Prediction of wrinkling and springback in sheet metal forming

D.M. Neto¹ • M.C. Oliveira¹ • J.L. Alves² • A.D. Santos³ • L.F. Menezes¹

¹CEMUC, Department of Mechanical Engineering, University of Coimbra, Portugal
²CMEMS, Department of Mechanical Engineering, University of Minho, Portugal
³FEUP, Faculty of Engineering, University of Porto, Portugal
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
Forming defects

New materials are more prone to develop forming defects:

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

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

![Graphs showing force evolution for Mild steel (DC06) and 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
Rail measurements

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

<table>
<thead>
<tr>
<th>Material</th>
<th>Section A</th>
<th>Section B</th>
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<tbody>
<tr>
<td>DC06</td>
<td>3.8</td>
<td>5.1</td>
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<tr>
<td>DP600</td>
<td>11.9</td>
<td>13.6</td>
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</table>
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.
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.

<table>
<thead>
<tr>
<th></th>
<th>DC06</th>
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<th>DP600</th>
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<tbody>
<tr>
<td></td>
<td>1/4 model</td>
<td>Full model</td>
<td>1/4 model</td>
<td>Full model</td>
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<tr>
<td>Nº increments</td>
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<td>4839</td>
<td>776</td>
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<td>8.4</td>
<td>10.1</td>
<td>9.1</td>
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<td>30.3</td>
<td>384.7</td>
<td>10.0</td>
<td>105.7</td>
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</table>
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
THANK YOU!
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