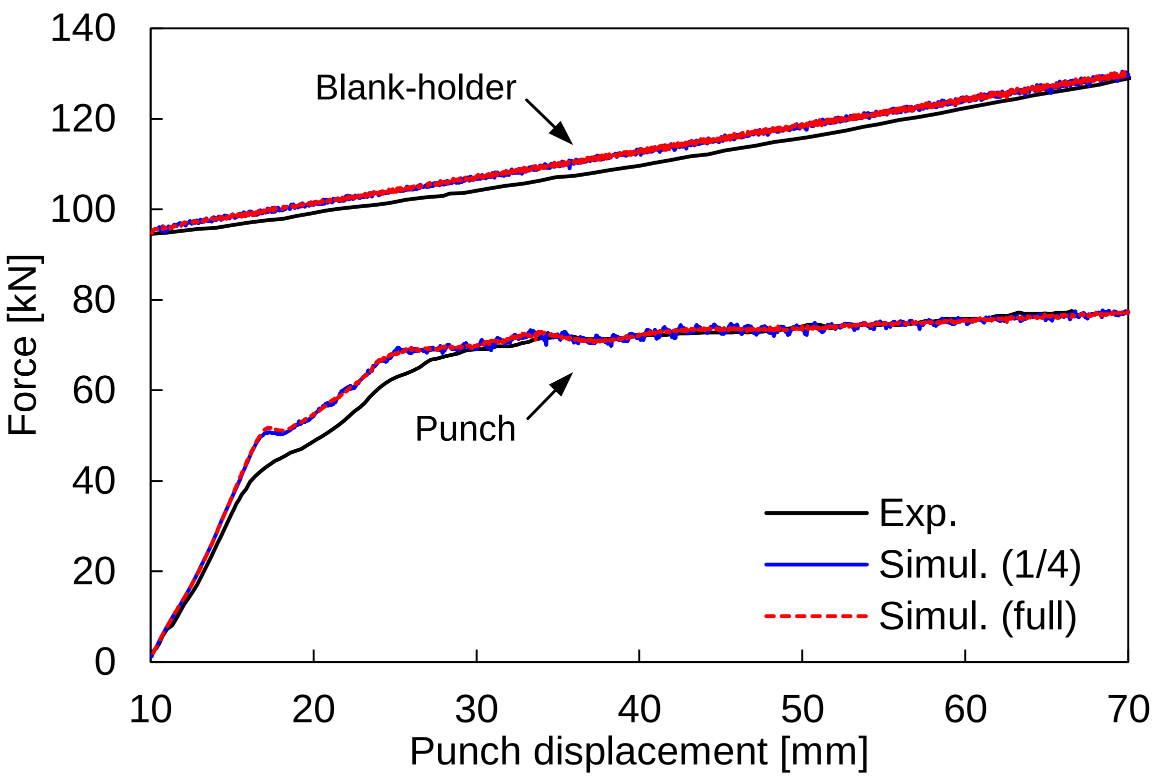
- Blank discretized with linear hexahedral finite elements
- Modelling both 1/4 of the blank (symmetry conditions) and the full blank geometry (slightly rotated)
- The full blank comprises 130,000 finite elements



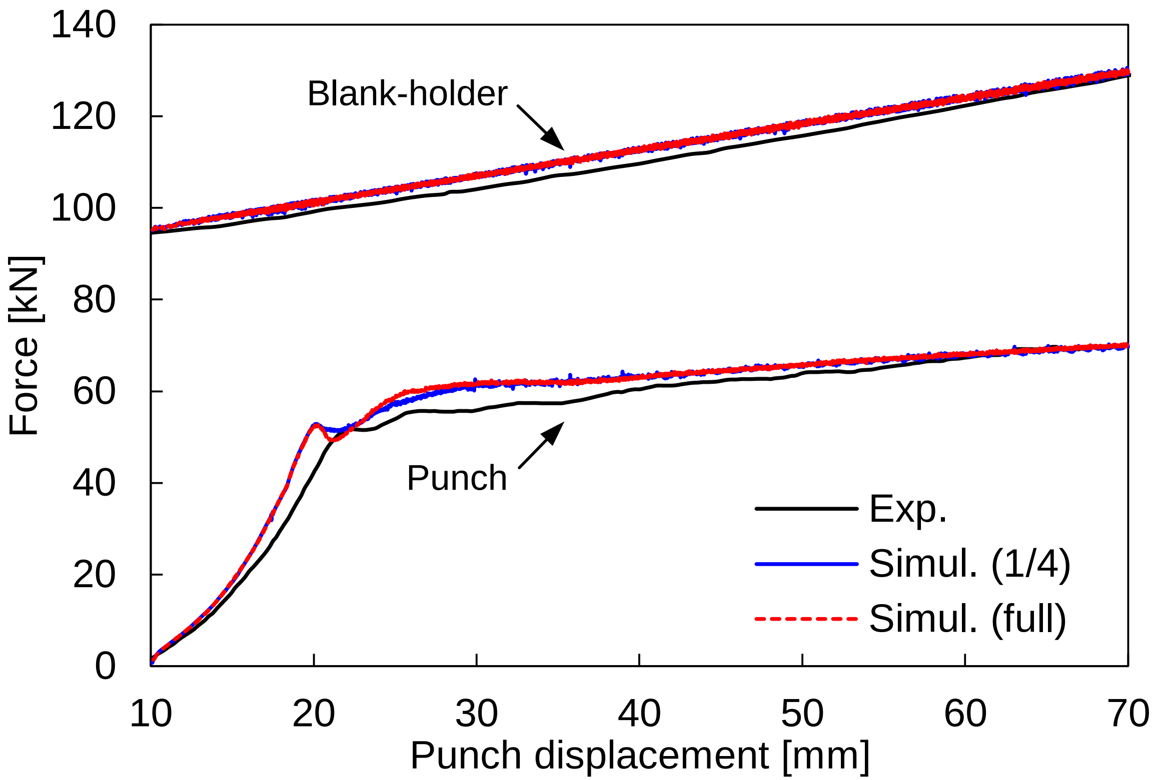
1/4 of the blank
32,500 finite elements

Forming forces

- Comparison between experimental and numerical force evolution



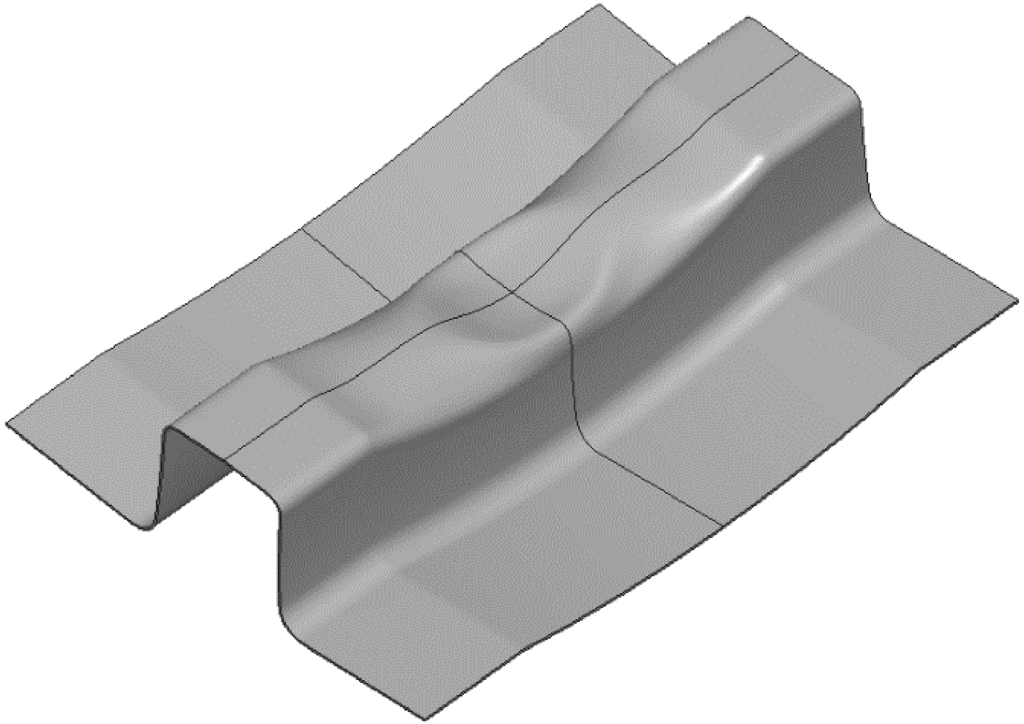
Mild steel (DC06)



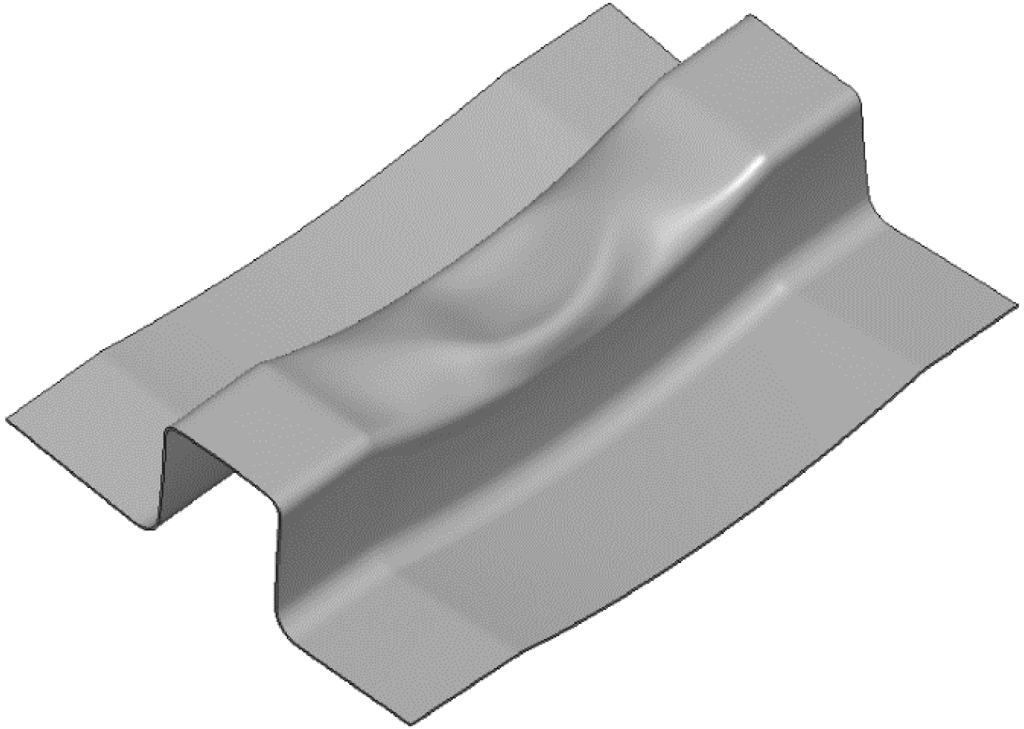
Dual phase steel (DP600)

Final geometry of the rail (DC06)

- Influence of applied symmetry conditions on the geometry of the wrinkles
- Asymmetrical wrinkle considering the full blank geometry



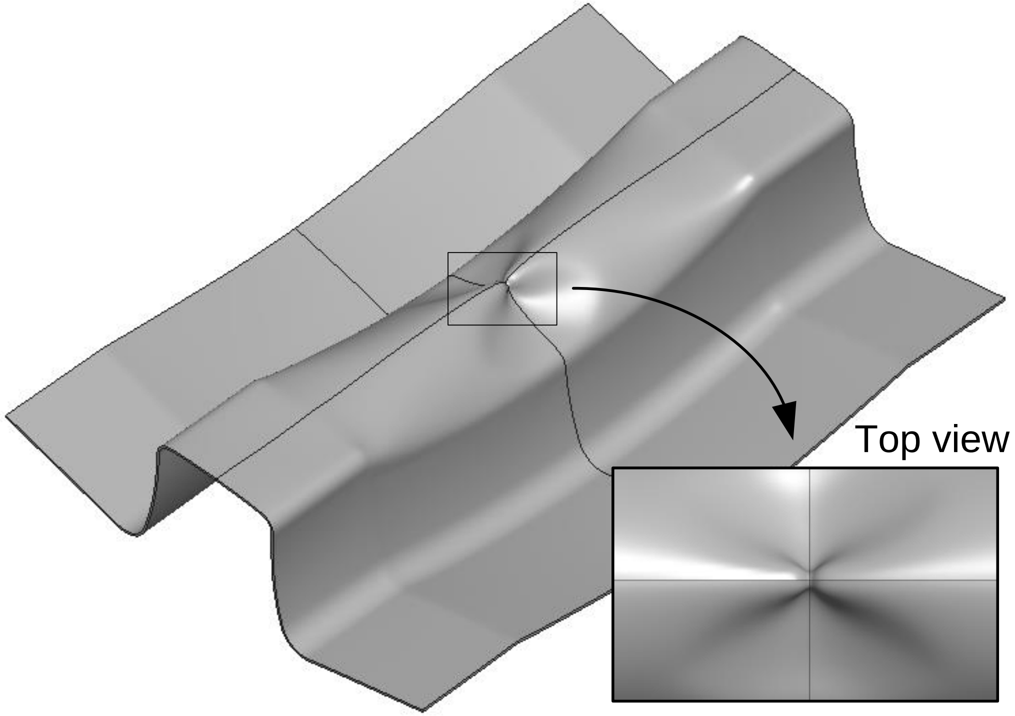
1/4 of the blank



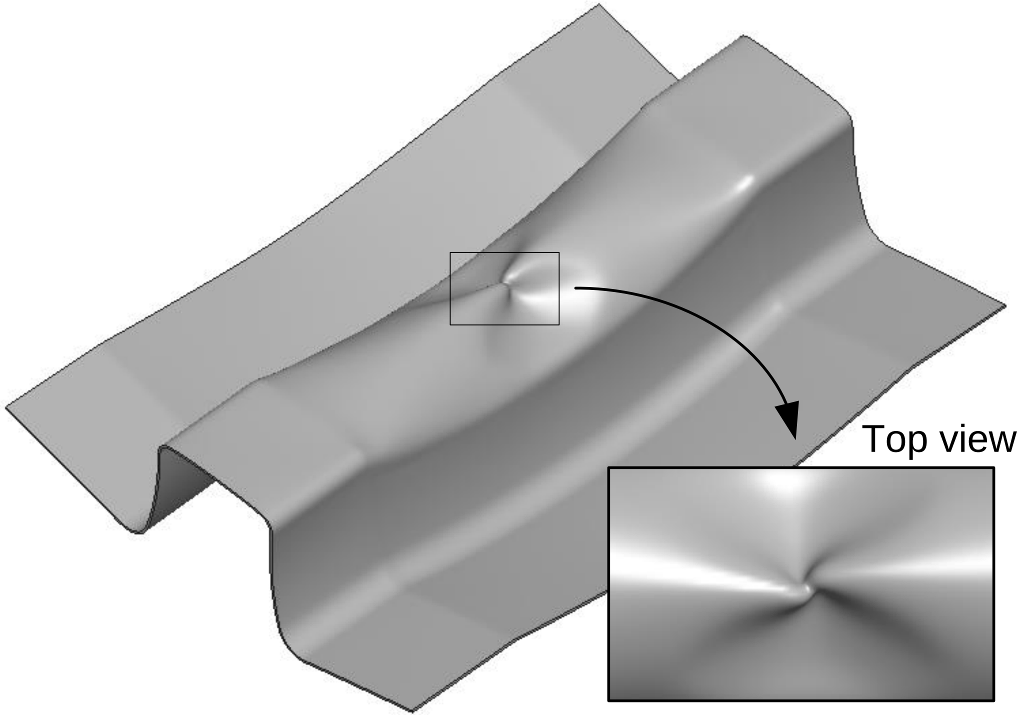
Full blank

Final geometry of the rail (DP600)

- Influence of applied symmetry conditions on the geometry of the wrinkles
- Anti-symmetrical wrinkle considering the full blank geometry



1/4 of the blank

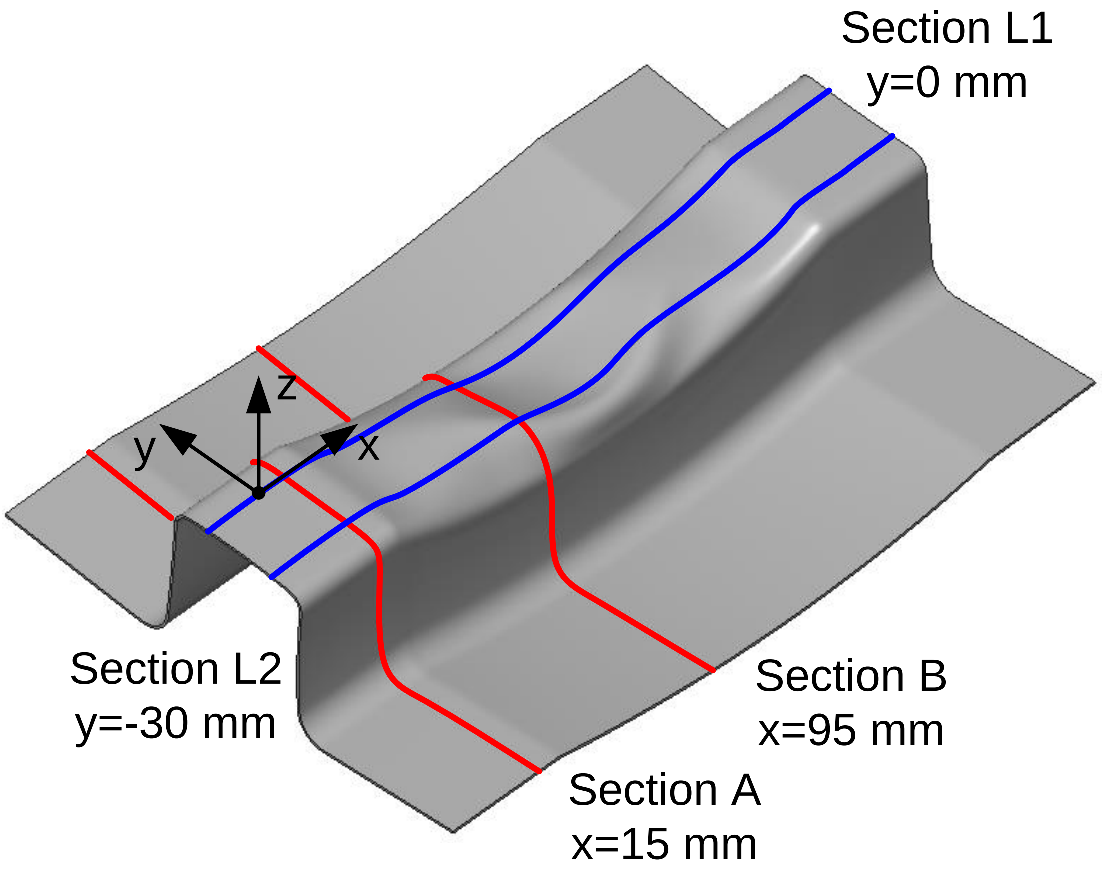


Full blank

Rail measurements

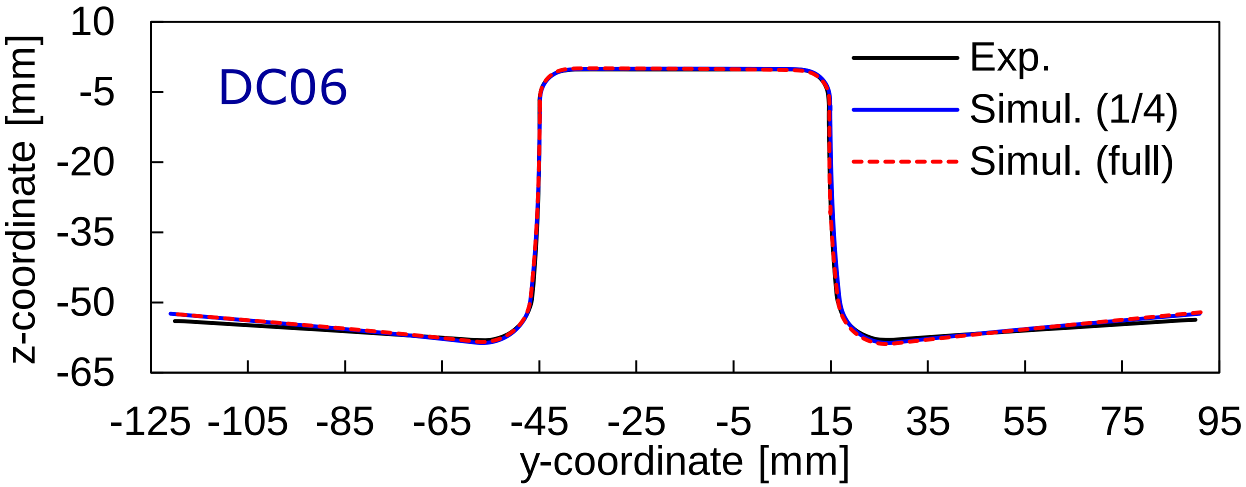
- Four section profiles of the rail are measured after springback, for each material

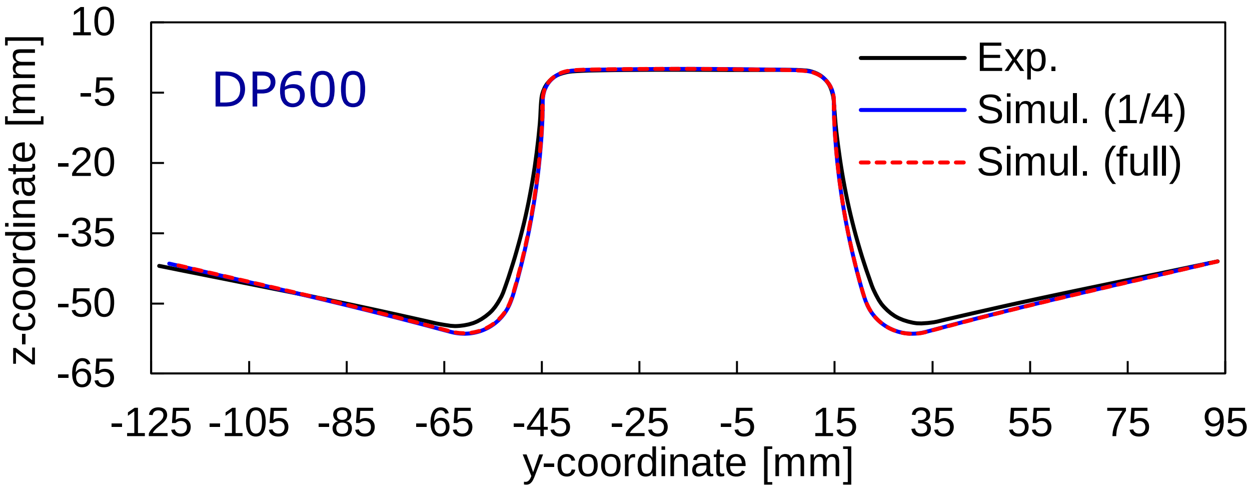
3D coordinate measuring machine

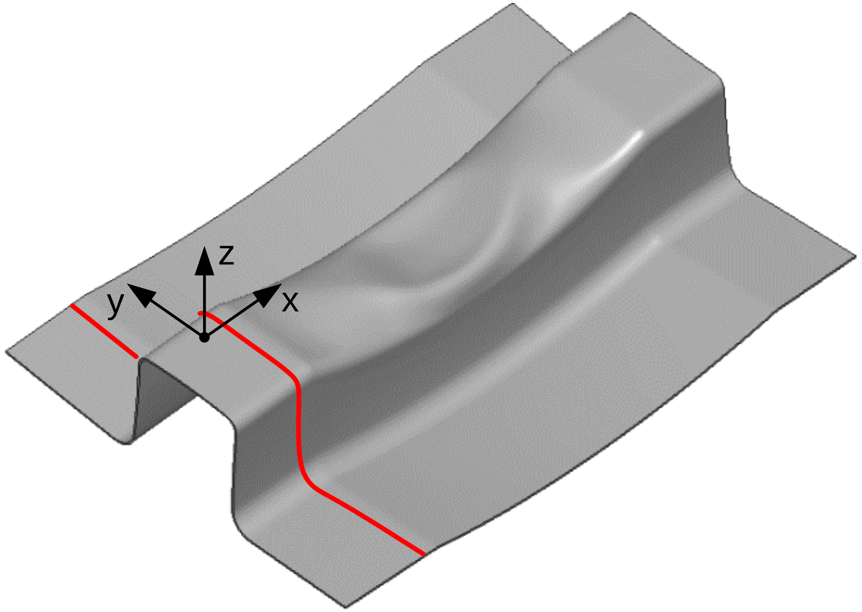


Section profile A (x=15 mm)

- Comparison between experimental and numerical section profile



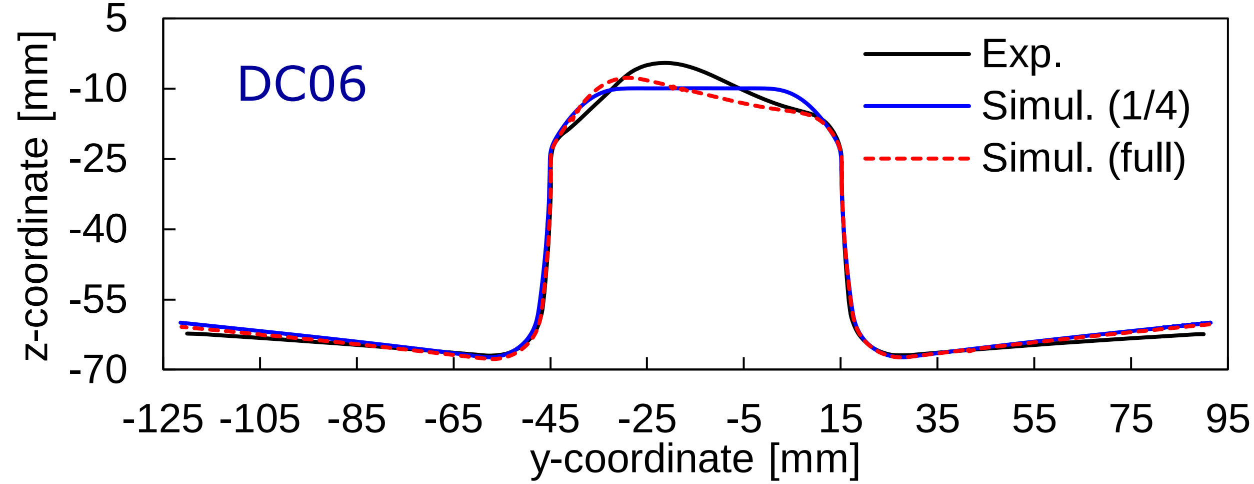


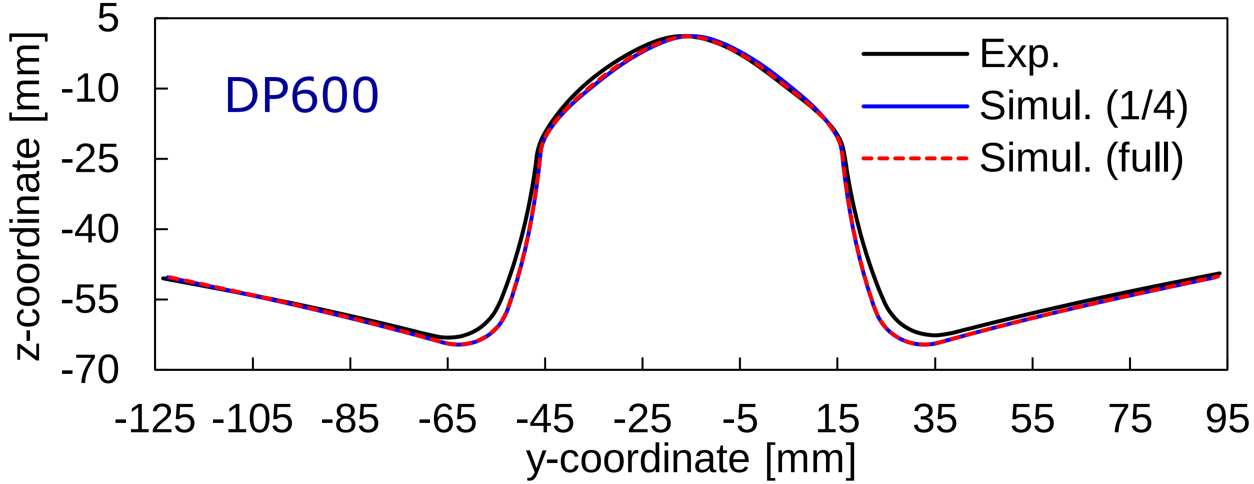


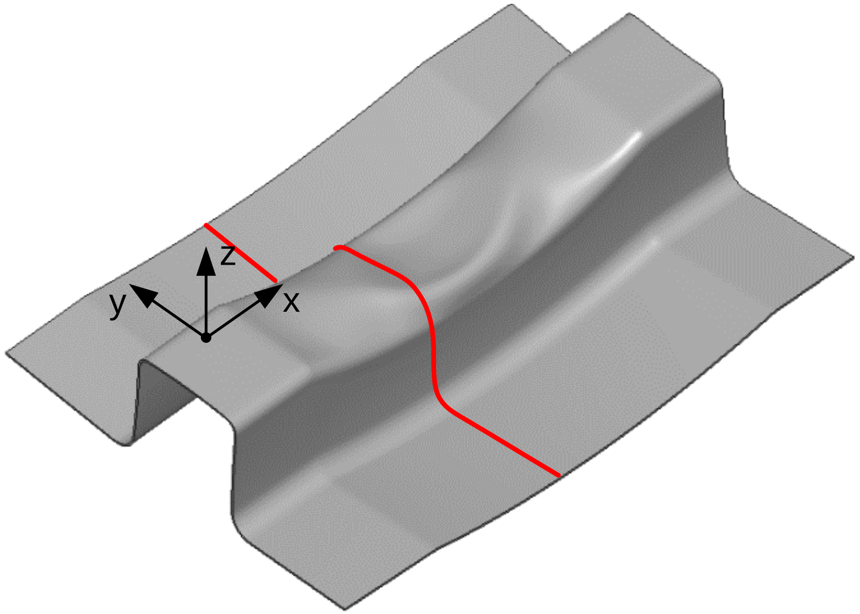
The springback is larger on the rail of high strength steel (DP600)

Section profile B (x=95 mm)

- Comparison between experimental and numerical section profile







Considering the mild steel, the two numerical models predict distinct geometries for the wrinkle

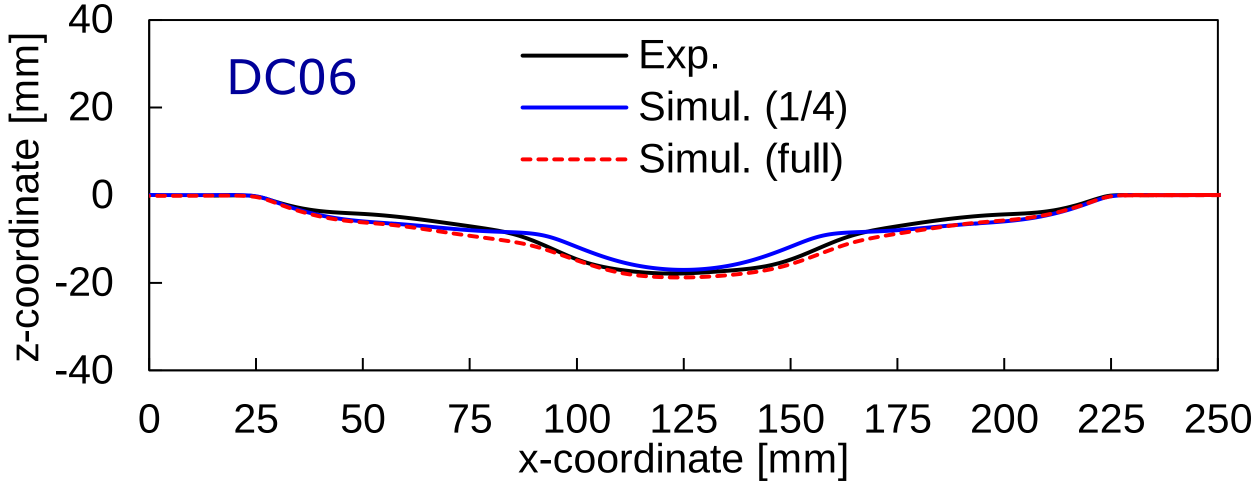
Springback angle of the flange

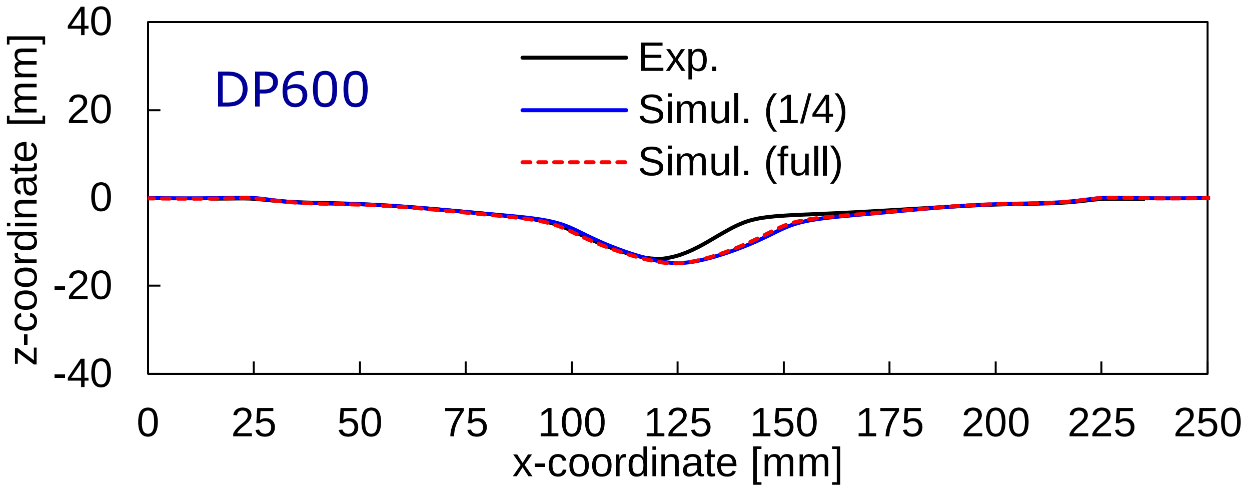
- Both finite element models provide identical predictions for the flange angle
- The springback is significantly larger on the rail of high strength steel (DP600)
- The springback angle is slightly overestimated by the numerical model

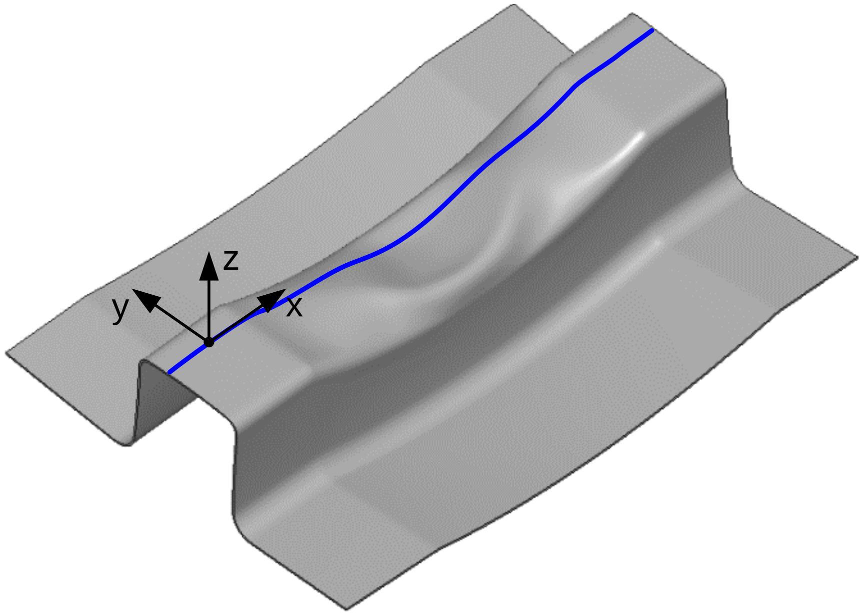
Material	Section A		Section B	
	Exp. [º]	Simul. [º]	Exp. [º]	Simul. [º]
DC06	3.8	5.1	3.9	6.2
DP600	11.9	13.6	11.7	12.6

Section profile L1 (y=0 mm)

- Comparison between experimental and numerical section profile







Considering the full blank geometry, the numerical predictions are in good agreement with the experimental measurements

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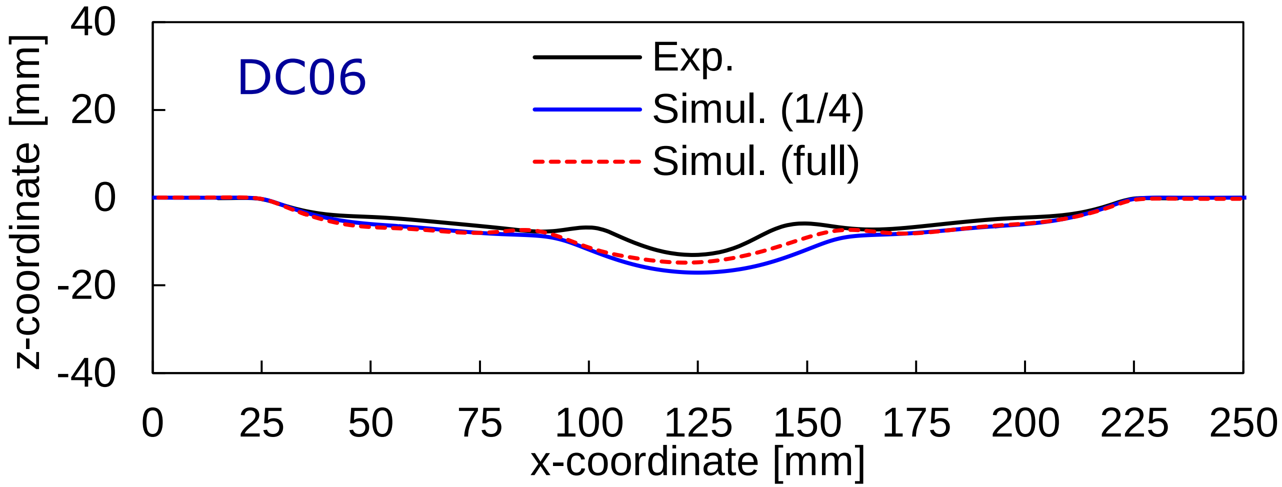
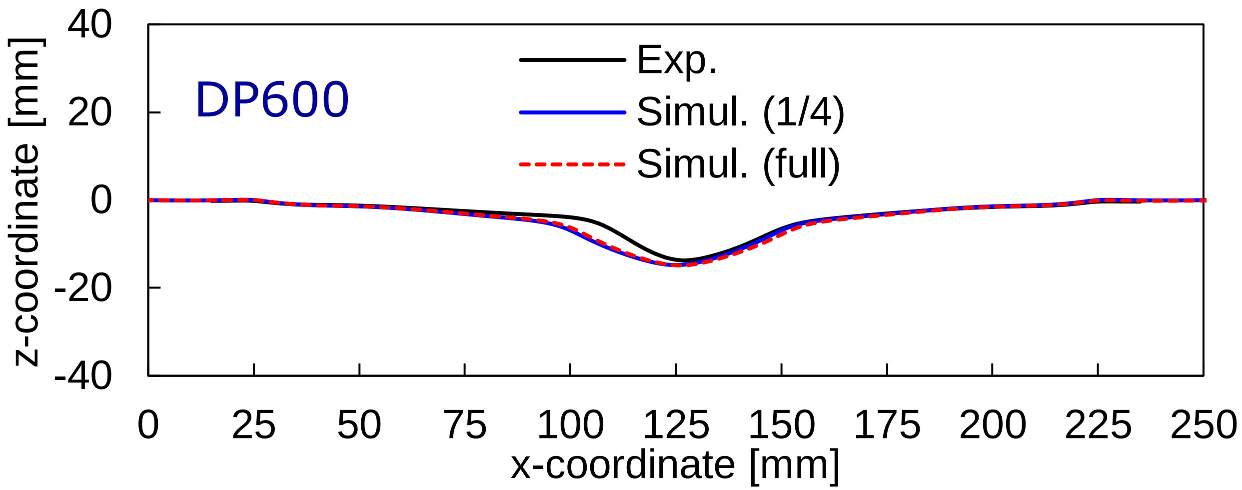
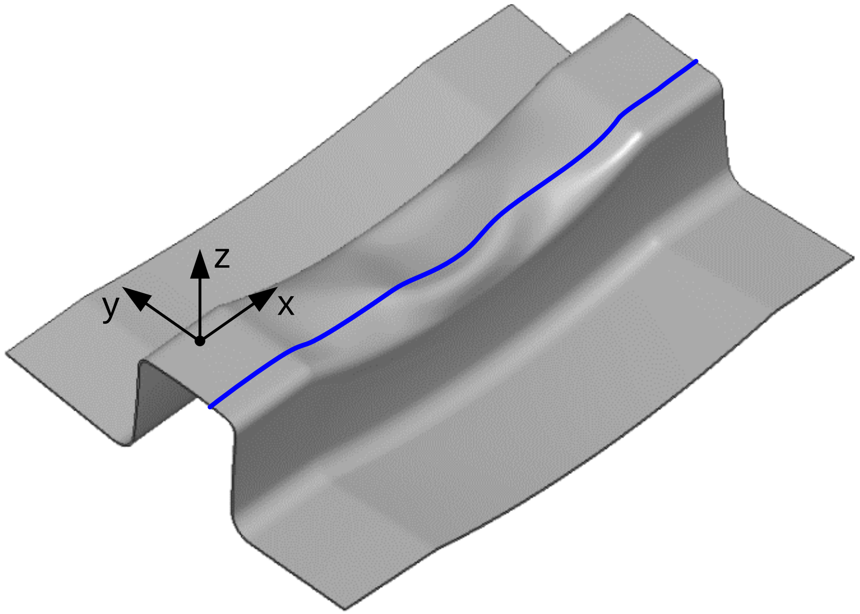
Section profile L2 (y=-30 mm)

- Comparison between experimental and numerical section profile







Considering the full blank geometry, the numerical predictions are in good agreement with the experimental measurements

Computational performance

- The full blank geometry leads to a significant increase of the computational cost
- The computational time of the numerical simulations is at least 10 times higher using the full blank
- The computational cost is significantly influenced by the material considered for the blank

	DC06		DP600	
	1/4 model	Full model	1/4 model	Full model
Nº increments	1823	4839	776	1544
Average nº iterations	9.4	8.4	10.1	9.1
Computational time [h]	30.3	384.7	10.0	105.7

Conclusions

- Influence of applied boundary conditions on the wrinkling prediction:
  - 1/4 of the blank geometry considering symmetry conditions
  - full blank geometry slightly rotated in relation to the forming tools
- Both finite element models provide identical results for the springback, but the shape of the wrinkle depends on the adopted numerical model
- The numerical results are in better agreement with the experimental ones when the full blank geometry is considered
- The computational cost considering the full blank is at least 10 times higher than using 1/4 of the blank

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THANK YOU!

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