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


**M. Medricky[1], R. Struck[1], C. Sunderkötter[1], D. Lorenz[2], P. Olle[3], B.-A. Behrens[3]**

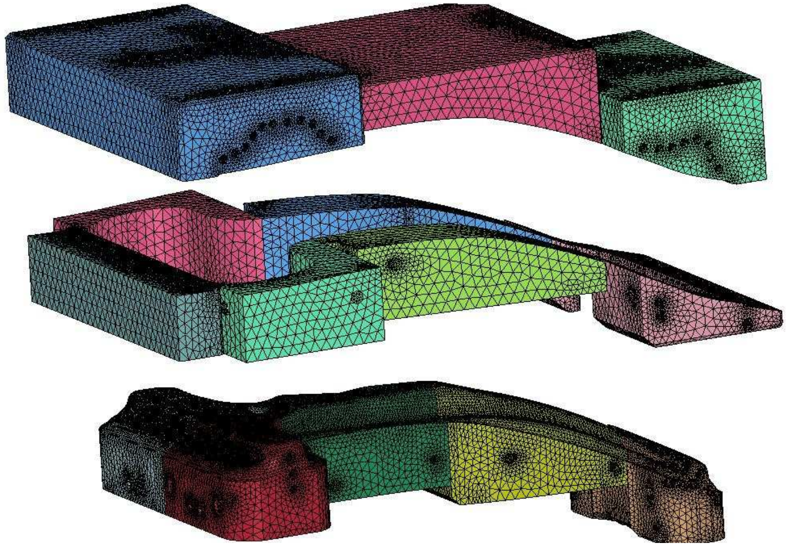
[1] Volkswagen Group Research, Wolfsburg

[2] DYNAmore GmbH, Stuttgart

[3] Institute of Metal Forming and Metal-Forming Machines, Hannover

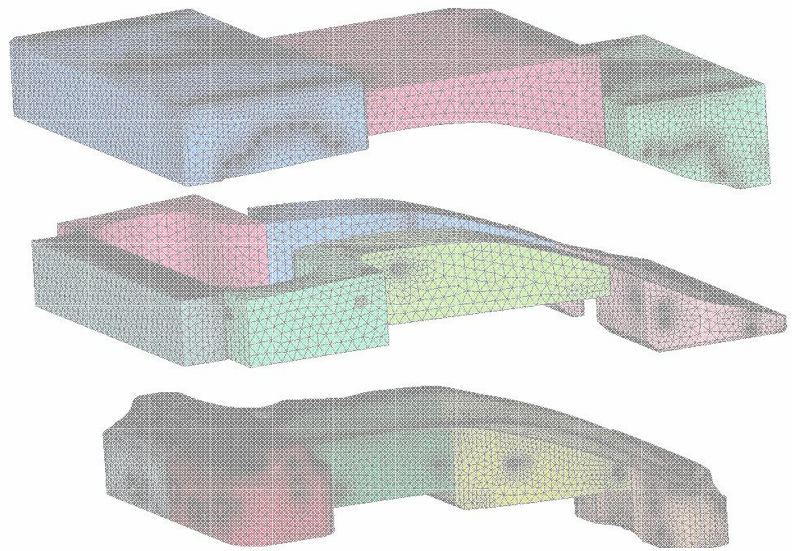
# Agenda

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



# 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

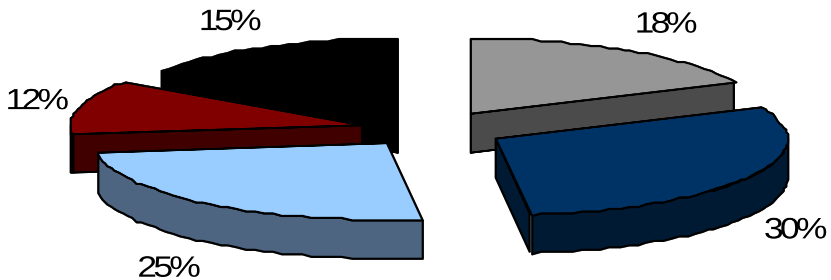


# Deployment of hot formed high strength steels

## Motivation

### Yield strength

- ≤ 140 MPa
- 180 - 240 MPa
- 260 - 300 MPa
- 300 - 420 MPa
- ≥ 1000 Mpa




percent by weight

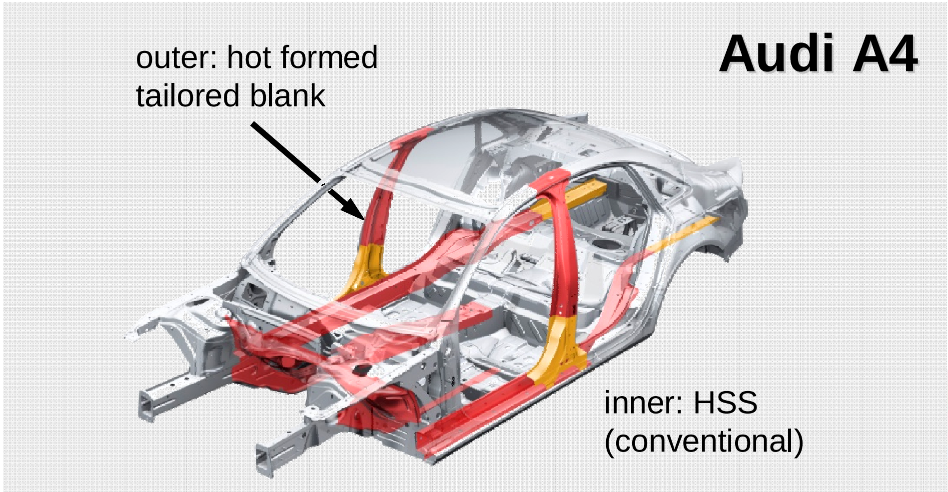
**! 15 % of hot formed steel**

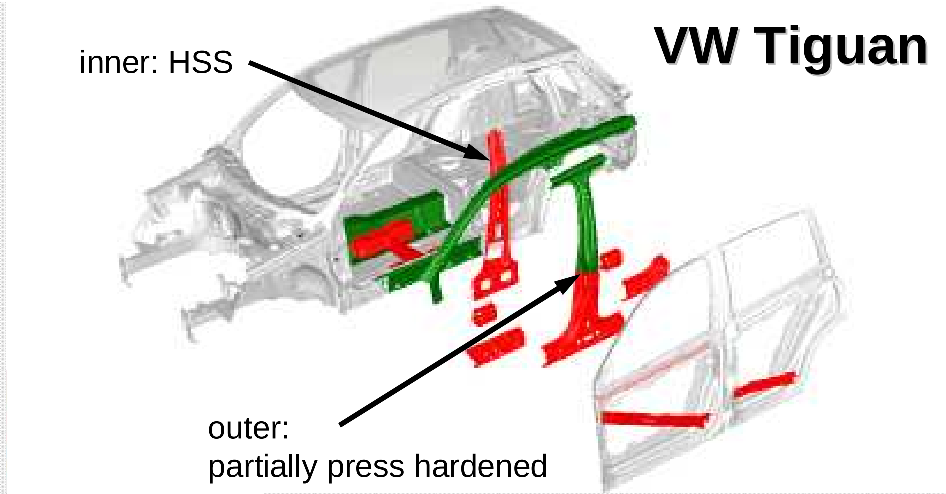
VW Passat B6

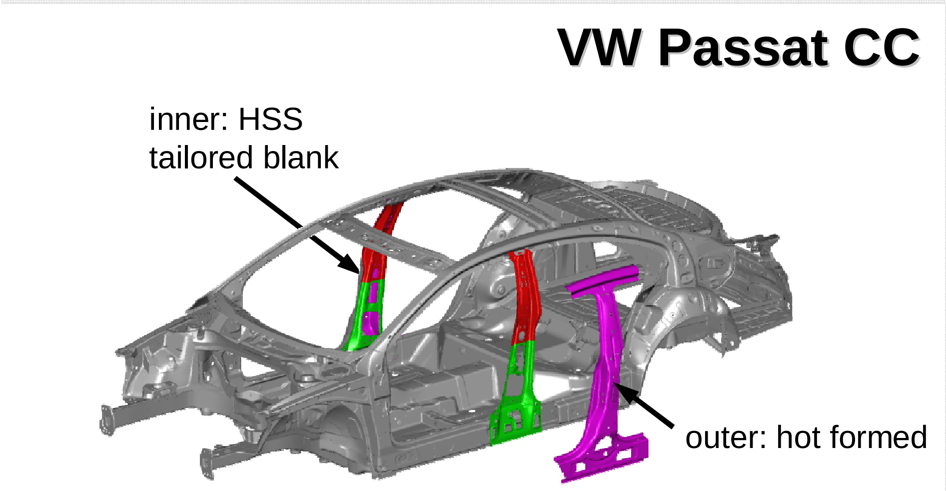
source: Cordes et. al. EuroCarBody Award 2005

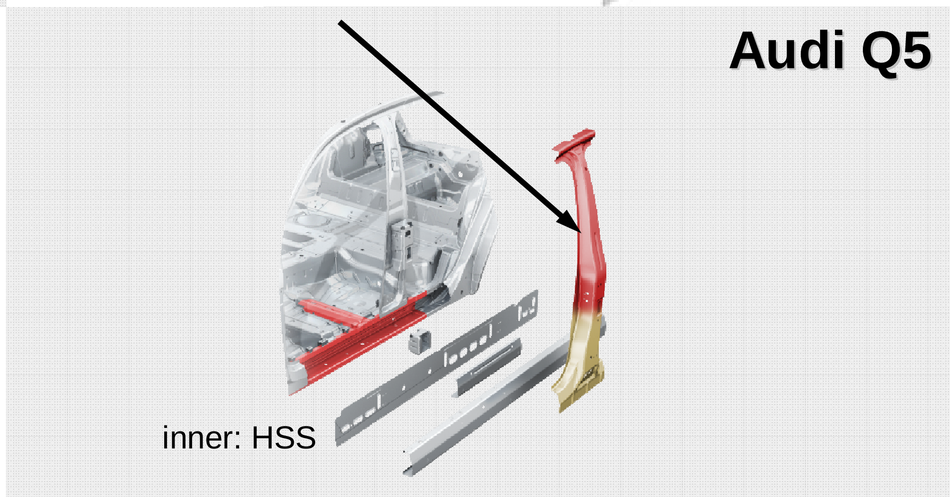
# Example – hot formed parts – B-pillar

## Motivation



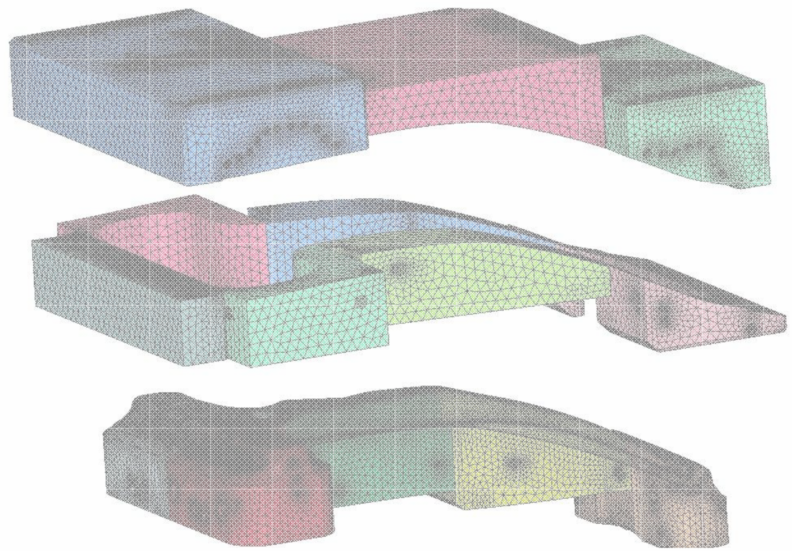



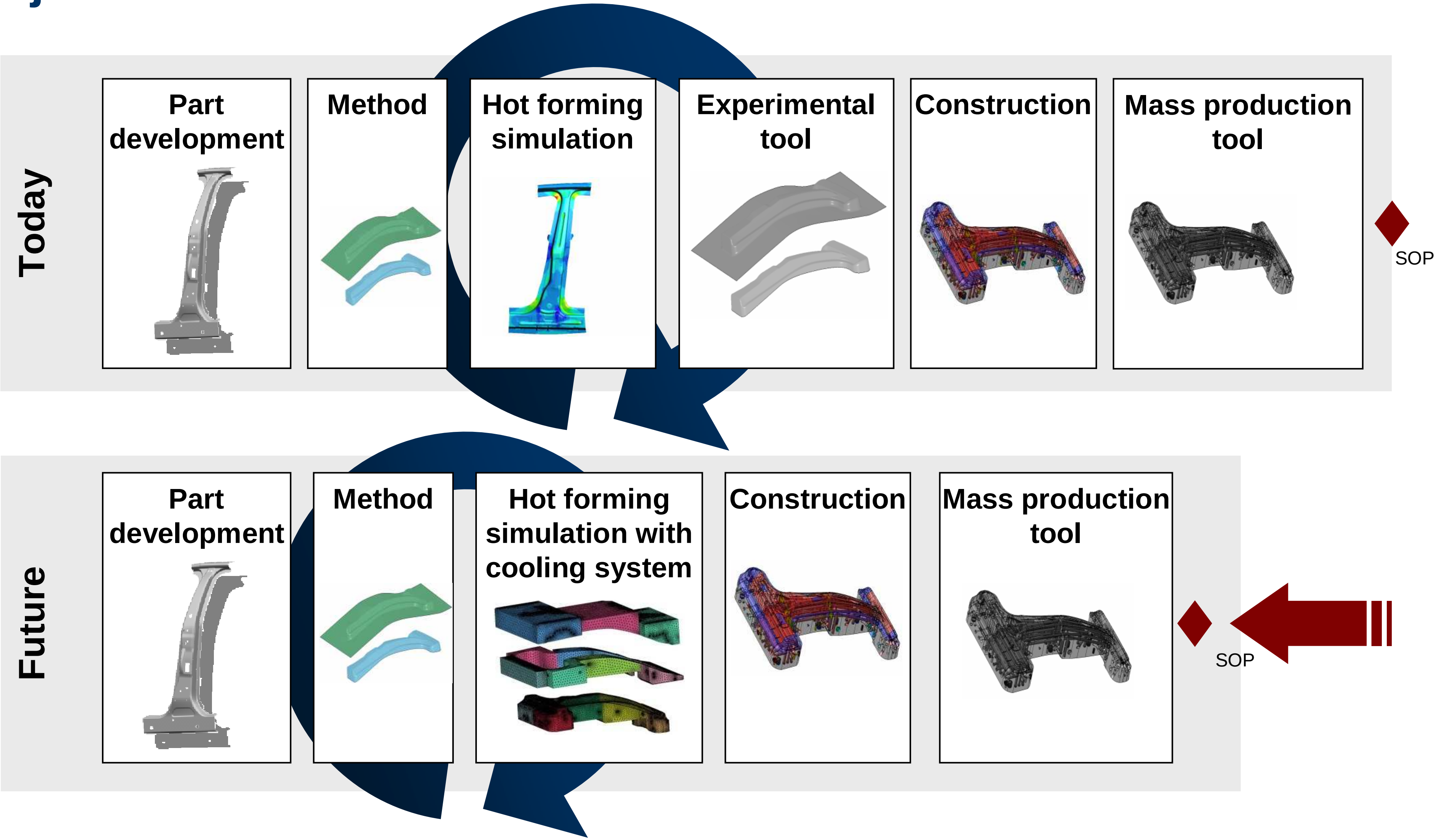

*source: Thiele/Hahn/Lamprecht/Hahn*

# 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

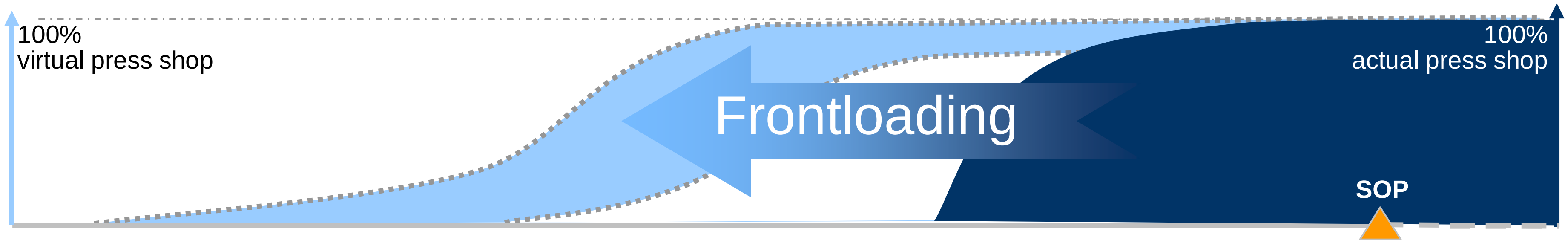


# Objectives


Today
Part development
Method
Hot forming simulation
Experimental tool
Construction
Mass production tool
SOP
Future
Part development
Method
Hot forming simulation with cooling system
Construction
Mass production tool
SOP

# Frontloading and achievable benefits

## Objectives

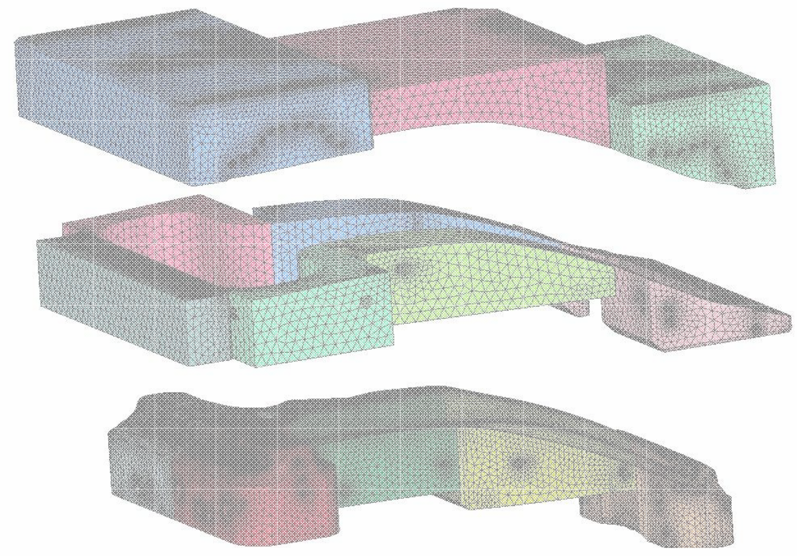



*source: Liebig*

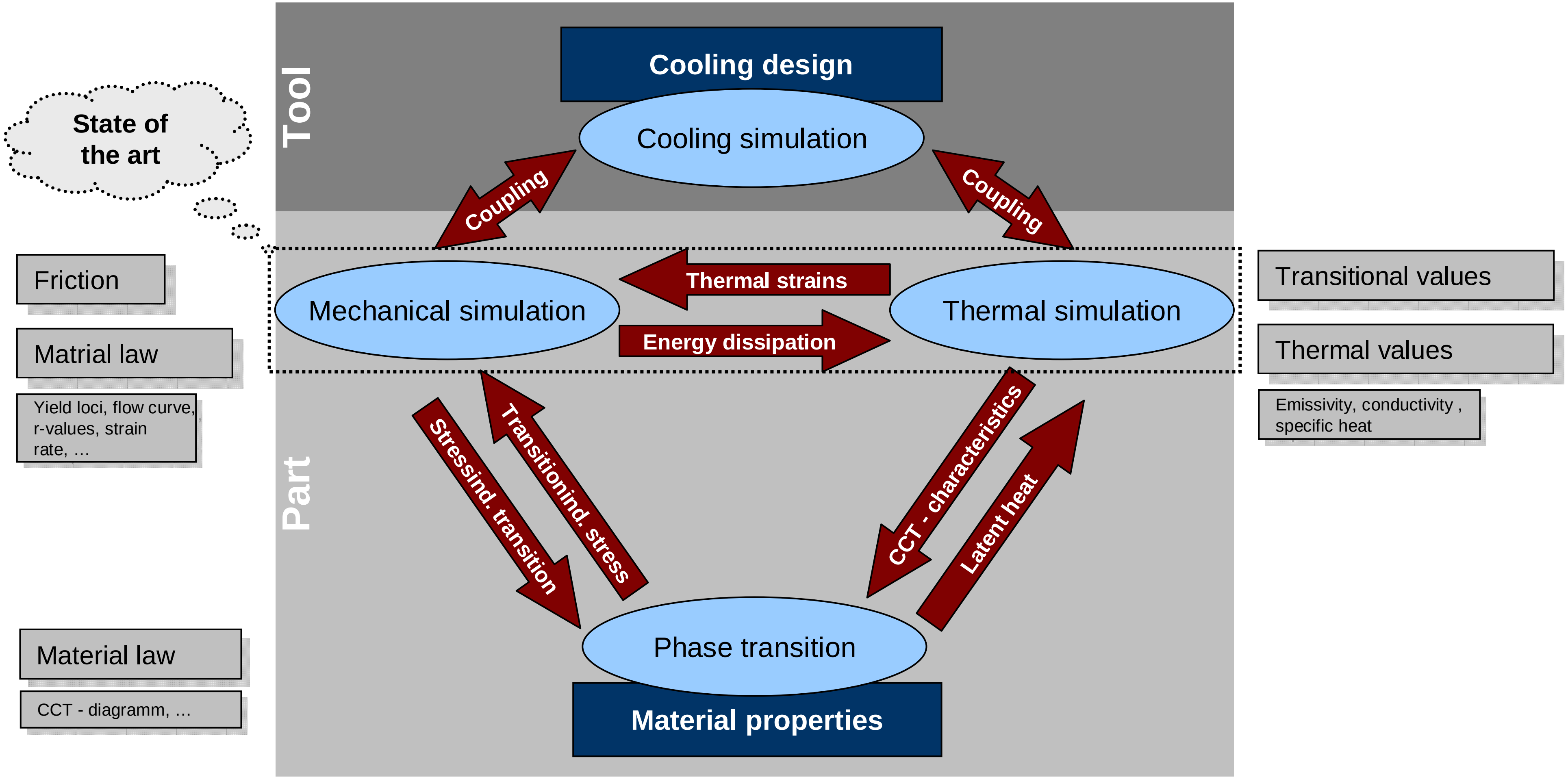

- Virtual optimization of the tool design
- Reducing try out through frontloading effects (time, cost)
- Optimizing process time (quenching)
- Virtual tuning of local material properties (quality)

# 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



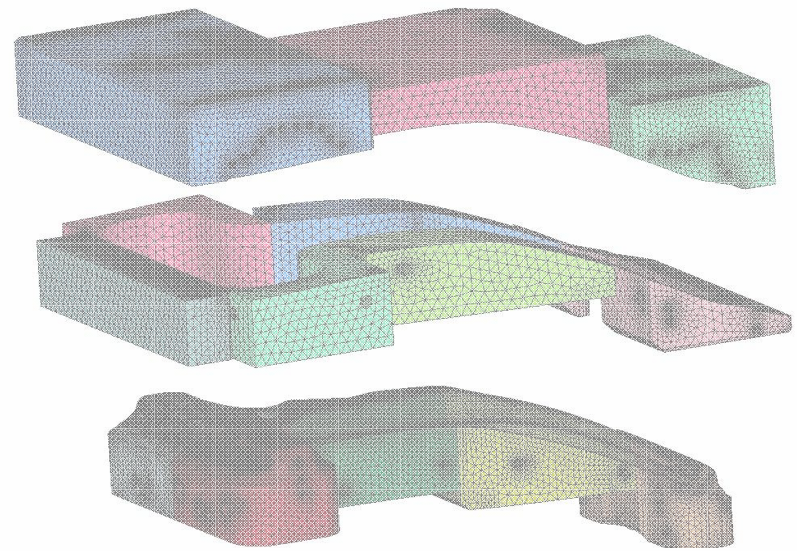
# State of the art



VOLKSWAGEN
AKTIENGESELLSCHAFT

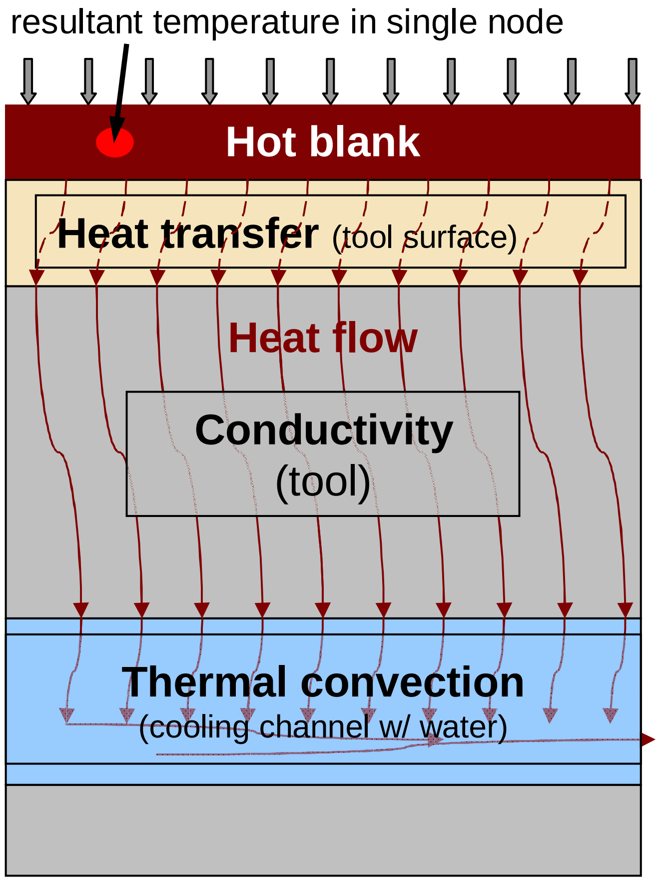
# Agenda

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



# Sensitivity analysis

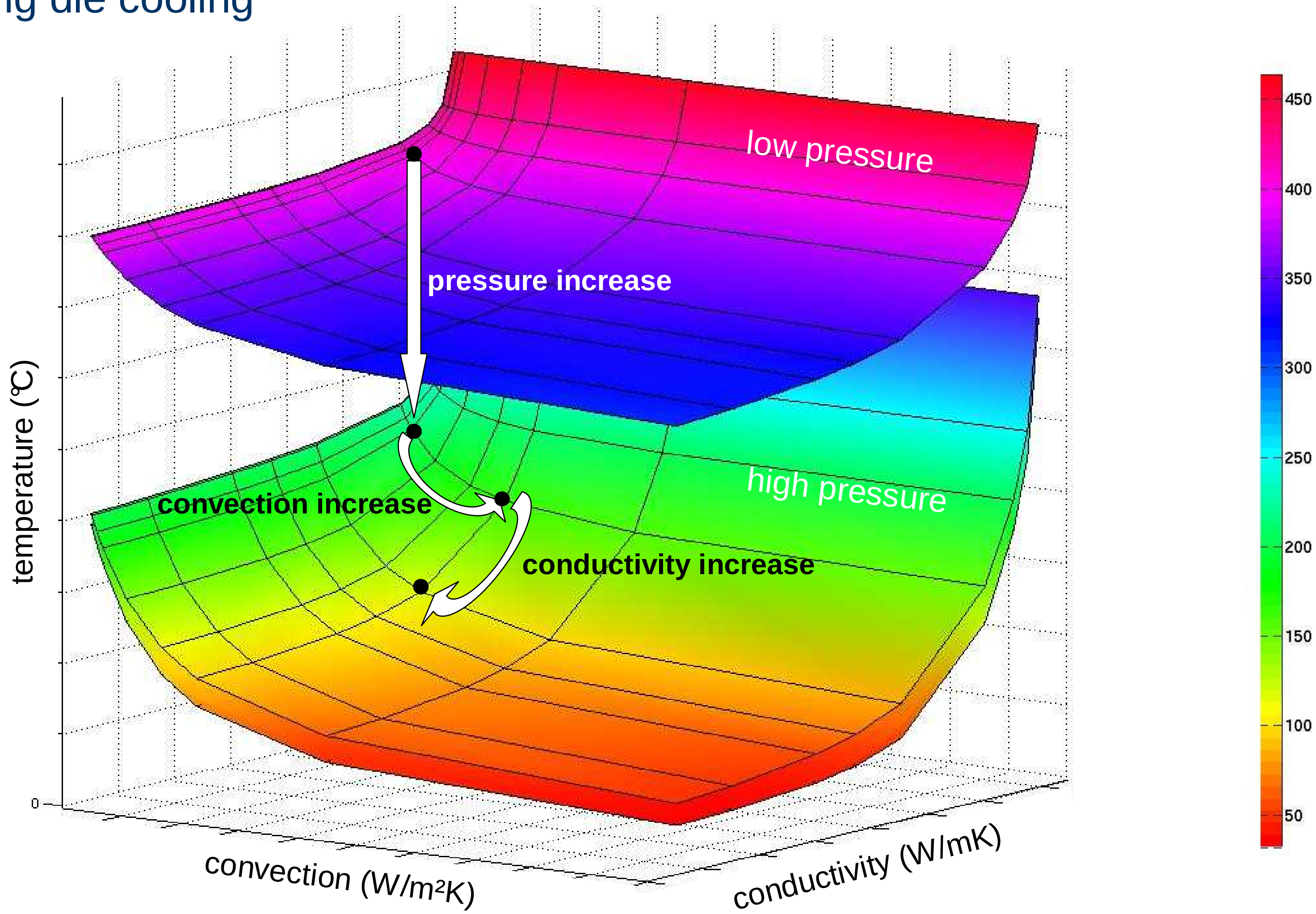
## Considering die cooling




| Parameter | Values |
|---|---|
| Contact pressure (MPa) | 1, 5, 10, 15, 20, 25, 30, 35, 40 |
| Thermal conductivity (W/mK) | 1, 5, 10, 20, 50, 66, 80, 110, 130 |
| Thermal convection (W/m²K) | 1, 50, 500, 1000, 6000, 9000, 20000, 50000 |

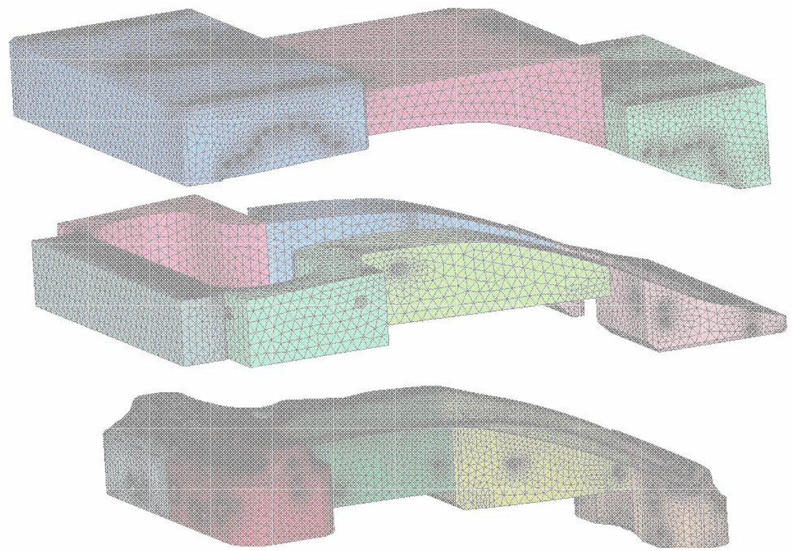
# Example – after 20 s of quenching

## Considering die cooling



# Agenda

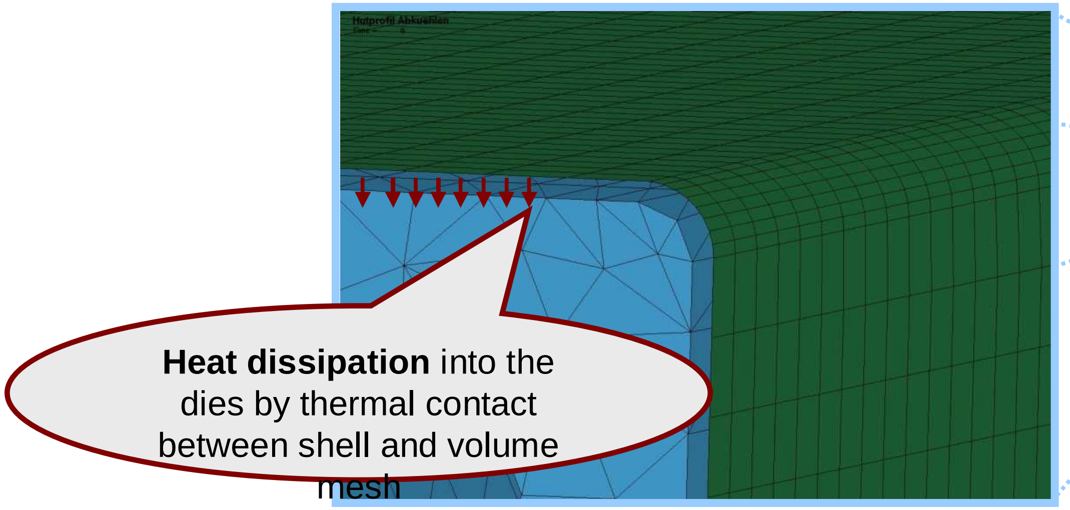
1. Motivation
2. Objectives
3. State of the art
4. Considering die cooling
    1. Methods
    2. Experimental tool
    3. Mass production tool
5. Conclusions and outlook

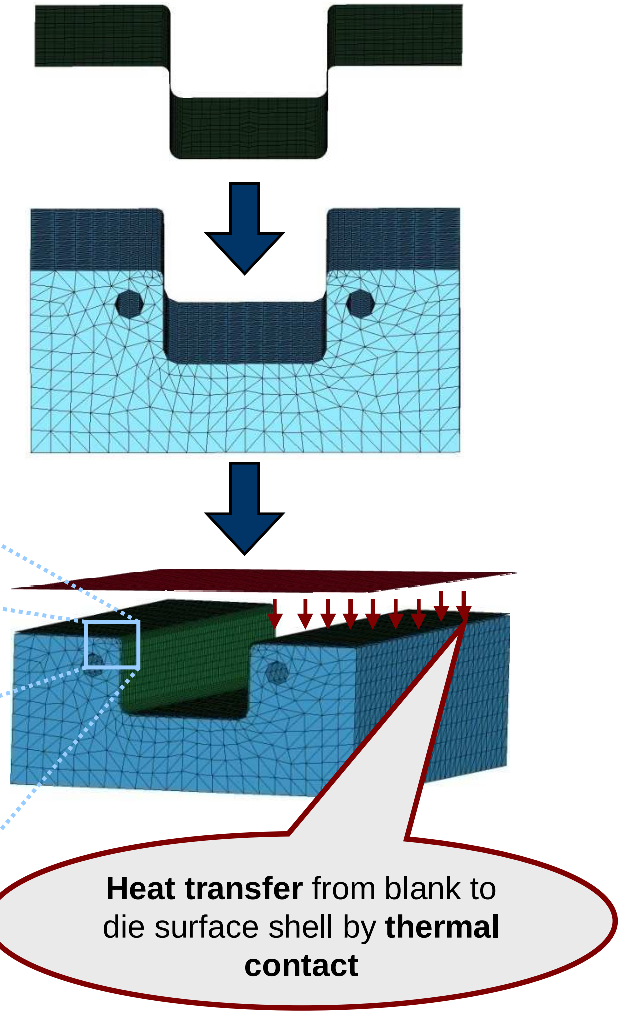


# Die model generation

## 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



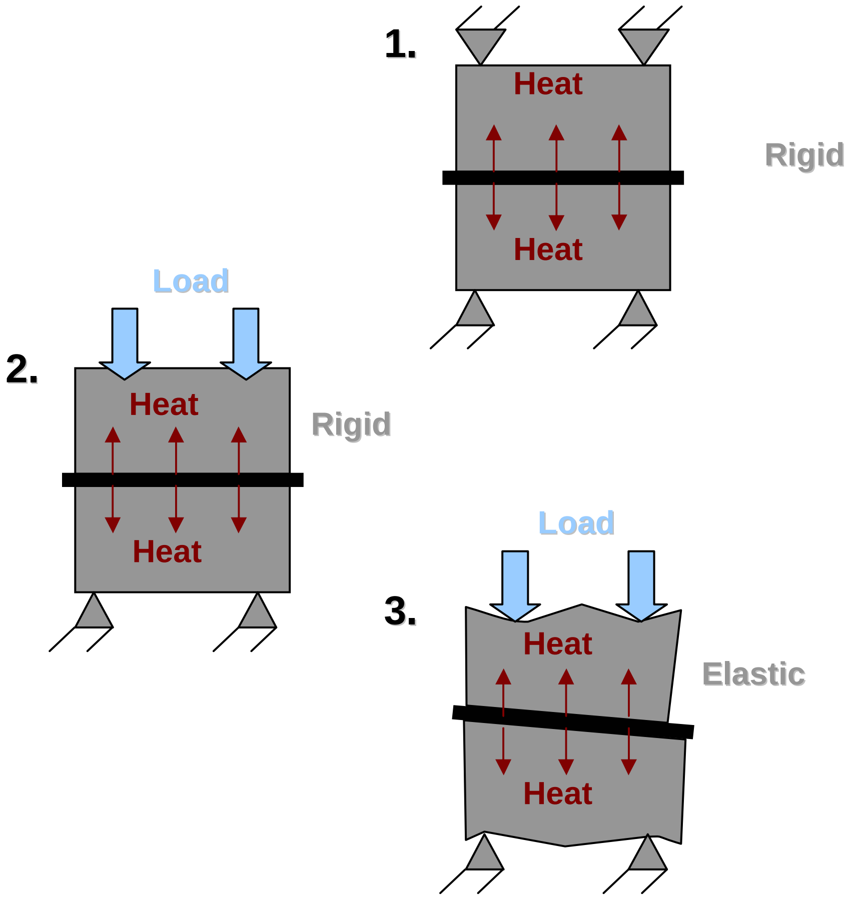
# Solution methods

## 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

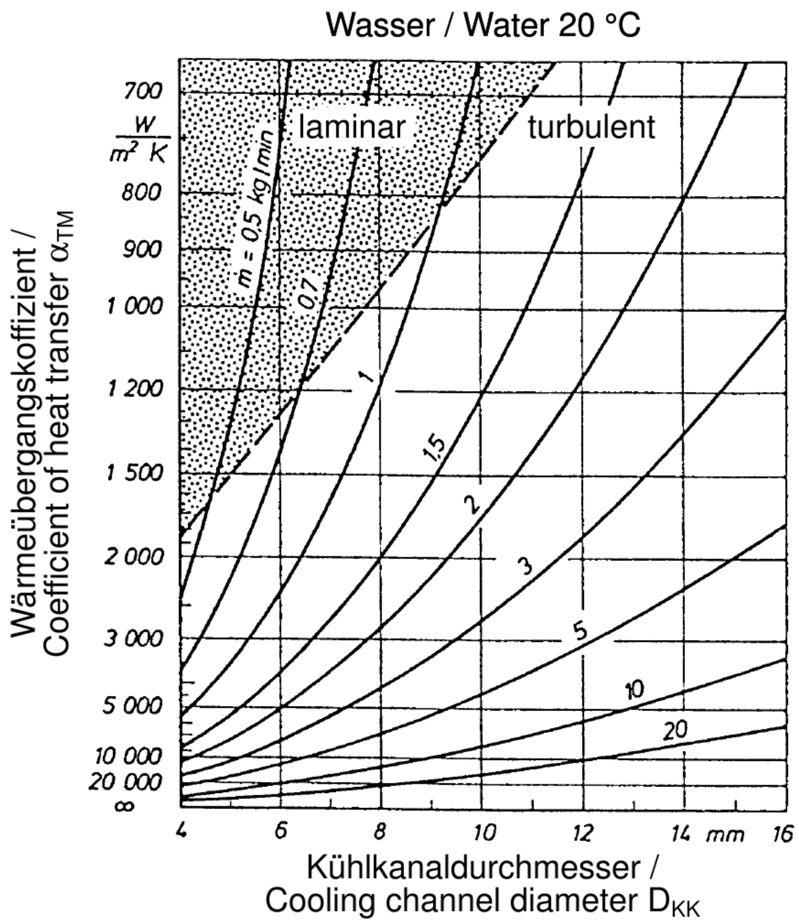
## Methods

- There are different possibilities to account for cooling passages

complexity

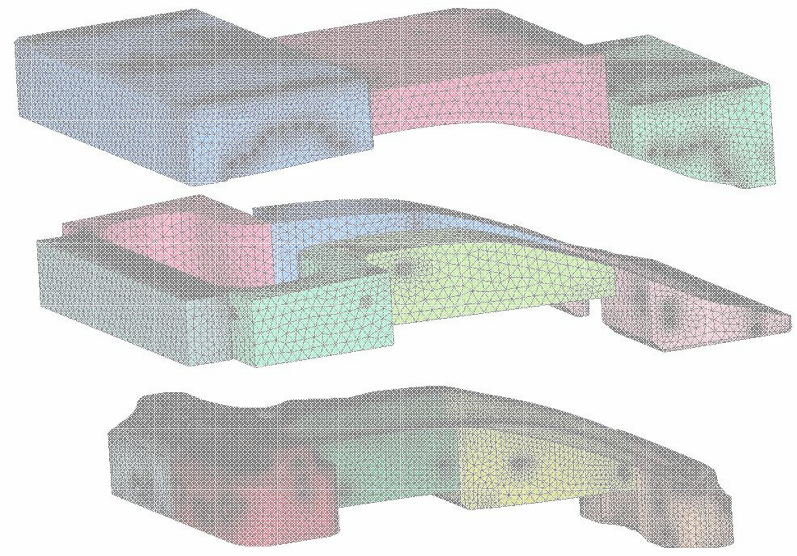
- Temperature boundary condition
- Convective boundary condition
- Application of new bulkflow feature
- Convective heat transfer coefficients
- From CFD simulation

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

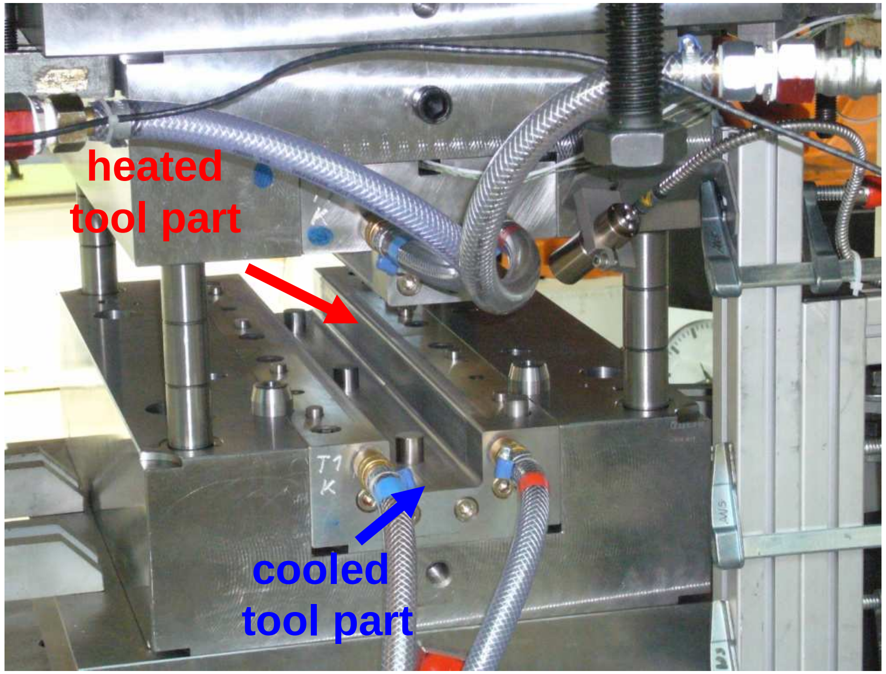


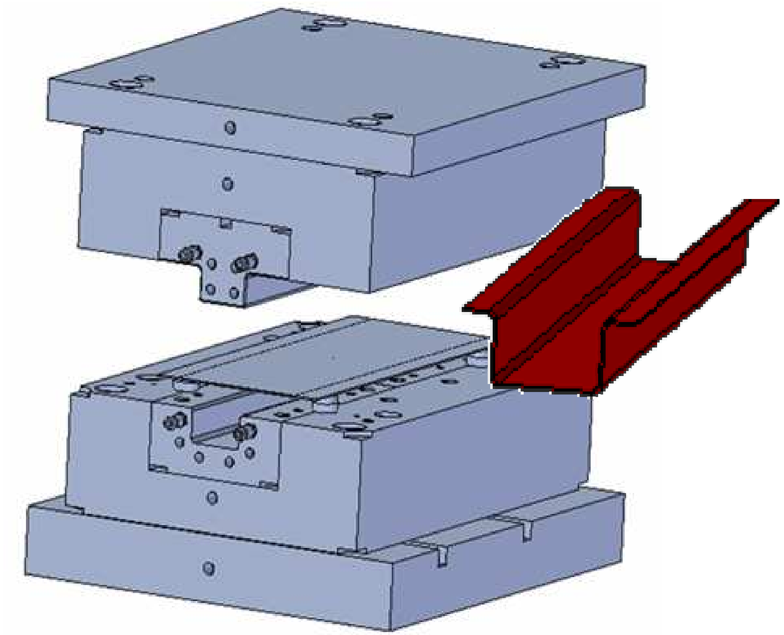
# Agenda

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



# Experiments
## Experimental tool



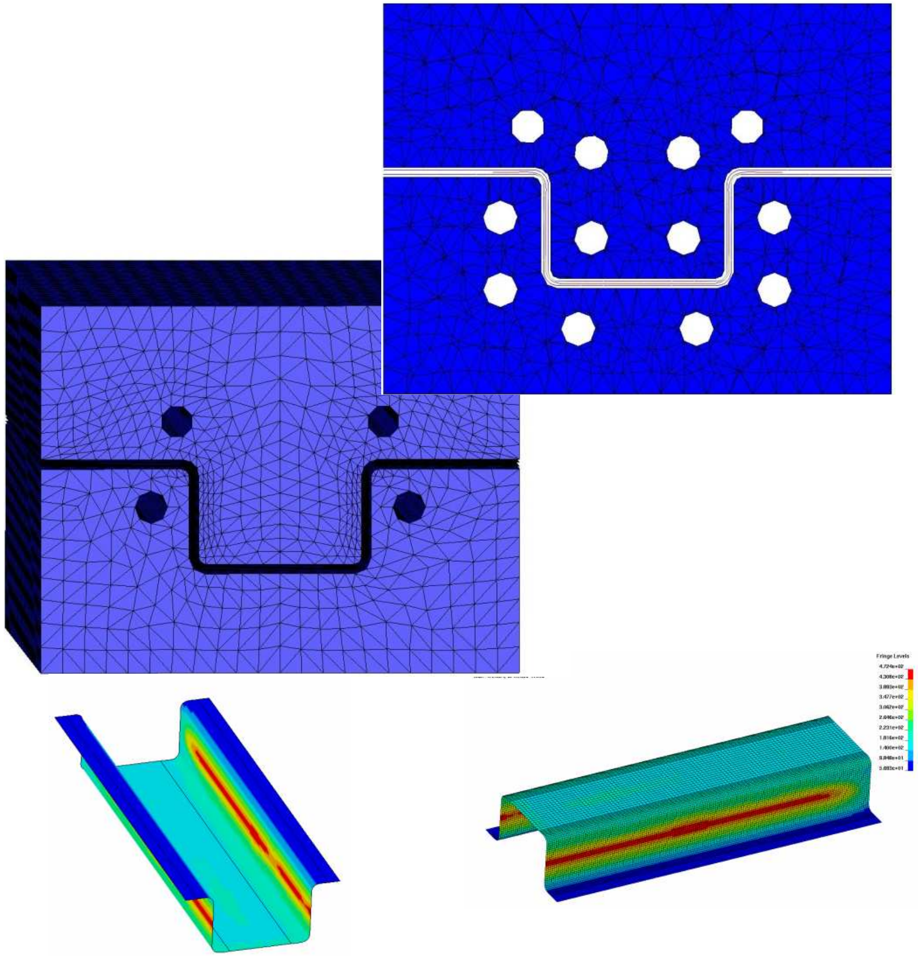



- Variation of several process parameters within the process chain
- Variation of tool material / cooling and heating etc.
- Analysis of measuring data, mechanical properties, microstructure etc.

# Simulation model

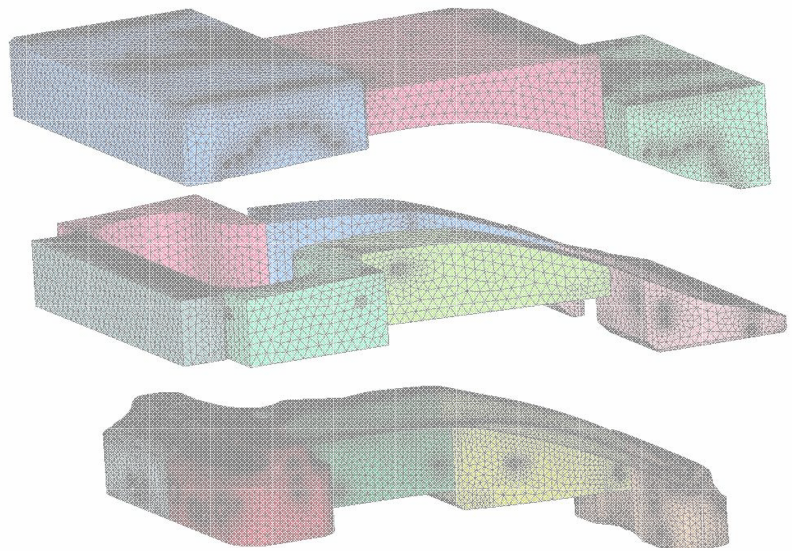
## Experimental tool

- 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



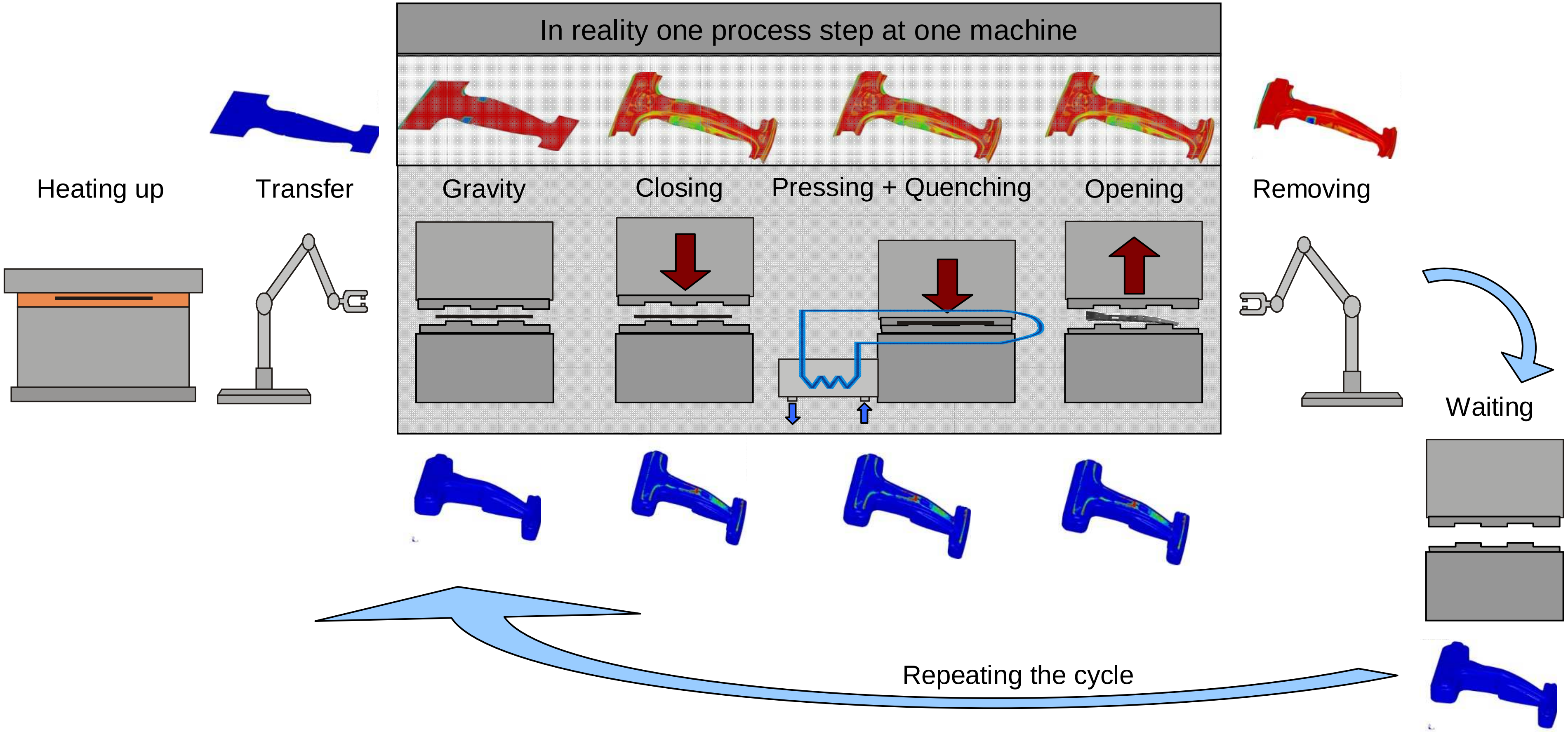
# Agenda

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



# Functional description – splitting the hot forming process

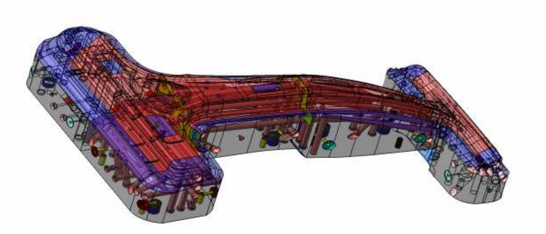
## Mass production tool



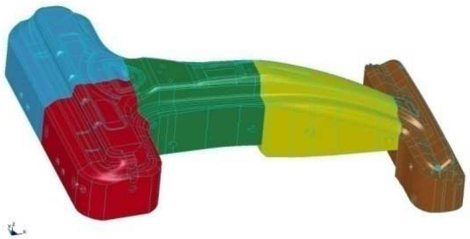
# Procedure – Building the simulation model

## Mass production tool

CAD



IGES



CAE

- Removing unnecessary parts like clamping and intermediate plates, frames, bolts, nuts, pipes, sealing, pads, fixtures, etc…
- Deleting small unimportant holes for bolts and handles

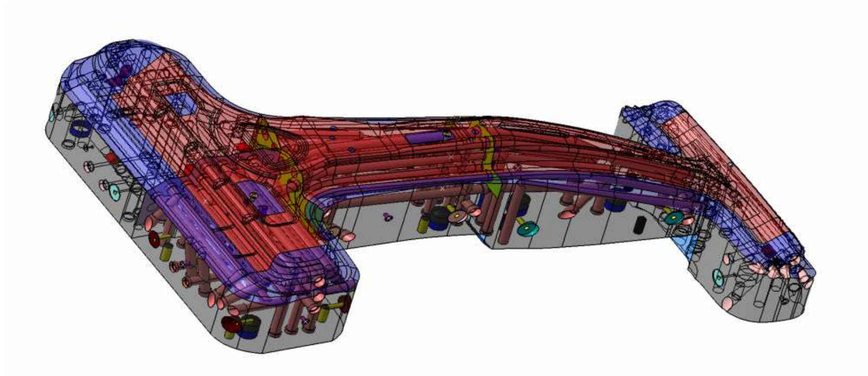
- Exporting in the IGES format

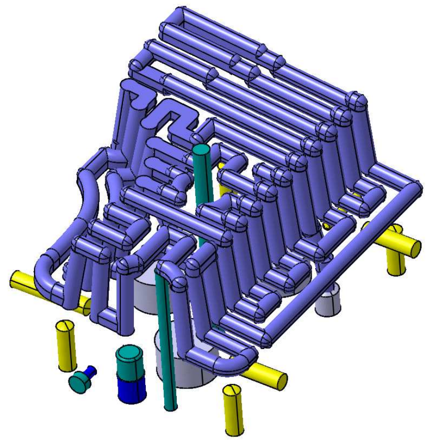
- Meshing in Hypermesh, Medina, and finishing in LS-Dyna
- Building the LS-Dyna Model

# Pitfalls – Building the simulation model

## Mass production tool

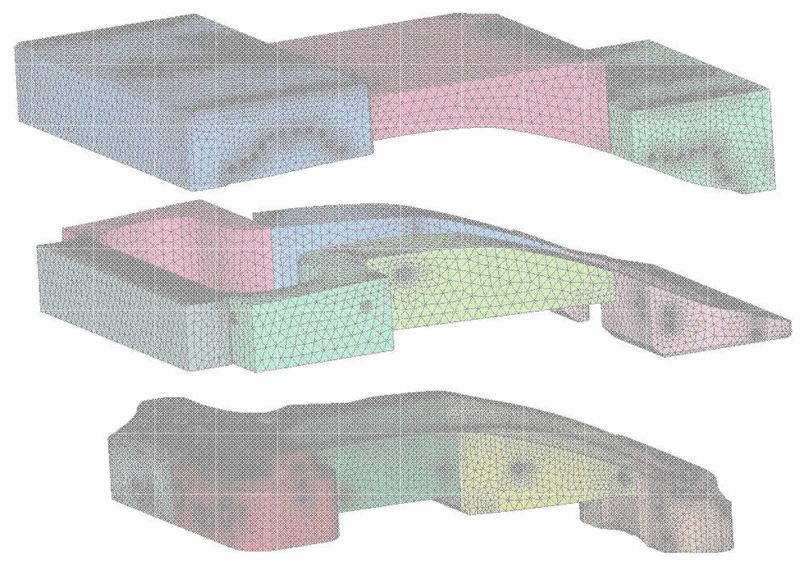
- High complexity of the CAD models - necessity of cleaning from unnecessary parts
- Complexity of the cooling channels - necessity of partial simplification
- Application of Bulkflow elements not possible - nonsymmetric matrix resulting in too much memory requirement - necessity of applying the convection cooling method
- The thermal tied contact simplifies the meshing process – experience for obtaining satisfactory results necessary





# Agenda

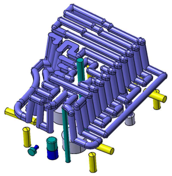
1. Motivation
2. Objectives
3. State of the art
4. Considering die cooling
    1. Methods
    2. Experimental tool
    3. Mass production tool
5. Conclusions and outlook



# 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