Thermo-mechanical coupled simulation of hot forming processes considering die cooling

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Agenda

1. Motivation
2. Objectives
3. State of the art
4. Considering die cooling
   1. Methods
   2. Experimental tool
   3. Mass production tool
5. Conclusions and outlook
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Deployment of hot formed high strength steels

Motivation

Yield strength

- ≤ 140 MPa: 15%
- 180 - 240 MPa: 18%
- 260 - 300 MPa: 25%
- 300 - 420 MPa: 30%
- ≥ 1000 Mpa: 12%

15% of hot formed steel

source: Cordes et. al. EuroCarBody Award 2005
**Example – hot formed parts – B-pillar**

**Motivation**

- **Audi A4**
  - Outer: hot formed tailored blank
  - Inner: HSS (conventional)

- **VW Tiguan**
  - Outer: partially press hardened
  - Inner: HSS

- **VW Passat CC**
  - Inner: HSS tailored blank
  - Outer: hot formed

- **Audi Q5**
  - Inner: HSS

Source: Thiele/Hahn/Lamprecht/Hahn

as of 11/12/09

Group research: K-EFW/F (M. Medricky)
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Objectives

Today
- Part development
- Method
- Hot forming simulation
- Experimental tool
- Construction
- Mass production tool

Future
- Part development
- Method
- Hot forming simulation with cooling system
- Construction
- Mass production tool

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group research: K-EFW/F (M. Medricky)
Frontloading and achievable benefits

Objectives

- Virtual optimization of the tool design
- Reducing try out through frontloading effects (time, cost)
- Optimizing process time (quenching)
- Virtual tuning of local material properties (quality)

source: Liebig
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State of the art

Cooling design

Cooling simulation

Coupling

Thermal simulation

Energy dissipation

Thermal strains

Mechanical simulation

Coupling

Phase transition

Material properties

Material law

Yield loci, flow curve, r-values, strain rate, ...

Transitional values

Emissivity, conductivity, specific heat

Friction

State of the art

Material law

CCT - diagramm, ...
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Sensitivity analysis
Considering die cooling

resultant temperature in single node

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contact pressure (MPa)</td>
<td>1, 5, 10, 15, 20, 25, 30, 35, 40</td>
</tr>
<tr>
<td>Thermal conductivity (W/mK)</td>
<td>1, 5, 10, 20, 50, 66, 80, 110, 130</td>
</tr>
<tr>
<td>Thermal convection (W/m²K)</td>
<td>1, 50, 500, 1000, 6000, 9000, 20000, 50000</td>
</tr>
</tbody>
</table>
Example – after 20 s of quenching
Considering die cooling
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Die model generation

Methods

1. Die surface geometry accurately modeled with shell elements
2. Die volume geometry modeled with volume elements
3. Shell and volume mesh coupled with contact definition

Heat transfer from blank to die surface shell by thermal contact

Heat dissipation into the dies by thermal contact between shell and volume mesh
Solution methods

Methods

- Cooling simulation starts with the final geometry of the forming simulation
- 3 different solution methods are possible

1. Thermal only simulation; tools rigid and fixed
2. Thermal-mechanical coupled with rigid tools; tool is loaded with force
3. Thermal-mechanical coupled with elastic tools; tool is loaded with force

- All methods can use contact between tool surface and volume
Cooling channels

Methods

• There are different possibilities to account for cooling passages

  • Temperature boundary condition
  • Convective boundary condition
  • Application of new bulkflow feature
  • Convective heat transfer coefficients
  • From CFD simulation

• Bulkflow feature is the simplest way to consider cooling systems in a thermal die analysis
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Experiments

Experimental tool

- Variation of several process parameters within the process chain
- Variation of tool material / cooling and heating etc.
- Analysis of measuring data, mechanical properties, microstructure etc.
Simulation model
Experimental tool

• Developing a process on the simplified model
• Revealing and eliminating possible problems
• Comparing with the real process
• Evaluation of the results
• Deriving the process for mass production tool
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Functional description – splitting the hot forming process

Mass production tool

In reality one process step at one machine

- Heating up
- Transfer
- Gravity
- Closing
- Pressing + Quenching
- Opening
- Removing
- Waiting
- Repeating the cycle
Procedure – Building the simulation model
Mass production tool

- Removing unnecessary parts like clamping and intermediate plates, frames, bolts, nuts, pipes, sealing, pads, fixtures, etc…
- Deleting small unimportant holes for bolts and handles
- Exporting in the IGES format
- Meshing in Hypermesh, Medina, and finishing in LS-Dyna
- Building the LS-Dyna Model
Pitfalls – Building the simulation model
Mass production tool

- High complexity of the CAD models - necessity of cleaning from unnecessary parts

- Complexity of the cooling channels - necessity of partial simplification

- Application of Bulkflow elements not possible - nonsymmetric matrix resulting in too much memory requirement - necessity of applying the convection cooling method

- The thermal tied contact simplifies the meshing process – experience for obtaining satisfactory results necessary
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Conclusions and Outlook

- Demand for precision increase in prediction of hot formed part properties
- Development of simulation process containing cooling systems
- Creation of experimental tool model and examining the method feasibility
- Creation of mass production tool model and examining the method feasibility
- Thermal tied contact for meshing simplification is applicable
- Bulkflow not applicable for complex tools
- Convection heat transfer in cooling channels used instead
- Comparison with the real mass production process
- Further development of the bulkflow method
Thank you