Sheet Metal Forming II

Prof. Dr.-Ing. F. Klocke

Simulation Techniques in Manufacturing

Sheet Metal Forming - Contents

- Modeling
  - Reasons for modeling
  - Connection: process modelling - process chain
- Simulation of Sheet Metal forming
  - Commercial FE codes for sheet metal forming
- Case Study
  - Part Evaluation: Step by step
  - Process optimisation by improved tool design
  - Evaluation of wrinkling
- Economical aspects of process modelling
Why process modelling?

- Manufacture complex parts
- Increase quality
- Increase reliability of production
- Apply new materials (Al, Mg, …)
- Use material more efficiently
- Reduction of tool cost
- Reduction of pre production trials
- Reduction of lead time
- Reduction of time required for training
- Increase reliability of production
- Increase reliability of production

Integration of process modelling into the process chain

- Design of car exterior
- Part design
- Means of production planning
- Tool design
- Tool manufacturing and testing
- Part production

Sheet metal forming simulation

- Part evaluation
- Process optimisation

Methods applied:
- 2D modelling
- One-step modelling
- Modelling with membrane elements
- Short computation time with sufficient precision

Methods applied:
- Simulation with membrane elements
- Simulation with shell elements
- High Precision within acceptable computation times
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Commercial FE codes for sheet metal forming

2D Modelling of selected cross sections:
- Abaqus www.abaqus.com
- Ansys www.ansys.com
- Autoform 2D www.autoform.ch
- Deform 2D www.deform.com
- Marc www.marc.com
- ...

Advantages:
- reduced computation time
- less sensitive to quality of input data
- usually less input data required

Disadvantages:
- difficult selection of cross sections to be modelled
- less accurate results

Source: BMW / Fontana Pietro SPA
Commercial FE codes for sheet metal forming

One-step simulation:

• Isopunch
• SIMEX
• Corps
• AutoForm Onestep
• ...

Advantages:
• reduced computation time
• usually less input data required
• suitable tool for part evaluation

Disadvantages:
• decreasing significance due to increasing computing power
• still not very accurate

Source: BMW

Commercial FE codes for sheet metal forming

Model with membrane elements:

• AutoForm Incremental
• Abaqus
• ...

Advantages:
• acceptable computation time
• suitable tool for part evaluation
• suitable for process optimisation
• basically accurate results

Disadvantages:
• long computation time
• problems when severe bending occurs
• not accurate enough in predicting wrinkles
• requires high quality input data

Source: BMW
Modeling

- Reasons for modeling
- Connection: process modelling - process chain

Simulation of Sheet Metal forming

- Commercial FE codes for sheet metal forming

Case Study

- Part Evaluation: Step by step
- Process optimisation by improved tool design
- Evaluation of wrinkling
- Economical aspects of process modelling
Part Evaluation: One step method

Steps:

1) Create mesh from 3D CAD model
2) create blank holder
3) simplified add-on
4) computation
5) interpretation of results

Source: BMW
Part Evaluation: One step method

Steps:

1) Create mesh from 3D CAD model
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1) Create mesh from 3D CAD model
2) create blank holder
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4) computation
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Source: BMW

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Case study: Process optimisation by improved tool design

Source: BMW
Process optimisation: Tool design

Source: BMW

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Process optimisation: Material data

<table>
<thead>
<tr>
<th>Young's modulus</th>
<th>Transverse shear correction factor</th>
<th>2.1e+05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poisson's ratio</td>
<td></td>
<td>0.29</td>
</tr>
<tr>
<td>Thickness</td>
<td></td>
<td>0.1</td>
</tr>
<tr>
<td>Out of plane hourglass coefficient</td>
<td></td>
<td>0.01</td>
</tr>
<tr>
<td>Rotation hourglass coefficient</td>
<td></td>
<td>0.01</td>
</tr>
</tbody>
</table>

Integration rule: Uniform

Hill's criterion: Standard

Lankford coefficient for normal anisotropy: -1

Vector / to rolling direction:

<table>
<thead>
<tr>
<th>X</th>
<th>Y</th>
<th>Z</th>
</tr>
</thead>
</table>

strain rate parameters:

1  2  3  4  5  6

Yield Stress: 171

Hardening curve:

<table>
<thead>
<tr>
<th>Tangent modulus</th>
<th>Stress</th>
</tr>
</thead>
<tbody>
<tr>
<td>2100</td>
<td>250</td>
</tr>
<tr>
<td>1500</td>
<td>280</td>
</tr>
<tr>
<td>900</td>
<td>314</td>
</tr>
<tr>
<td>999</td>
<td>372</td>
</tr>
<tr>
<td>530</td>
<td>405</td>
</tr>
<tr>
<td>175</td>
<td>440</td>
</tr>
<tr>
<td>79</td>
<td>461</td>
</tr>
</tbody>
</table>

Source: BMW

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Process optimisation: Process parameters

![Diagram of process parameters](image)

Source: BMW

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Process optimisation: Numerical parameters

![Diagram of numerical parameters](image)

Source: BMW
Process optimisation: Forming process

- CAD-data tool & blank
- Process data
- Numerical data
- Material-data

Meshing

GENERIS

PAM-Stamp Input file

Source: BMW

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Process optimisation: Forming sequence

Source: BMW
Process optimisation: Forming sequence

Source: BMW
Process optimisation: Forming sequence
Process optimisation: Forming sequence

Source: BMW
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Case study: Evaluation of wrinkling

Source: BMW

Distribution of effective strain during and after the drawing process
Process optimisation: Evaluation of wrinkling

distribution of effective stress during and after the drawing process

Source: BMW

Process optimisation: Comparison between simulation and real part

wrinkling

Source: BMW
Process optimisation: Comparison between simulation and real part

rupturing

Source: BMW

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Modelling sheet metal forming: Quality of the computed results

<table>
<thead>
<tr>
<th>Result</th>
<th>Quality qualitatively</th>
<th>Quality quantitatively</th>
</tr>
</thead>
<tbody>
<tr>
<td>rupture</td>
<td>++</td>
<td>+</td>
</tr>
<tr>
<td>wrinkles</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>springback</td>
<td>+</td>
<td>0</td>
</tr>
</tbody>
</table>

Flow chart of a modelling project

Part design Part geometry → Material selection → tools (CAD) → Process parameters → Simulation → Simulation all

Start tool design yes

no
Effort for a sheet metal modelling project

<table>
<thead>
<tr>
<th>Change of</th>
<th>responsible</th>
<th>effort CAD</th>
<th>effort Simulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process parameters</td>
<td>Process design</td>
<td>----</td>
<td>1h -- 3h</td>
</tr>
<tr>
<td>(friction, beads, ...)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>die setup (blank holder, etc. ...)</td>
<td>Process design</td>
<td>1d -- 1w</td>
<td>3h -- 1d</td>
</tr>
<tr>
<td>Material quality and thickness</td>
<td>Body design</td>
<td>----</td>
<td>1h -- 3h</td>
</tr>
<tr>
<td>Part geometry</td>
<td>Body design</td>
<td>1d -- 1w</td>
<td>3h -- 1d</td>
</tr>
</tbody>
</table>

Total effort for a medium sized part: Usually 2 weeks

Source: BMW

Preprocessing effort for a modelling project in sheet metal forming

![Graph showing effort for preprocessing from 1993 to 2000](image)

Source: BMW
Development of computing power and computation time

Increase of computing power

1993: 20% → 2000: 100%

Reduction of computation time for a large car body part

1993: 50h → 2000: 15h

Development of hardware cost

1993: 100% → 2000: < 1%

Source: BMW
Prerequisites for the industrial application of process modeling

<table>
<thead>
<tr>
<th>Time:</th>
<th>Cost:</th>
<th>Quality:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short response times</td>
<td>Low project</td>
<td>Reliable results</td>
</tr>
<tr>
<td></td>
<td>cost</td>
<td></td>
</tr>
</tbody>
</table>

Integration into the process chain of a car body

Source: BMW

Simulation of crashworthiness for the Ford Explorer (LS-Dyna)

Source: Livermore Software Technology