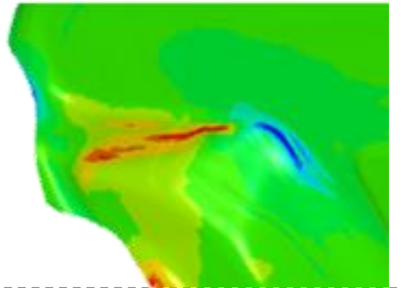
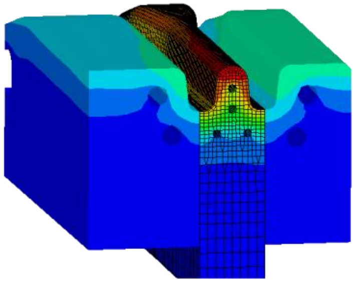
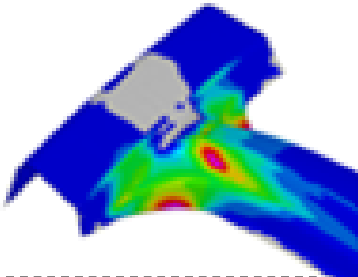
Hot Stamping Process Simulation with LS-DYNA

Capabilities and Benefits

David Lorenz
DYNAmore GmbH



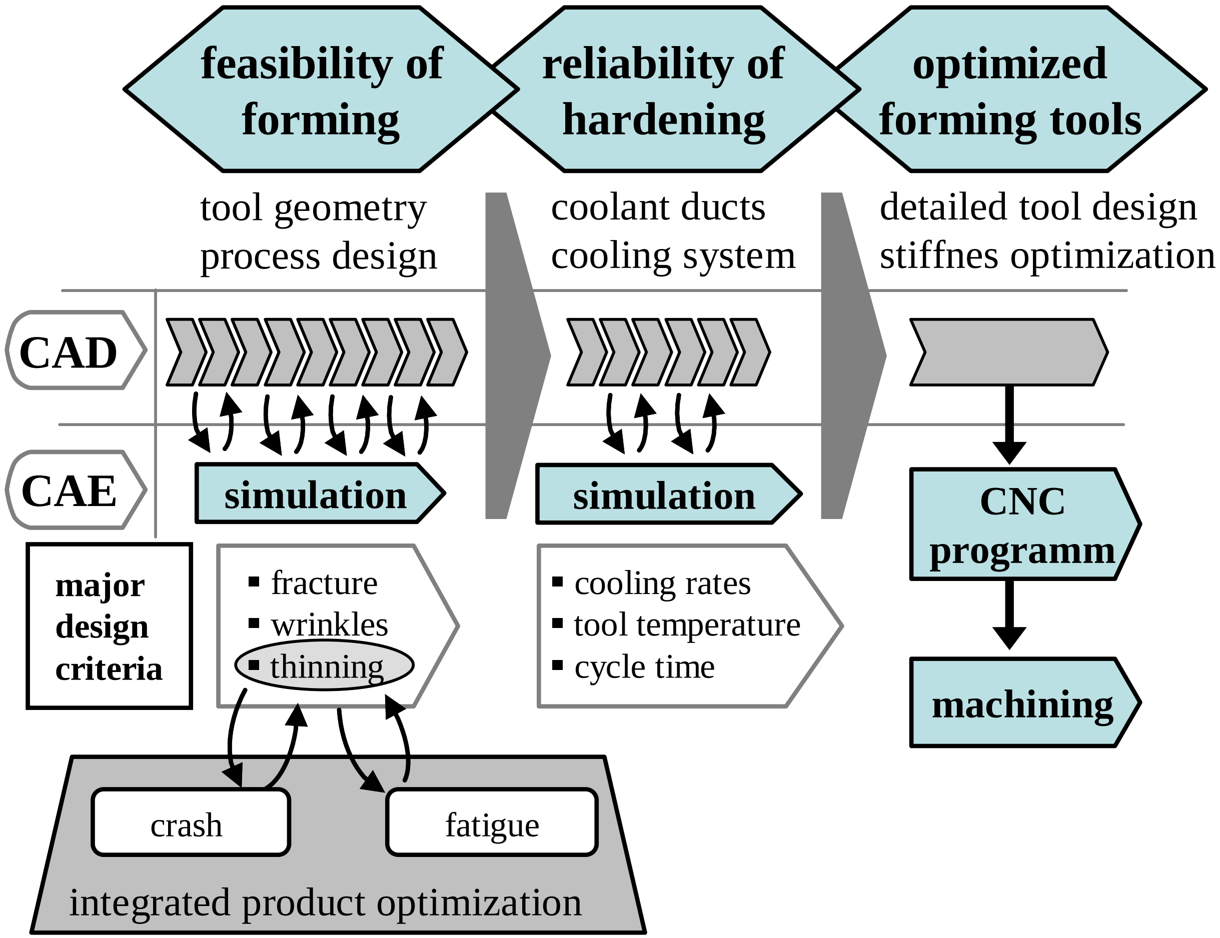




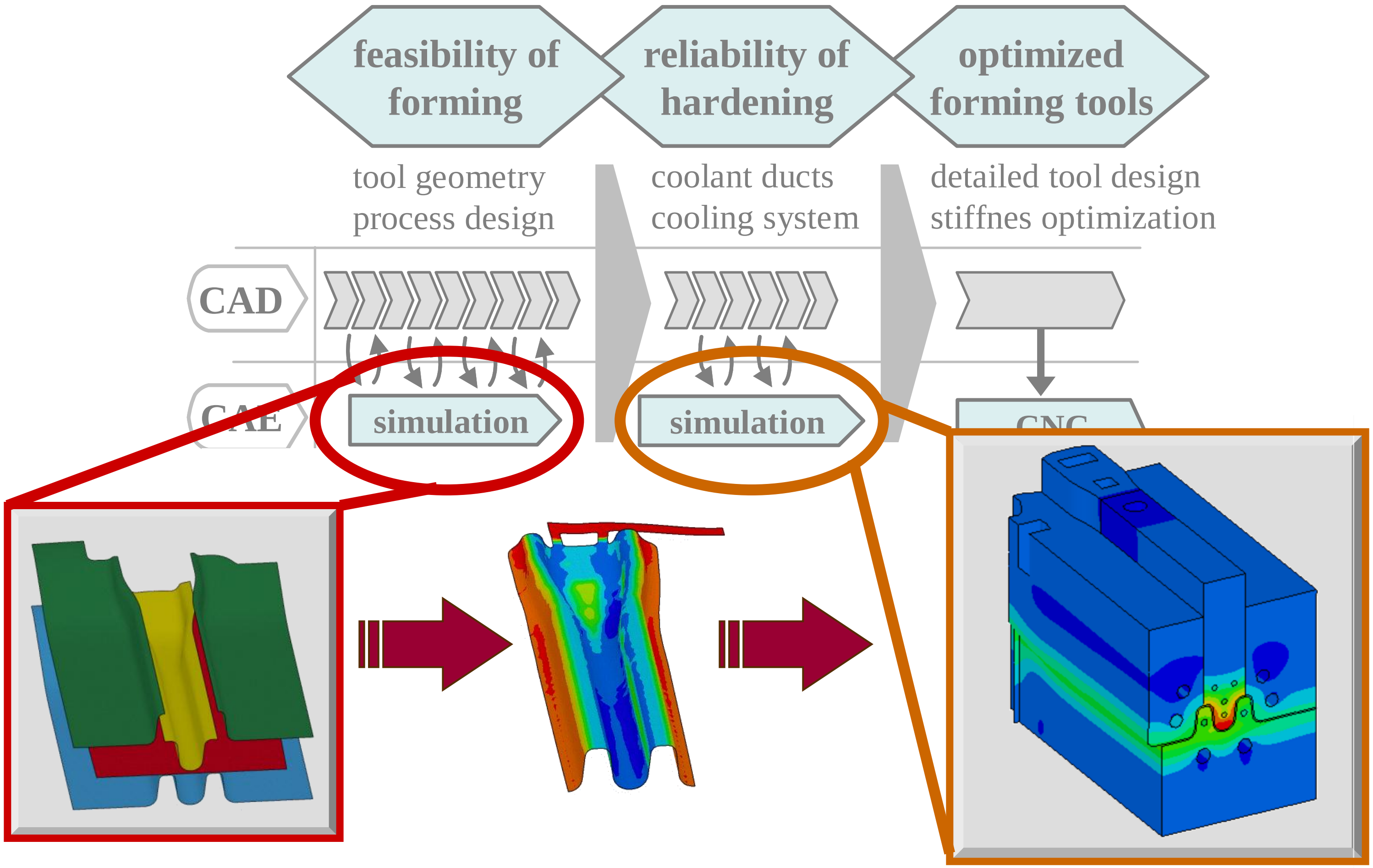
Agenda

1. **Hot Stamping and Presshardening of Boron Steel**
2. **Hot Stamping Feasibility Studies**
3. **Presshardening Cooling Simulations**
4. **Prediction of Microstructure in Presshardening**
5. **2-stage forming of intermediate induction heat treated aluminum**
6. **prediction of frictional thermal load on forming tools**

Hot Stamping of Boron Steel



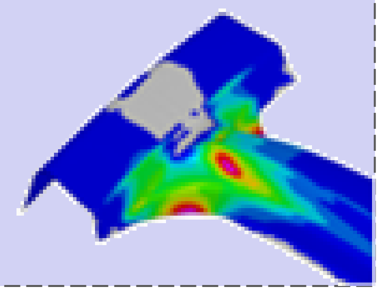
Hot Stamping of Boron Steel



Hot Stamping Feasibility Studies

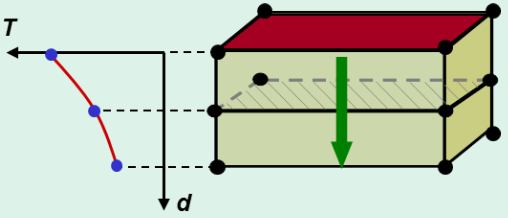
High predictive quality of a simulation requires detailed consideration of essential effects

- Which are essential effects affecting simulation accuracy?
- How are these effects considered in our models?



Simulation requires efficient model approaches to be an effective enginering tool

- Simple tool modeling without loss in accuracy?
- Numerical measures to speed up simulations?



Accuracy of forming simulations strongly depends on the consideration of temperature dependent viscoplasticity

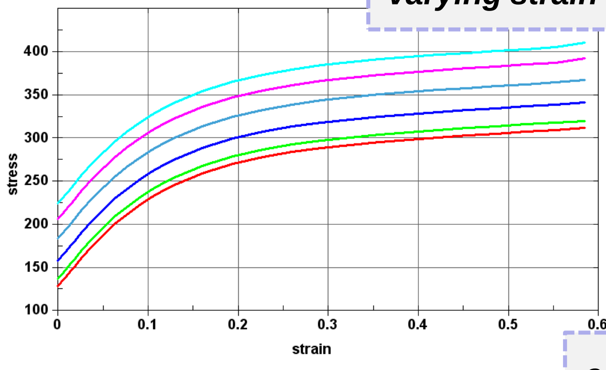
```
*DEFINE_TABLE_3D
    ...
20.0     101
    ...
500.0    104
    ...
800.0    108
    ...
```

temperature

*DEFINE_TABLE

const. Temperature

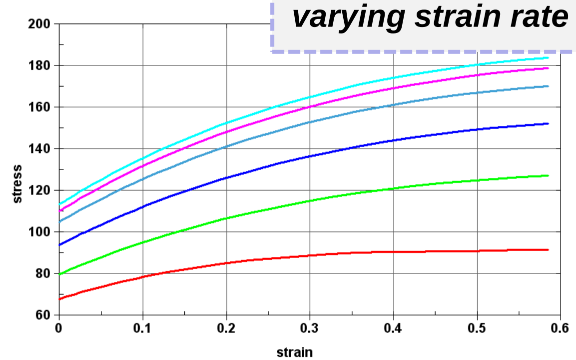
varying strain rate



*DEFINE_TABLE

const. Temperature

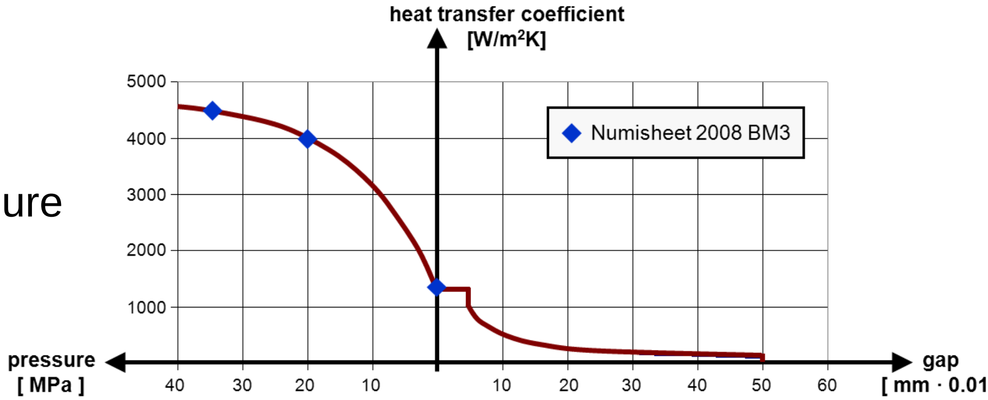
varying strain rate

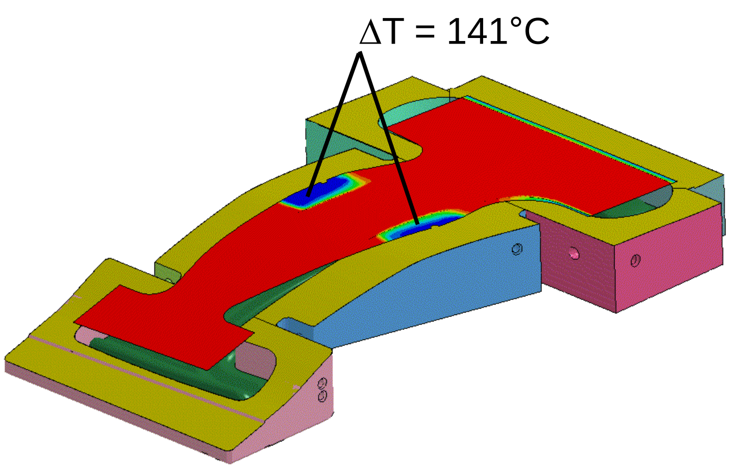


Direct tabulated input requires a lot of material data …

Temperature dependent material properties require an accurate calculation of the inhomogenuous blank temperature during the forming operation

- heat transfer to the dies by
  - → contact, depending on contact pressure
  - → gap conductance
- ambient heat transfer
  - → radiation
  - → convection

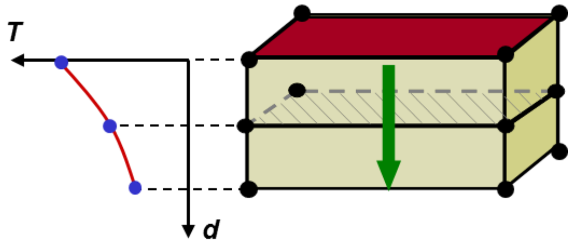




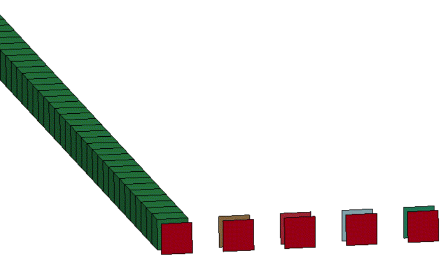
Tool surface temperature directly affects the heat flux from blank to the die

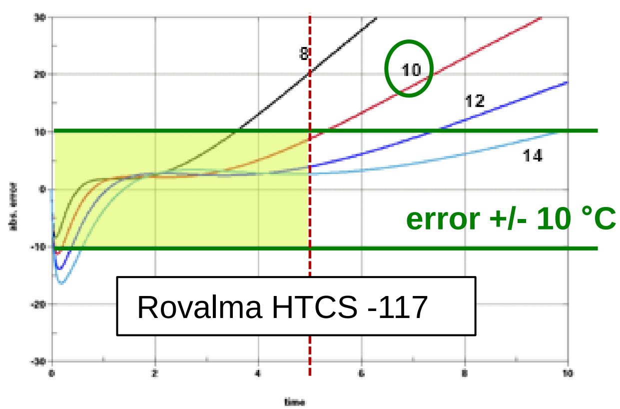
$$\dot{q}_{cont} = h_{cont} \cdot \left(T_{blank} - T_{tool}\right)$$

thermal thick shell



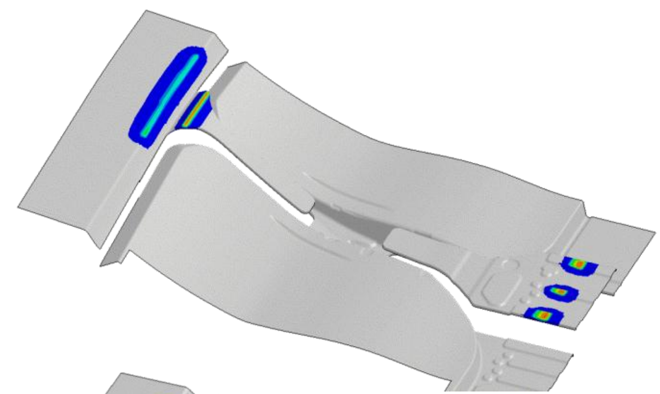
thickness calibration

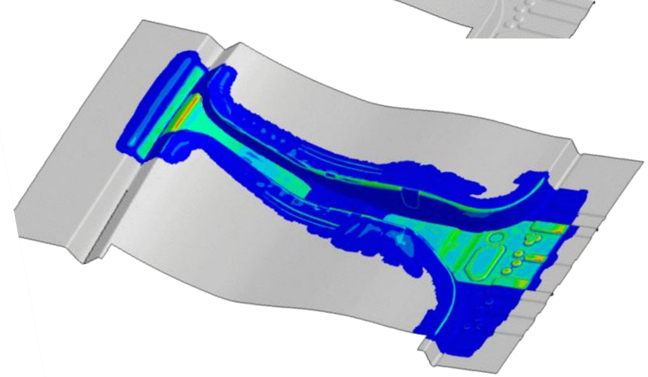




max. contact time ~5s

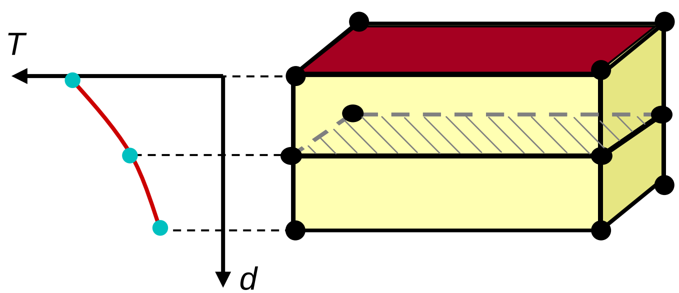
Tool surface temperature before and after forming operation





Tool surface temperature directly affects the heat flux from blank to the die

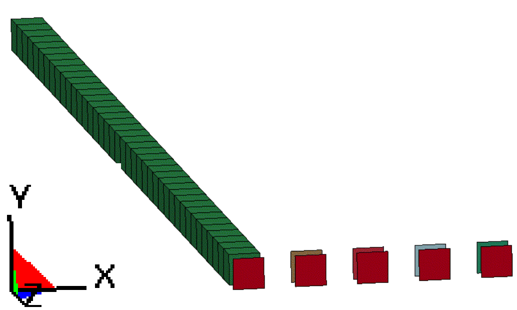
$$\dot{q}_{cont} = h_{cont} \cdot \left(T_{blank} - T_{tool} \right)$$



CONTROL_SHELL** ***TSHELL=1

+

CONTROL_CONTACT** ***ITHOFF=1

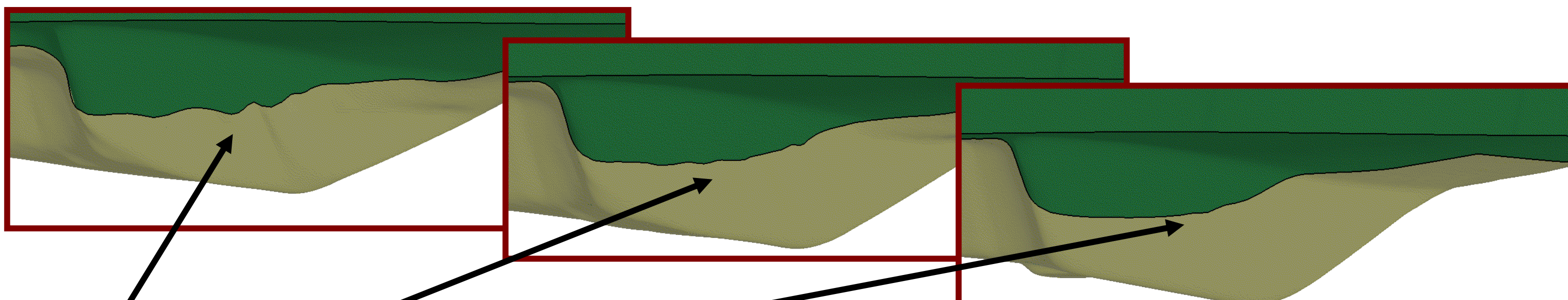


tool thickness for different materials

1.2367	λ = 28 W/mK	d_{tool} = 10.0 mm
HTCS-117	λ = 41 W/mK	d_{tool} = 12.0 mm
HTCS-130	λ = 62 W/mK	d_{tool} = 16.0 mm

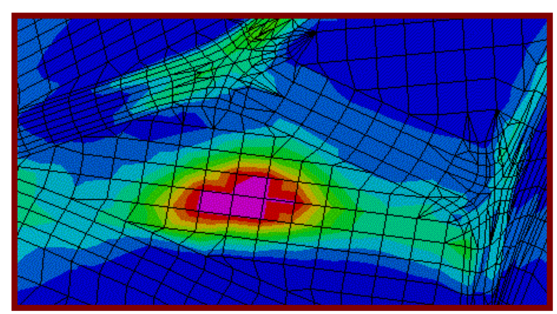
Accurate wrinkling analysis

- wrinkling control in areas of unsupported deformation is a difficult task
- Wrinkless should **flatten** during die closing



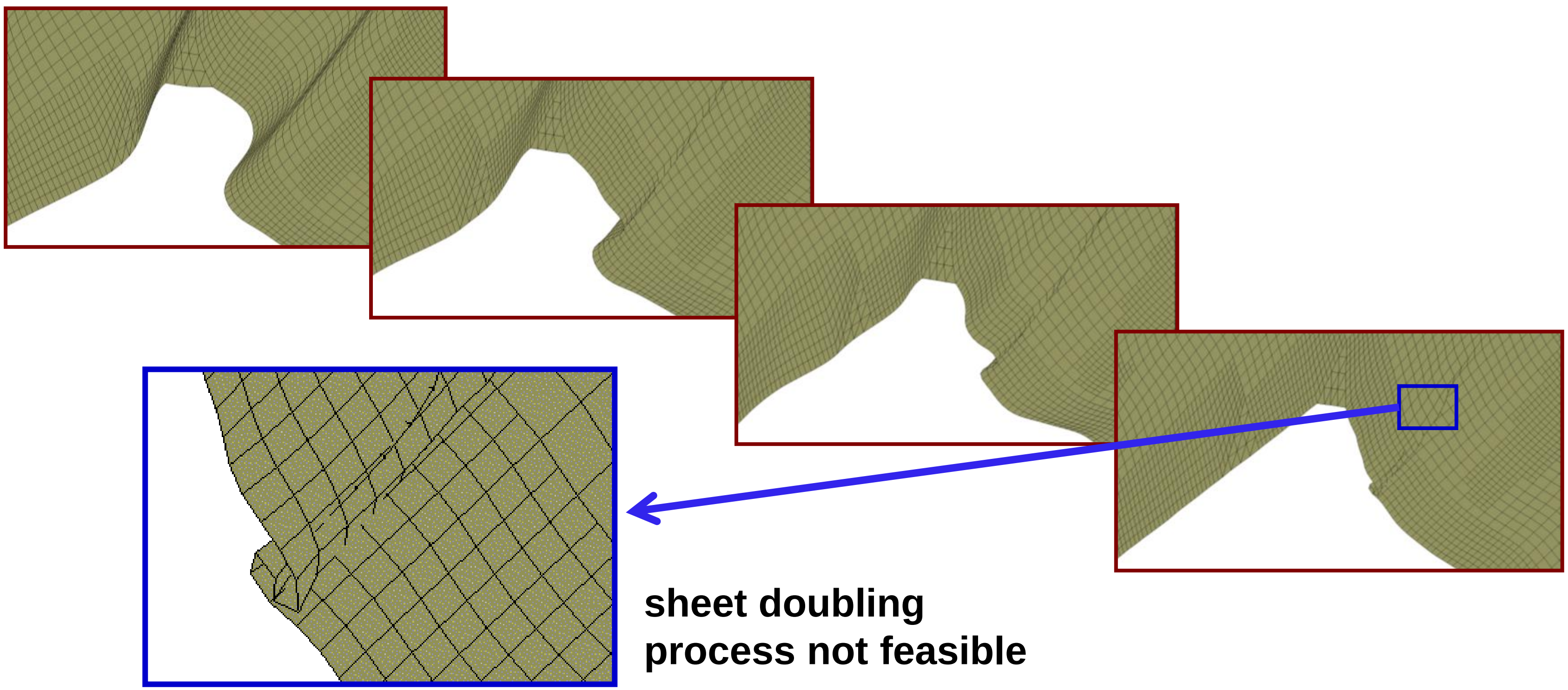
wrinkle flattening successful

Check if contact pressure on forming die is critical



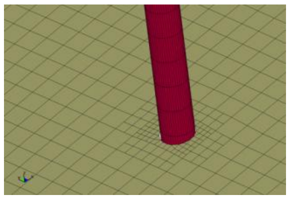
Accurate wrinkling analysis

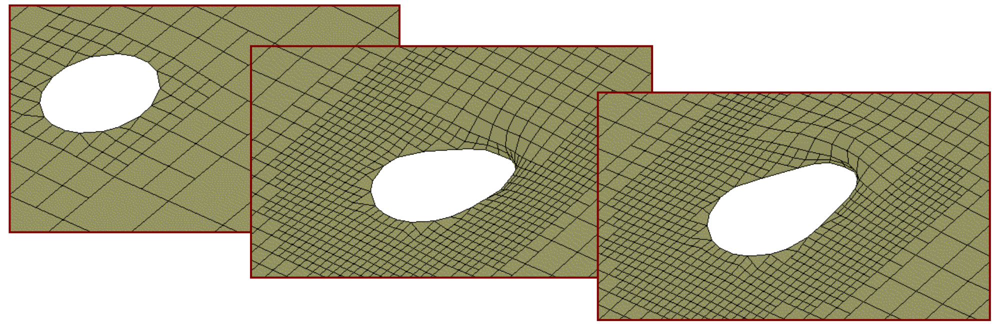
- wrinkling control in areas of unsupported deformation is a difficult task
- Sheet doubling during wrinkle deformation is an important failure mode in hot stamping
- Prediction of this failure is impossible without geometrical representation of wrinkles

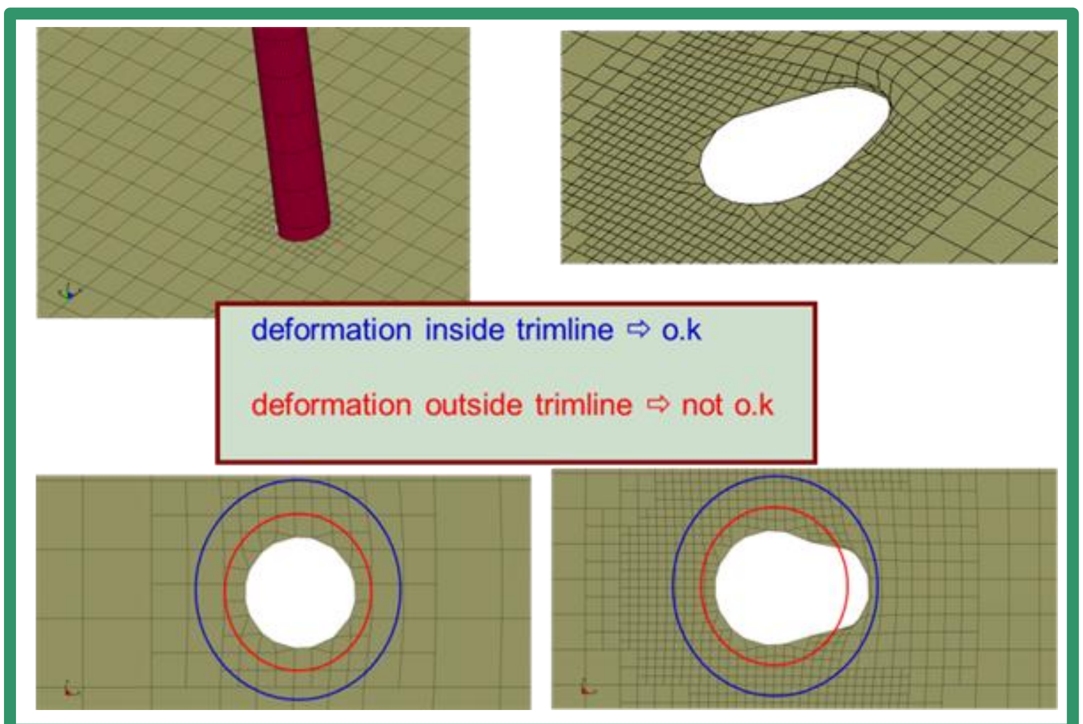


sheet doubling
process not feasible

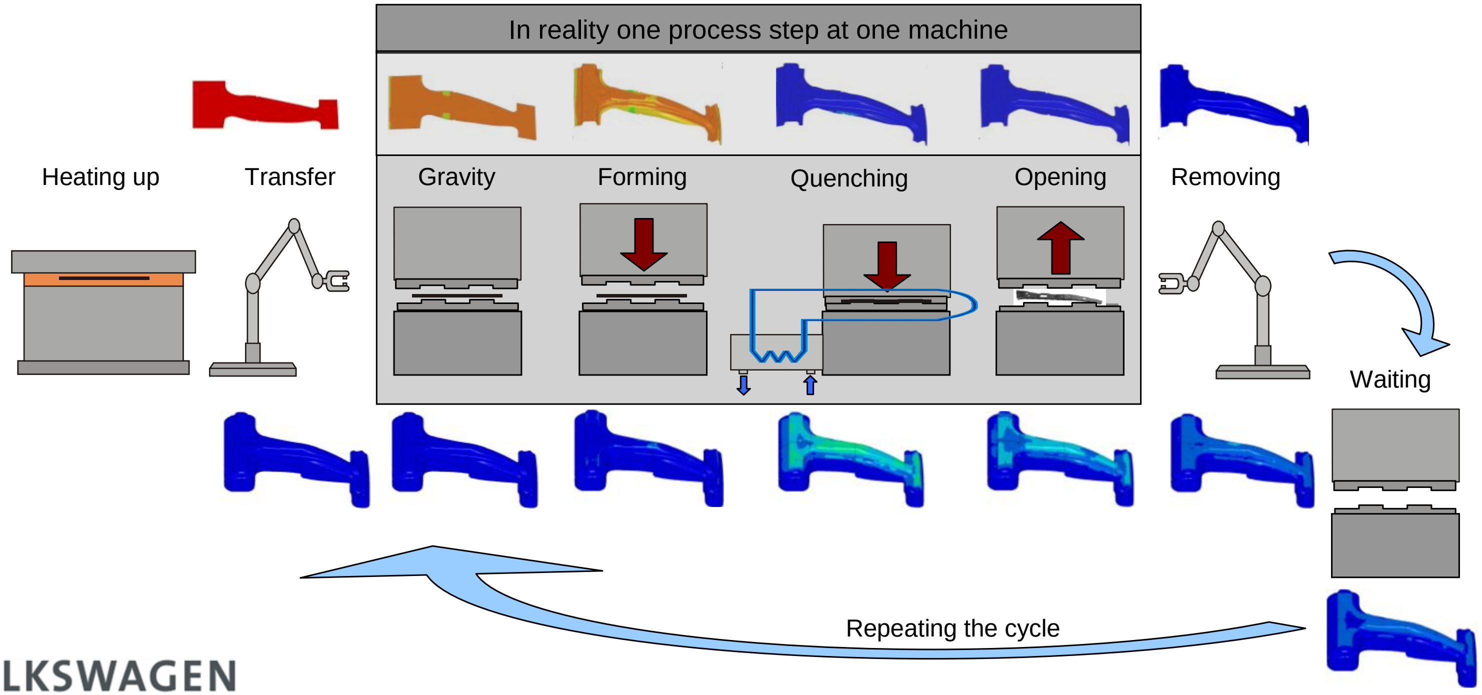
Local deformation due to contact with guide pins







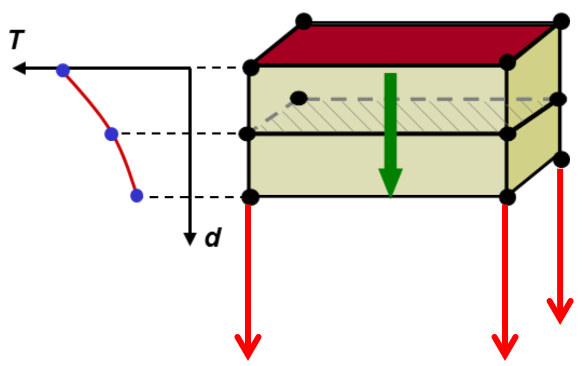
Presshardening Cooling Simulations

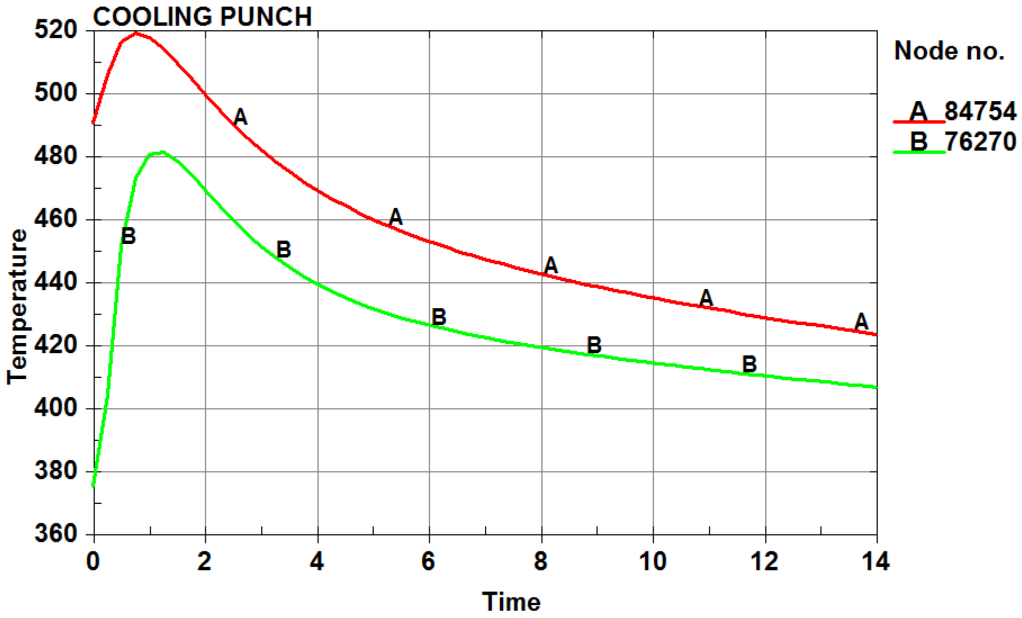


courtesy of M. Medricky
Volkswagen AG

A simple and fast shell only model for the cooling step

use the thermal thick shell



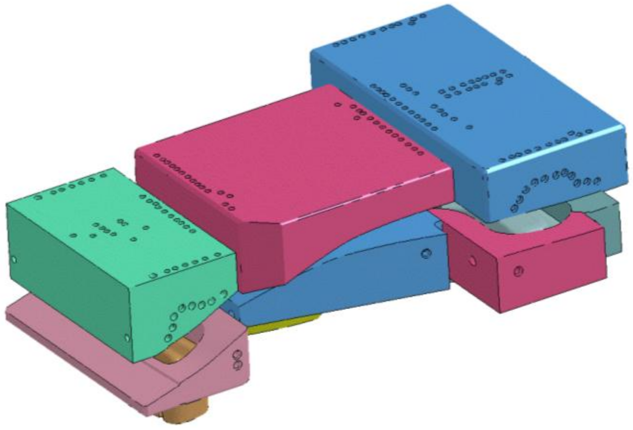


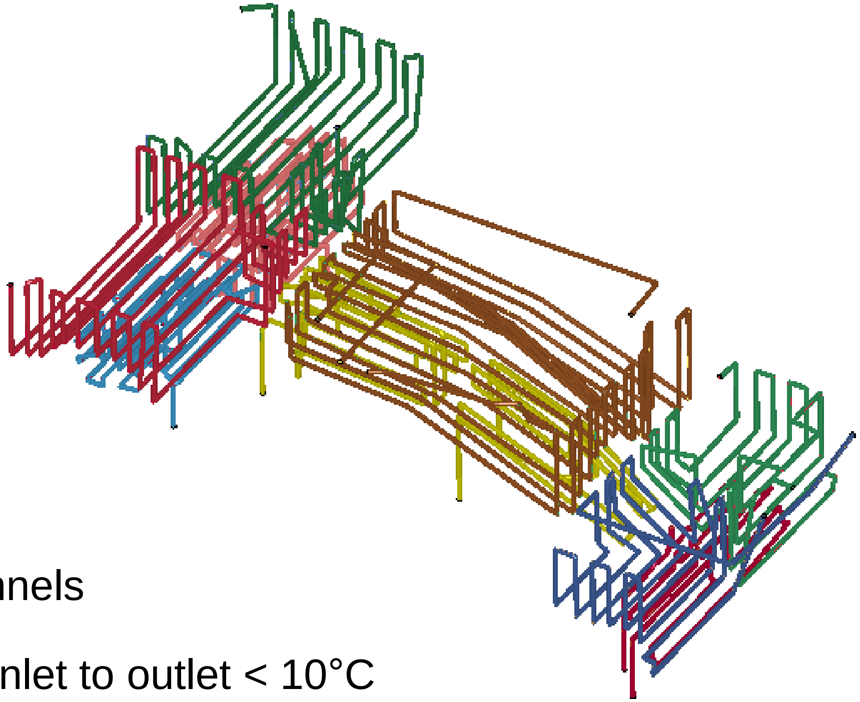
and add an artificial heat flux to the backside

→ the thickness is directly computed from thermal material properties

→ the heat flux is directly computed from the thickness and the conductivity

Modelling the watercooling system





- High mass flow through cooling channels
- Increase of water temperature from inlet to outlet < 10°C

→ convection boundary condition

$$\dot{q} = h_{con} \cdot \left(T_{wall} - T_{water}\right)$$

?

Calculating h_{con}

- application of convection BCs on channel walls is simple and sufficient
- convection coefficient by established analytical solutions for pipe flow

$$h = 0.023 \frac{k}{D} \mathrm{Re}^{0.8} \mathrm{Pr}^{0.3}$$

Dittus-Boelter (conservative)

$$h = 0.023 \frac{k}{D} \mathrm{Re}^{0.8} \mathrm{Pr}^{0.3} \left(\frac{\mu_{bulk}}{\mu_{wall}} \right)^{0.14}$$

Sieder-Tate (temperature correction)

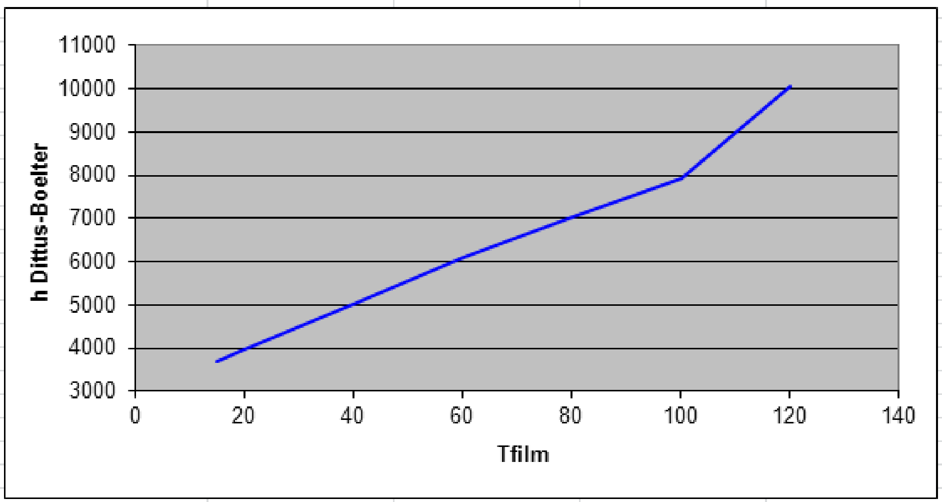
$$h = \left(\frac{k}{D} \right) \left[\frac{(f/8)(\mathrm{Re} - 1000)\mathrm{Pr}}{1 + 12.7 (f/8)^{1/2} \left(\mathrm{Pr}^{2/3} - 1 \right)} \right]$$

Gnielinski (wall friction effect)

- average flow velocity is required
  1. given mass flow rate per channel
  2. calculation with pipe network calculator
  3. computed with CFD analysis

using an excel sheet to calculate $h_{con}(d,v,T)$

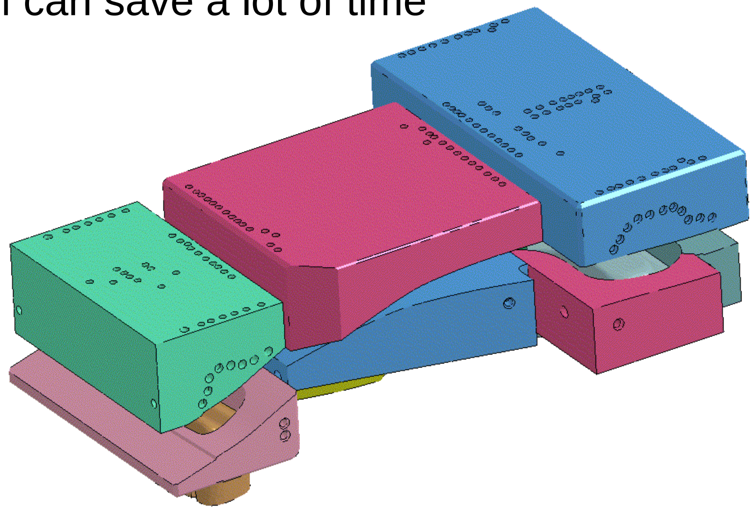
Diameter [mm]	6						
Cross Section [m^2]	2,82743E-05						
Flow Velocity [m/s]	5						
Fluid Temp [°C]	10						
Wall Temp [°C]	20	40	80	120	160	200	240
Film Temp [°C]	15	20	40	60	80	100	120
Density [kg/m^3]	999,162	998,028	991,886	983,171	971,885	958,028	941,599
Capacity [J/kgK]	4183,387	4181,743	4179,629	4184,657	4196,829	4216,143	4242,600
Viscosity [kg/ms]	0,001	0,001	0,001	0,000	0,000	0,000	0,000
Conductivity [W/m°C]	0,595	0,603	0,631	0,654	0,670	0,681	0,686
Re	2,67858E+07	2,99017E+07	4,55179E+07	6,44180E+07	8,26606E+07	1,03645E+08	165586390,111
Pr	7,863	6,941	4,328	2,932	2,209	1,717	1,055
h [W/m^2°C]	3710	3954	5026	6112	7027	7935	10048



Cooling Simulation of a B-Pillar

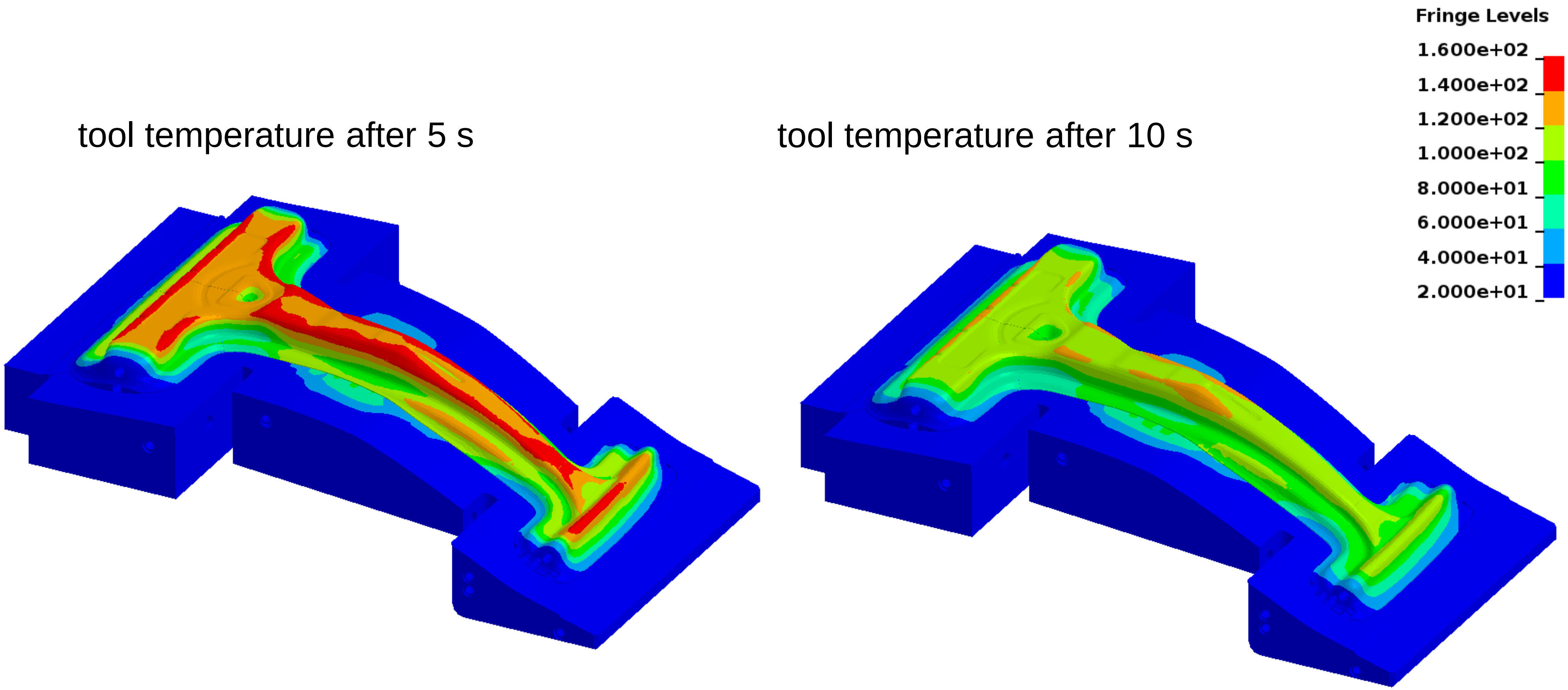
- 3D mesh required for all active tool segments
- mesh contains geometry of cooling channels
- mesh generation in preprocessor is a timeconsuming task

→ 3D mesh generation in CAD System can save a lot of time



Presshardening Cooling Simulations

Cooling Simulation of a B-Pillar

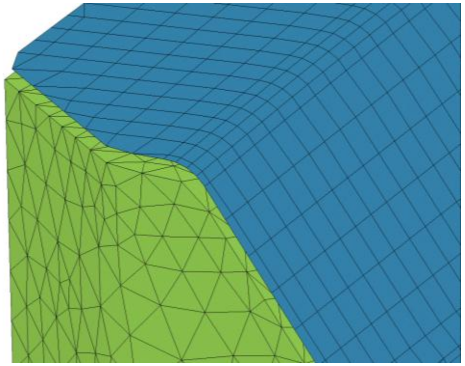


Cycled cooling simulations - Conclusion

- If you want to verify your tool design (number of cooling bores, diameter, distance from surface) you must simulate the whole start up period.

- If you capture only the first stroke in your simulation you will always get optimistic answers, even for bad tool designs.

- An insufficient cooling design can only be compensated by longer cycle times, which will cost much money.

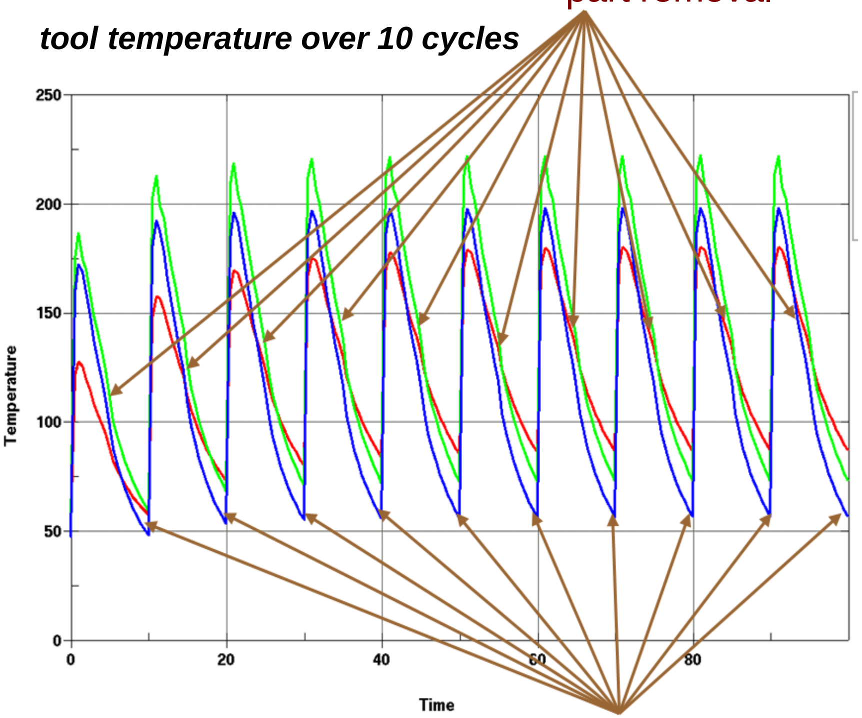


Hot Stamping of an A-Pillar

- model size: 284.602 shells, 2.946.238 tet4, 634.193 nodes
- total CPU time ~20 min per stroke @ 1node with 8CPUs
- **Fully hardened part is desired → check time-temp curves**

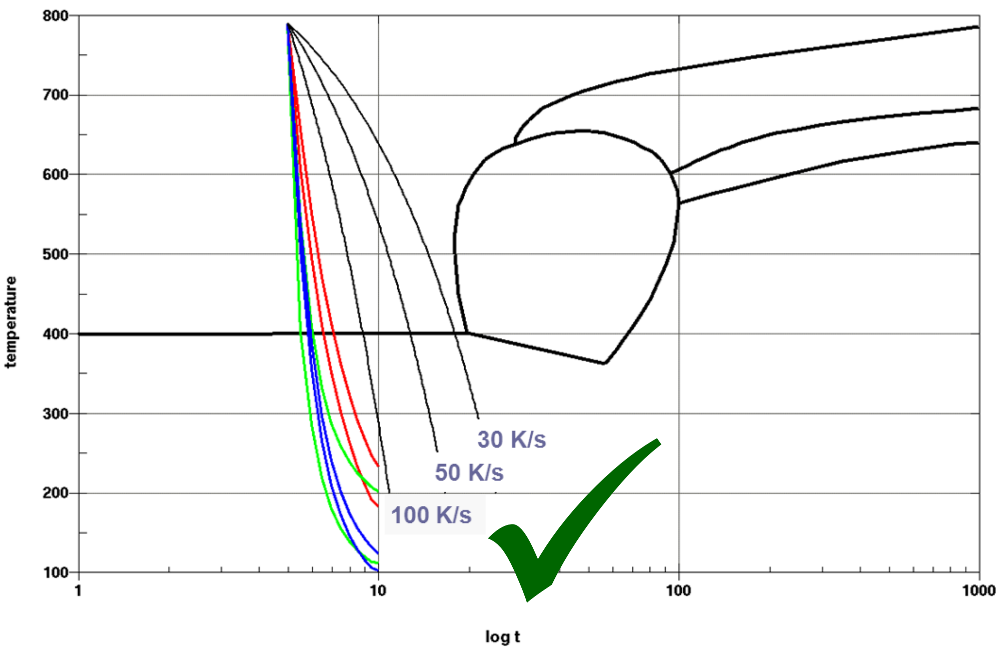
part removal

tool temperature over 10 cycles



initial tool temperature

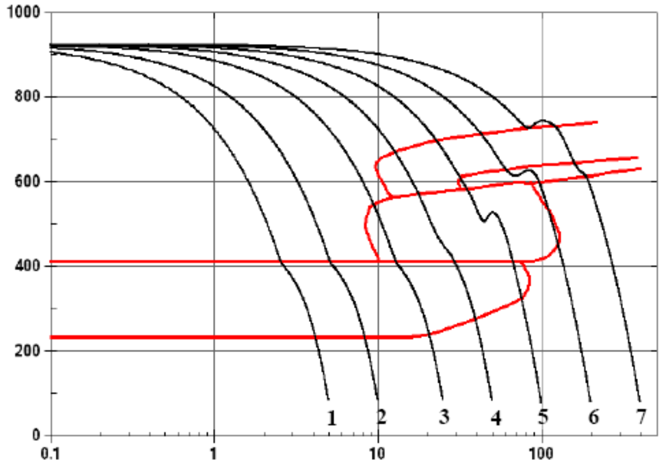
part cooling over 10 cycles



MAT_UHS_STEEL (MAT_244) for advanced simulations

user input:

- alloying elements in mass percent
  B, C, Co, Mo, Cr, Ni, V, W, Cu, P, Al, As, Ti
- latent heats for phase change reaction
- activation energy for phase transformation
- initial grain size
- yield curves for each phase
- thermal expansion coefficients

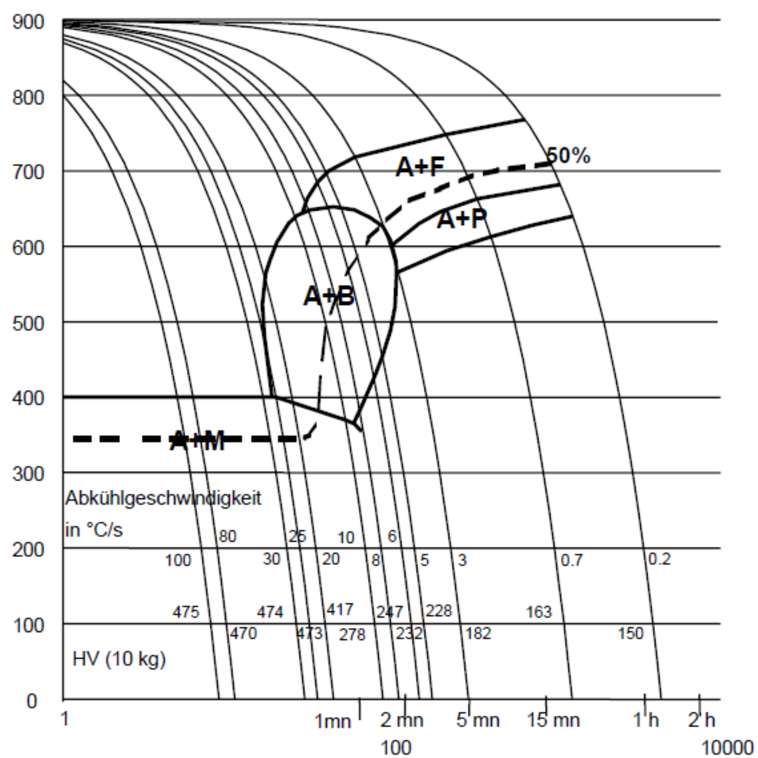


recalculated CCT diagramm

material output:

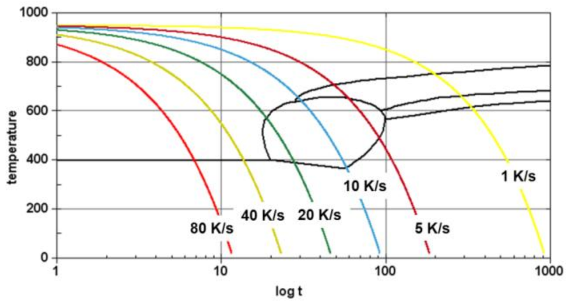
- current phase fraction of ferrite, pearlite, bainite and martensite
- computed Vickers hardness
- resulting yield strength
- austenite grain size

Parameter Identification for MAT_UHS_STEEL (MAT_244)



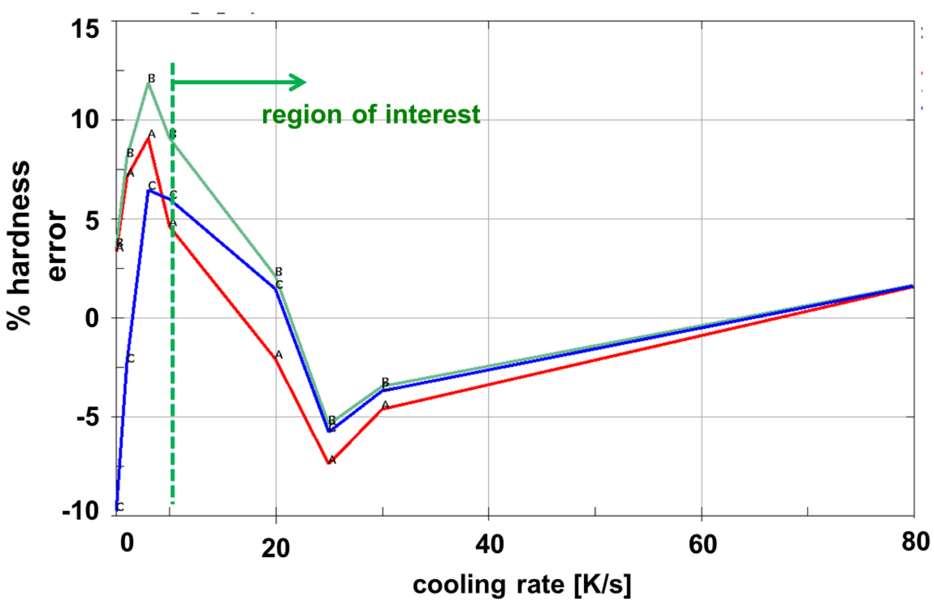
dT/dt	HV_{10}	
100 K/s	475	
80 K/s	470	
30 K/s	474	
25 K/s	473	
20 K/s	417	→ martensite + bainite
10 K/s	247	→ no ferrite
8 K/s	232	→ small amount of ferrite
3 K/s	182	→ small amount of pearlite

Parameter Identification for MAT_UHS_STEEL (MAT_244)

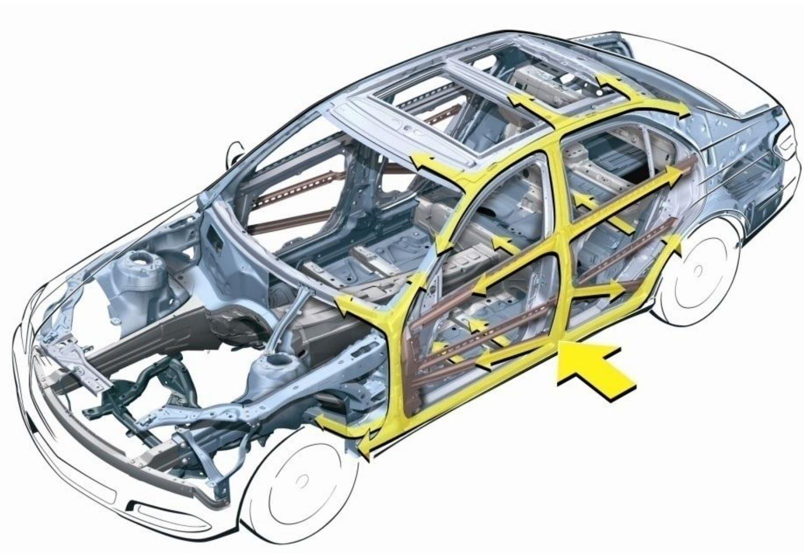


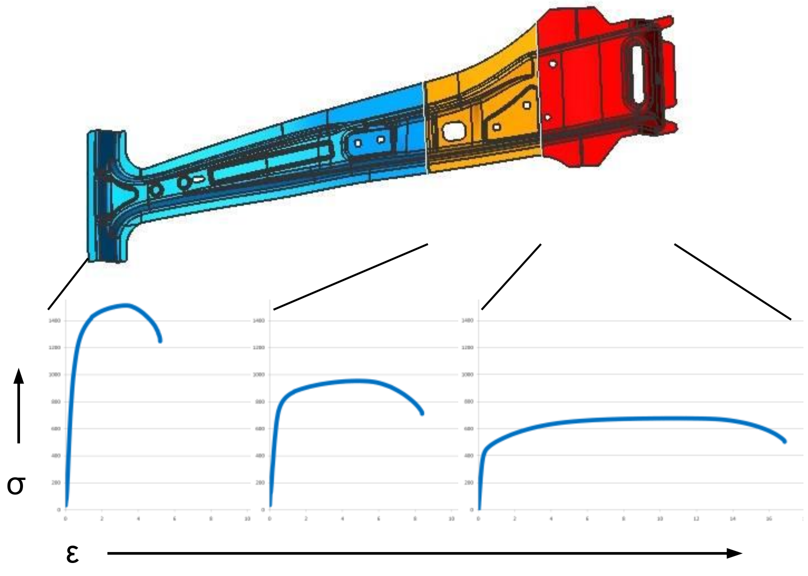
#	QR2	QR3	QR4	KFER	KPER	ALPHA
A	11600	14900	15400	3.0e+5	4340	0.033
B	11600	14900	15600	3.0e+5	4340	0.033
C	11600	14500	15600	2.0e+5	4340	0.033

Relative error in calculated Vickers hardness



Design a Process to get parts with tailored properties

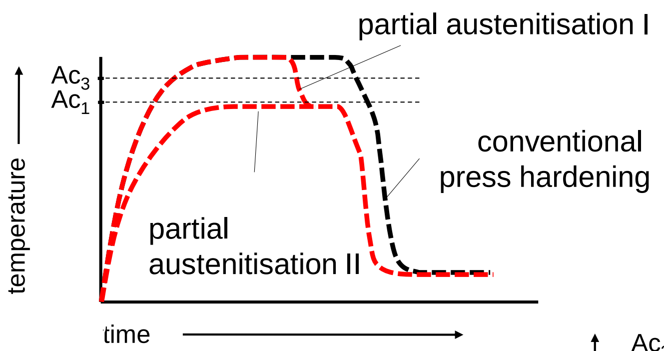




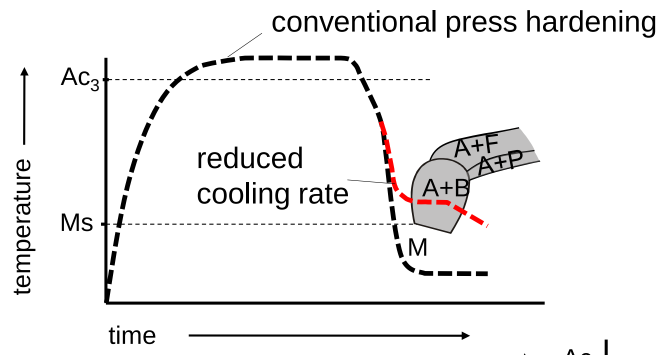
by courtesy of Daimler AG

Solving the task to get tailored properties

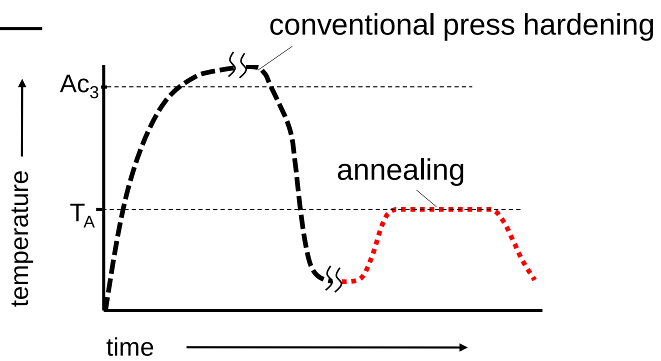
in the furnace by partial heating



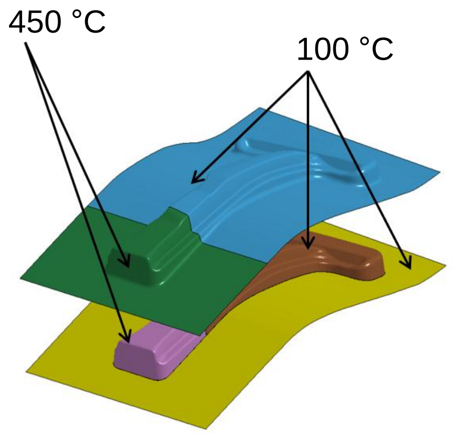
in the tool by partial tool heating

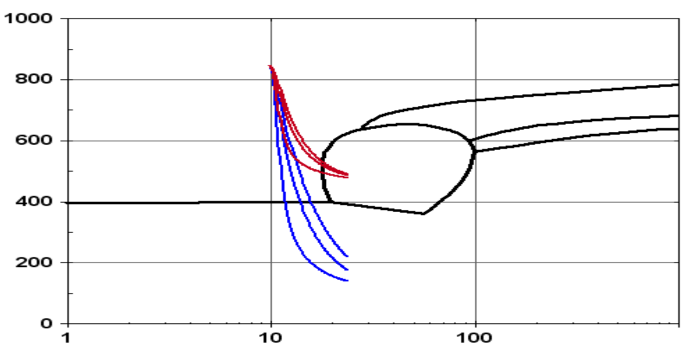


in a second process step

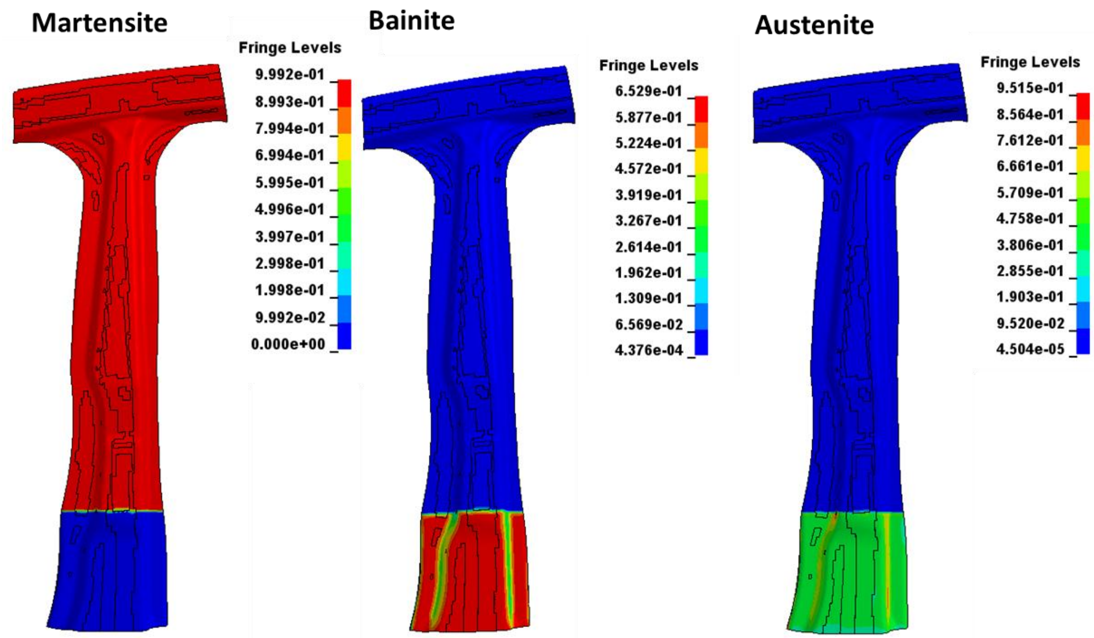


Tailored Tempering Process in principle



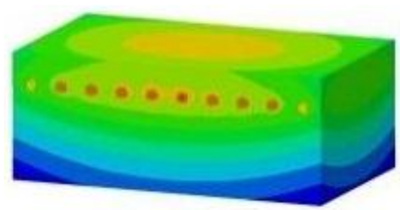
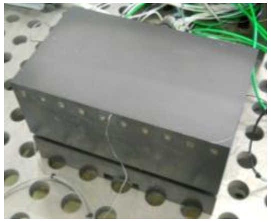
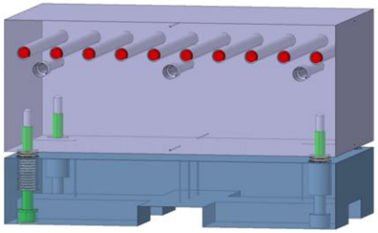


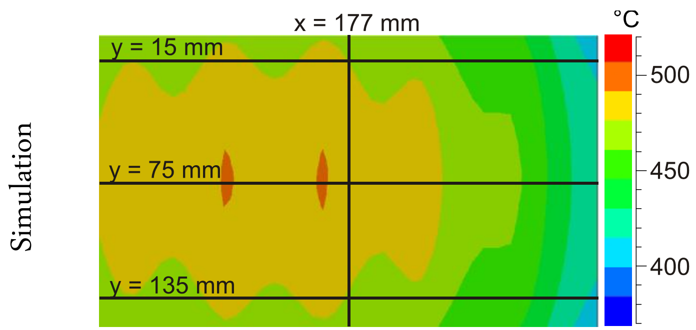
Microstructure after 14 s closing time (MAT_244)

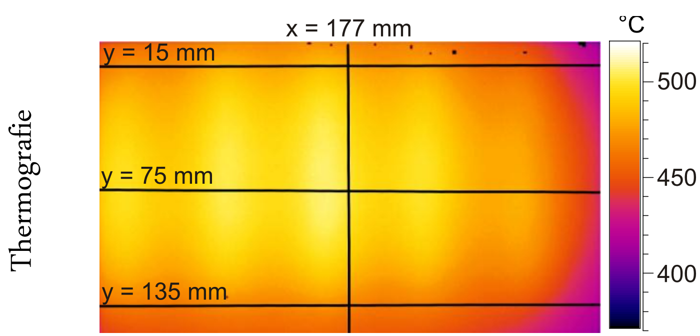


Calibration of die heating process

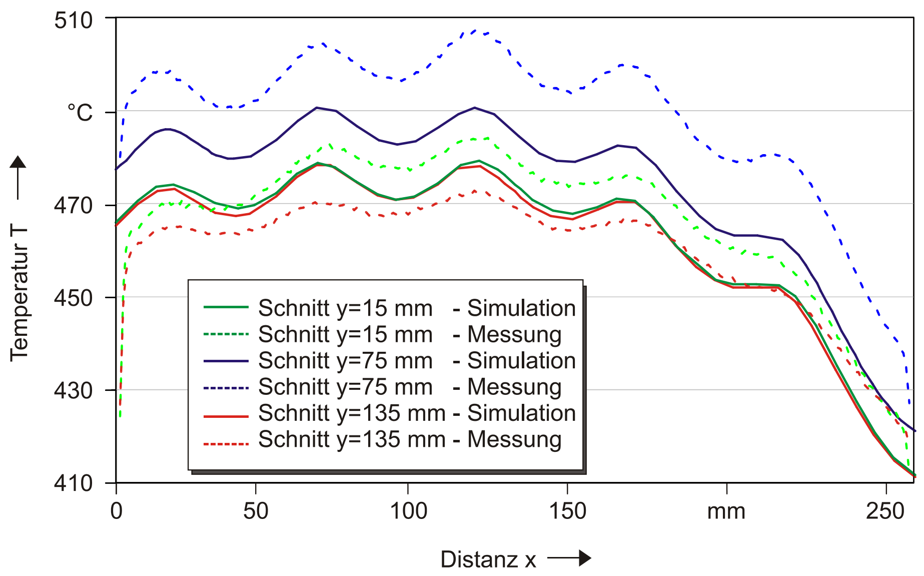
A simple tool setup for simulation calibration





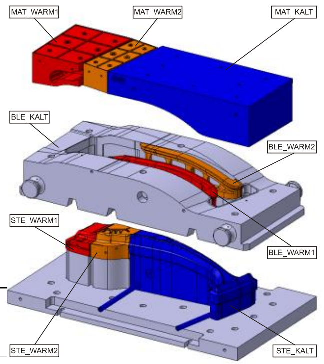
testcase every 2nd heater switched off



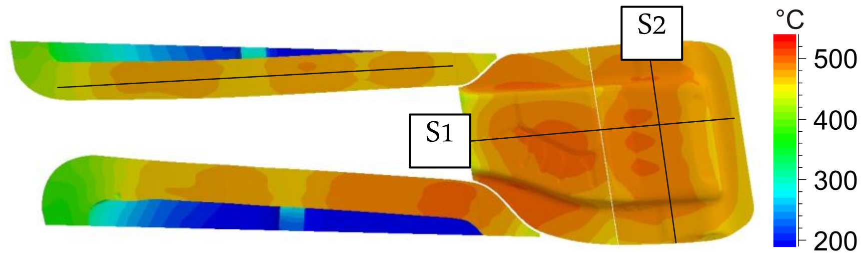
Calibration of die heating process

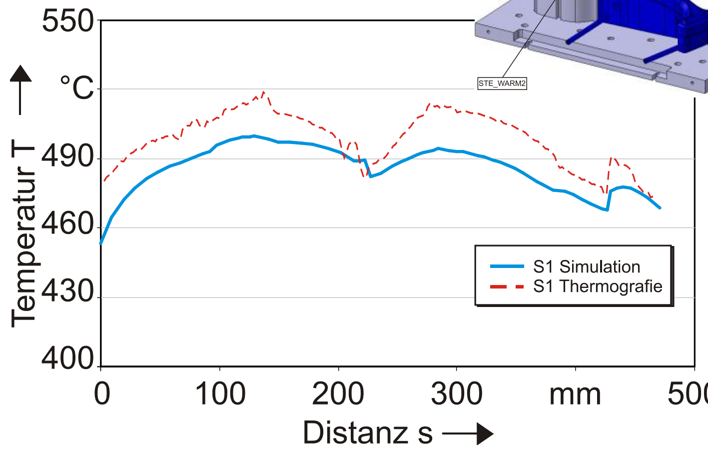
B-Pillar tool for validation of heating simulation

→ direct use of the calibration parameters without adjustment

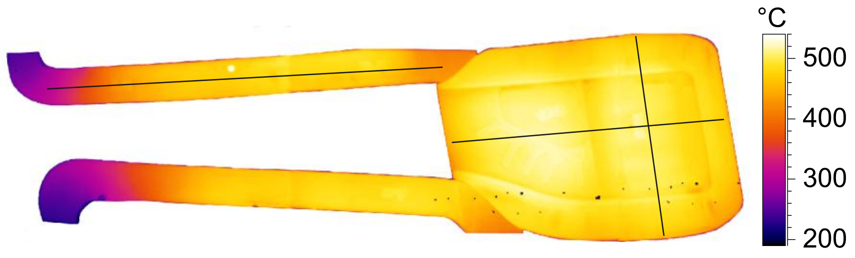


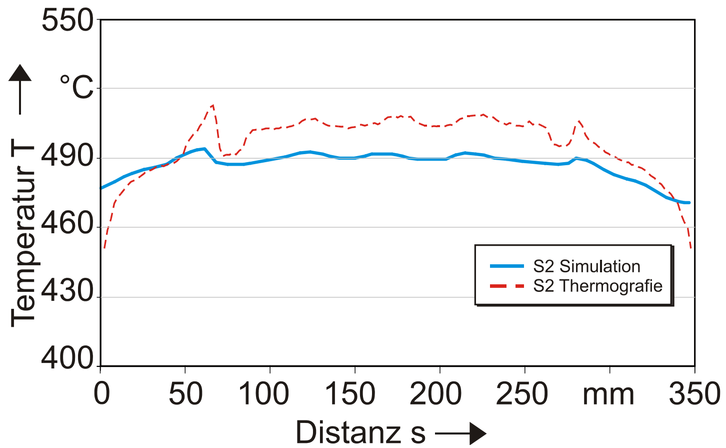
Simulation





Thermographie

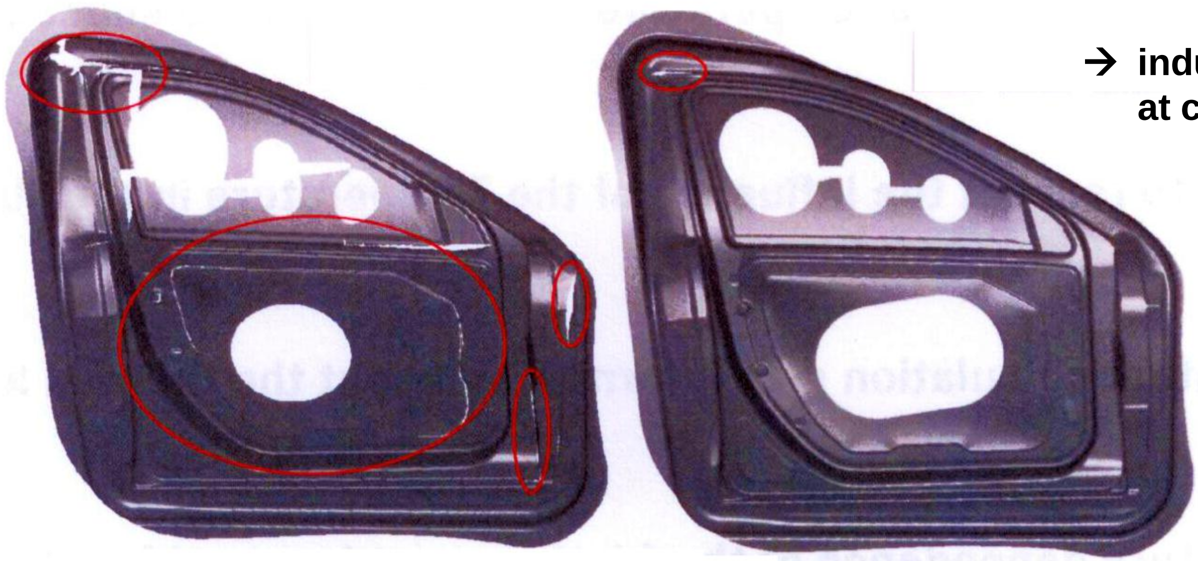




Heat supported coldforming of aluminum

The main task

1stage cold forming | **2 stage coldforming with local intermediate heattreatment (IHT)**

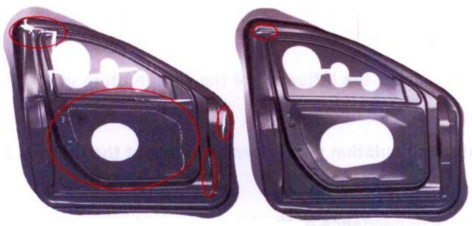


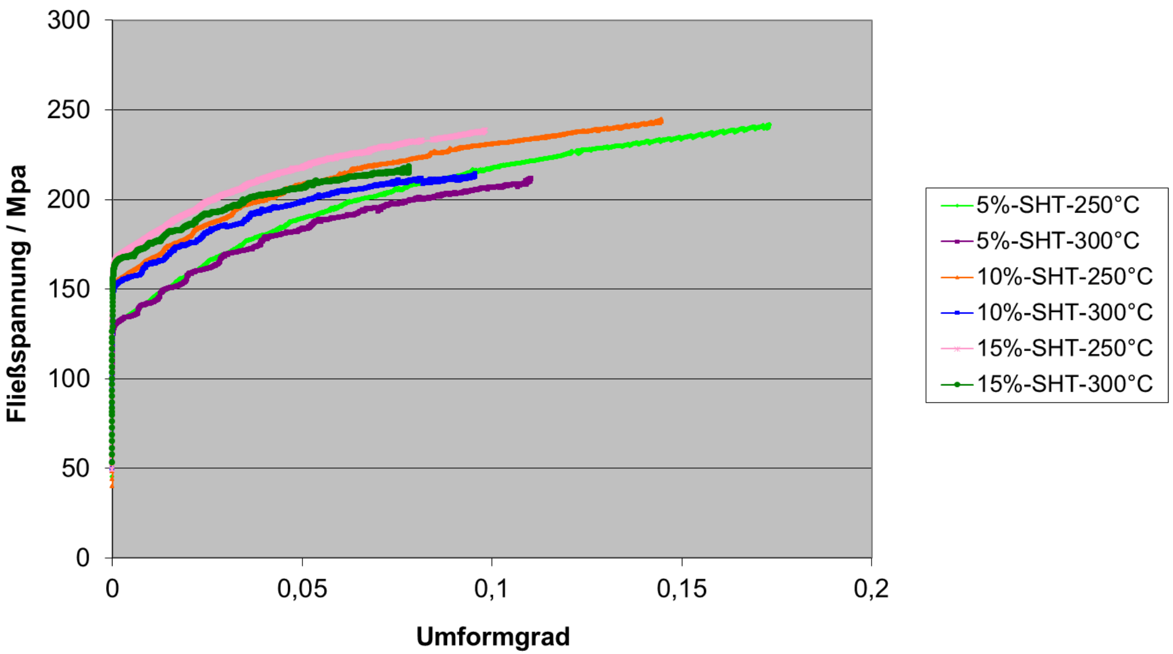
→ inductive heating at critical zones

Quelle: Prof. Roll Daimler AG, Automotive Grand Challenges 2011

- increased formability due to adapted material properties
- Systematic material calibration for various prestrain and heating temperature
- ***Integration into an existing materialmodel (MAT_36 MAT_133) possible?***

Experimental material characterization



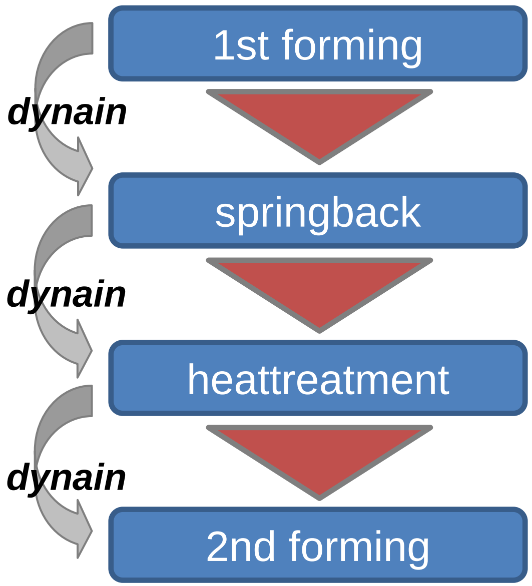


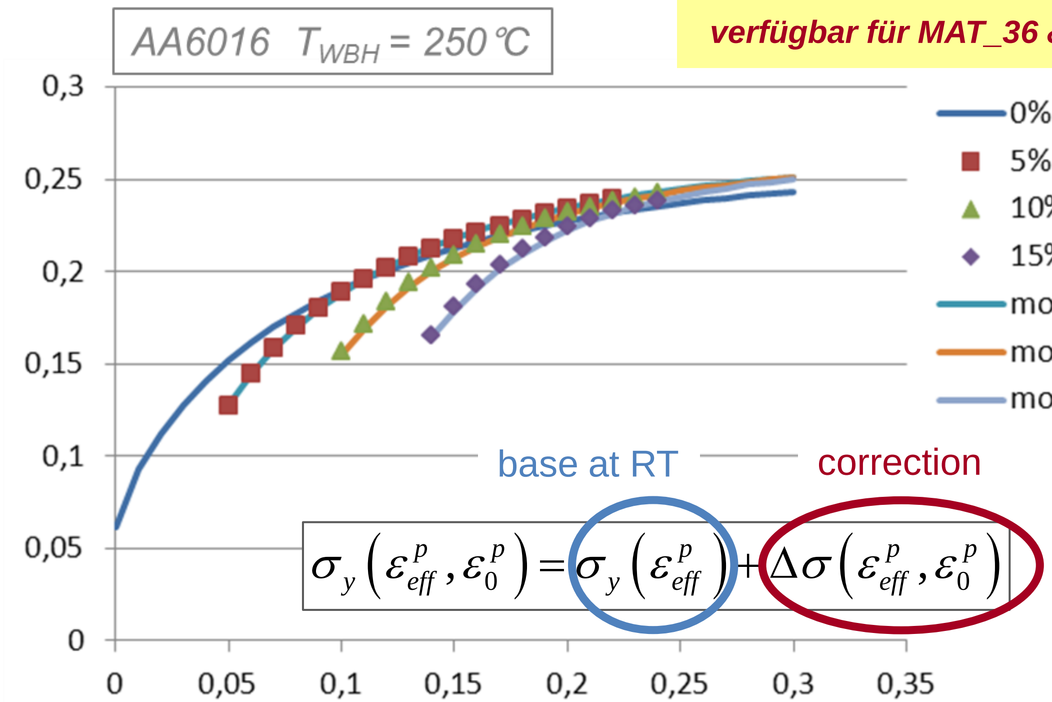
- Reduction of yield stress due to heat treatment
- Higher slope compared to base material → higher formability

→ **hardening curves should be parametrized over prestrain and IHT temperature**

The solution in LS-DYNA

verfügbar für MAT_36 & MAT_133





$$\sigma_y\left(\varepsilon_{eff}^p,\varepsilon_0^p\right)=\sigma_y\left(\varepsilon_{eff}^p\right)+\Delta\sigma\left(\varepsilon_{eff}^p,\varepsilon_0^p\right)$$

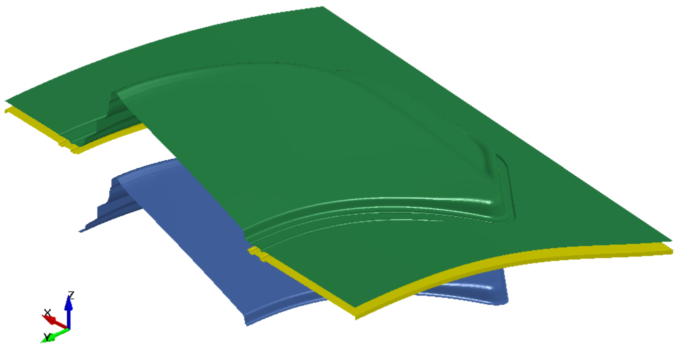
Springback simulation → unloading, equilibrium, elastic stresses

heat treatment simulation → reale temperature distibution → IHT temperature

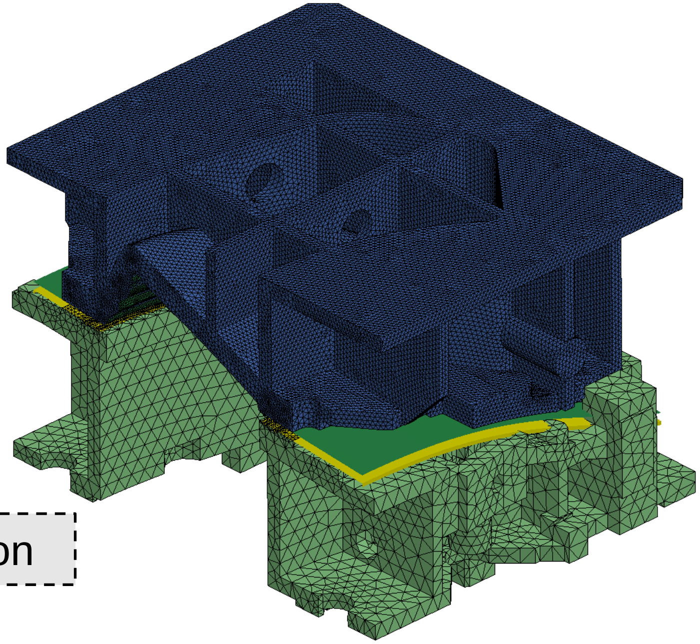
T_{WBH} = max{$T(t)$} evaluate correction term $\Delta\sigma$ → save in ***dynain***

prediction of frictional thermal tool load

compute and store friction energy in forming simulation

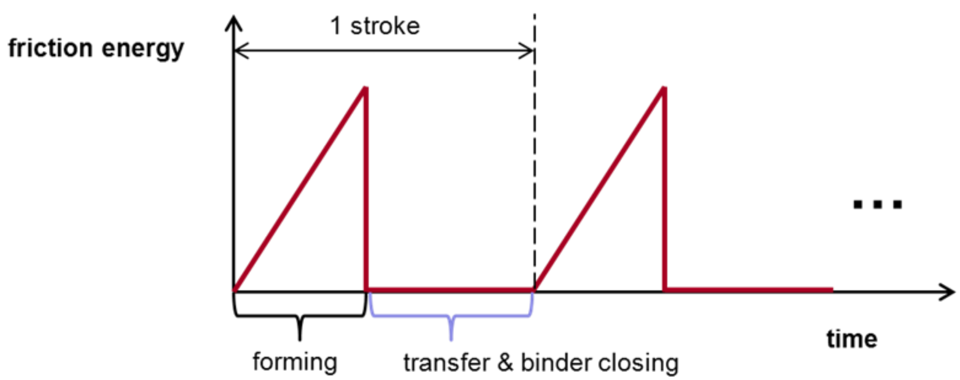


Convert energy to heat flux in a pure thermal simulation



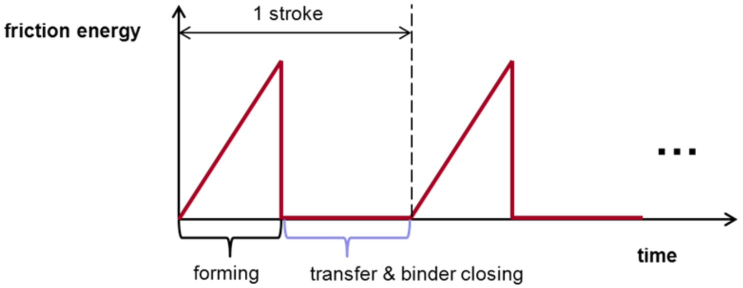
by courtesy of Adam Opel AG

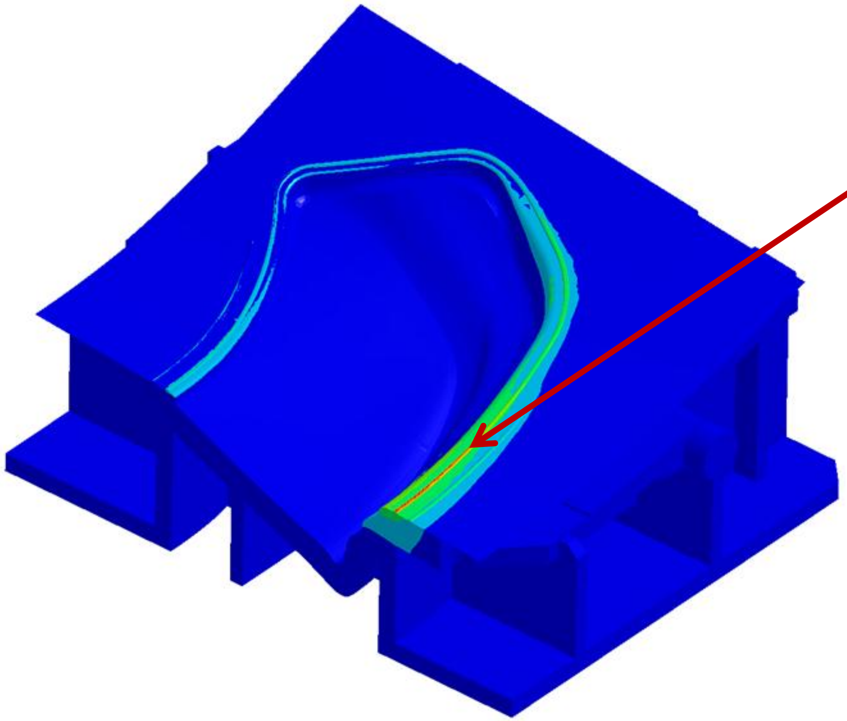
Repeat this cycle for many times in one single simulation

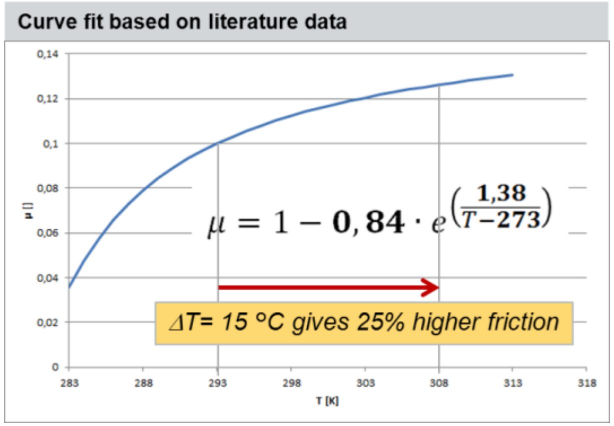


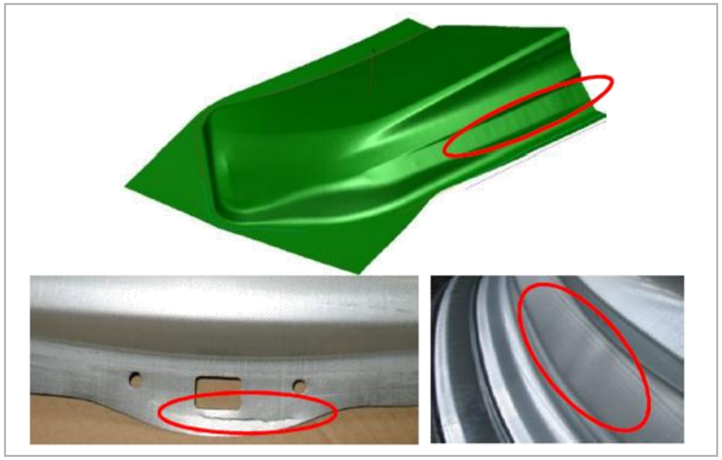
prediction of frictional thermal tool load

Result after 200 strokes @ 15 strokes per minute









by courtesy of Adam Opel AG

prediction of frictional thermal tool load

Result after 200 strokes @ 15 strokes per minute

1 110 389 TET4 Elements

50 000 shell elements

275 736 nodes

stroke rate 15 min^{-1}

stroke time 4s, forming time 0.61s

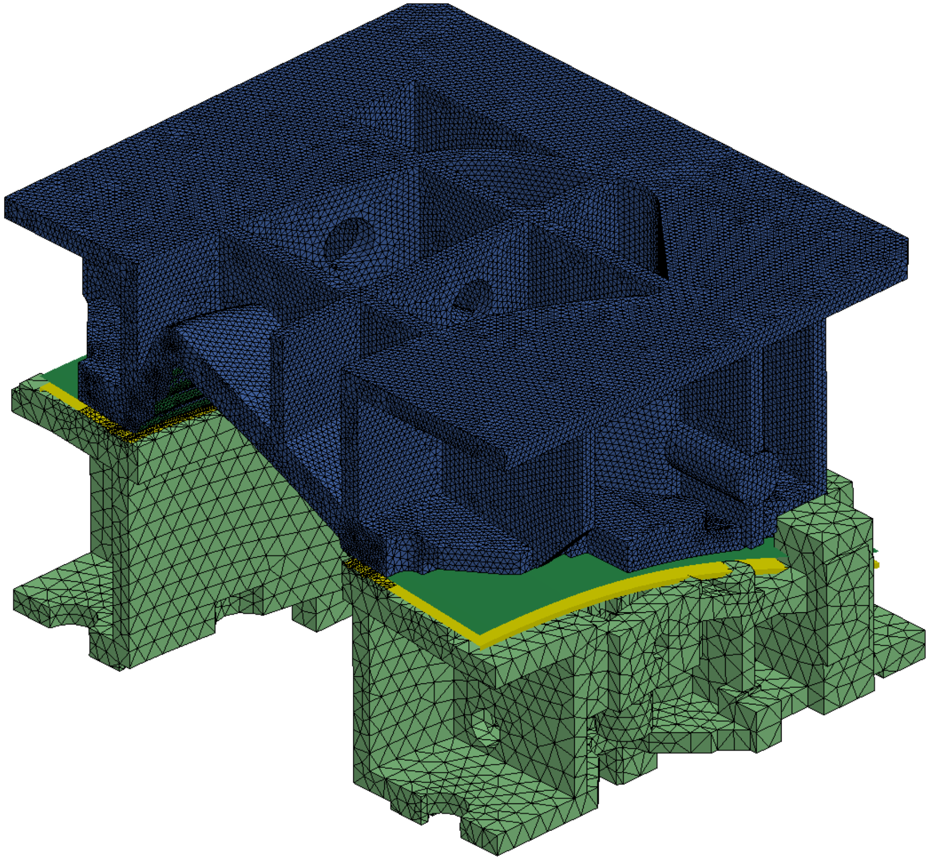
total time for 200 strokes 800s

8 thermal timesteps per stroke

1600 timesteps for entire solution

running with mpp971_d_R6.1

Total CPU time 2½ hours @ 4 cores



→ solve the 200 strokes thermal is much faster than 1 stroke forming simulation

questions