LS-DYNA Conference 2017

An Analysis of the Hot-forming process with thermal and ICFD simulations

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profile of the Aalen University

- 5.700 students
- over 50 bachelor- and master- courses
- ranking in Germany (from total of 102 universities of applied sciences)
  - economic science 1. place
  - mechanical engineering 3. place
- institution for further education (occupational studies)
  - 4 bachelor courses
  - 6 master courses
- 270 scientific papers
- 120 research associates
- 50 doctoral candidates

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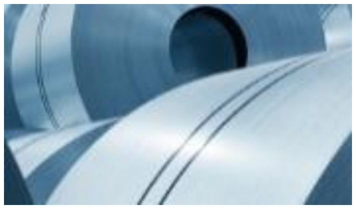
Four strong Divisions




Steel	Special Steel	Metal Engineering	Metal Forming
Global quality leader	**Global leader**	**Global leader**	**Global leader**
Global quality leadership in highest quality steel strip and global market leader in heavy plate for the most sophisticated applications as well as casings for large turbines.	Global leadership in tool steel; leading position in high speed steel and special forged parts	European market leader in rails and processed wire, global market leader in turnout technology as well as in complete railway systems; leading position for welding consumables and seamless tubes	Center of competence for highly refined sections, tubes, and precision strip steel products as well as for ready-to-install system components made of pressed, stamped and roll-formed parts

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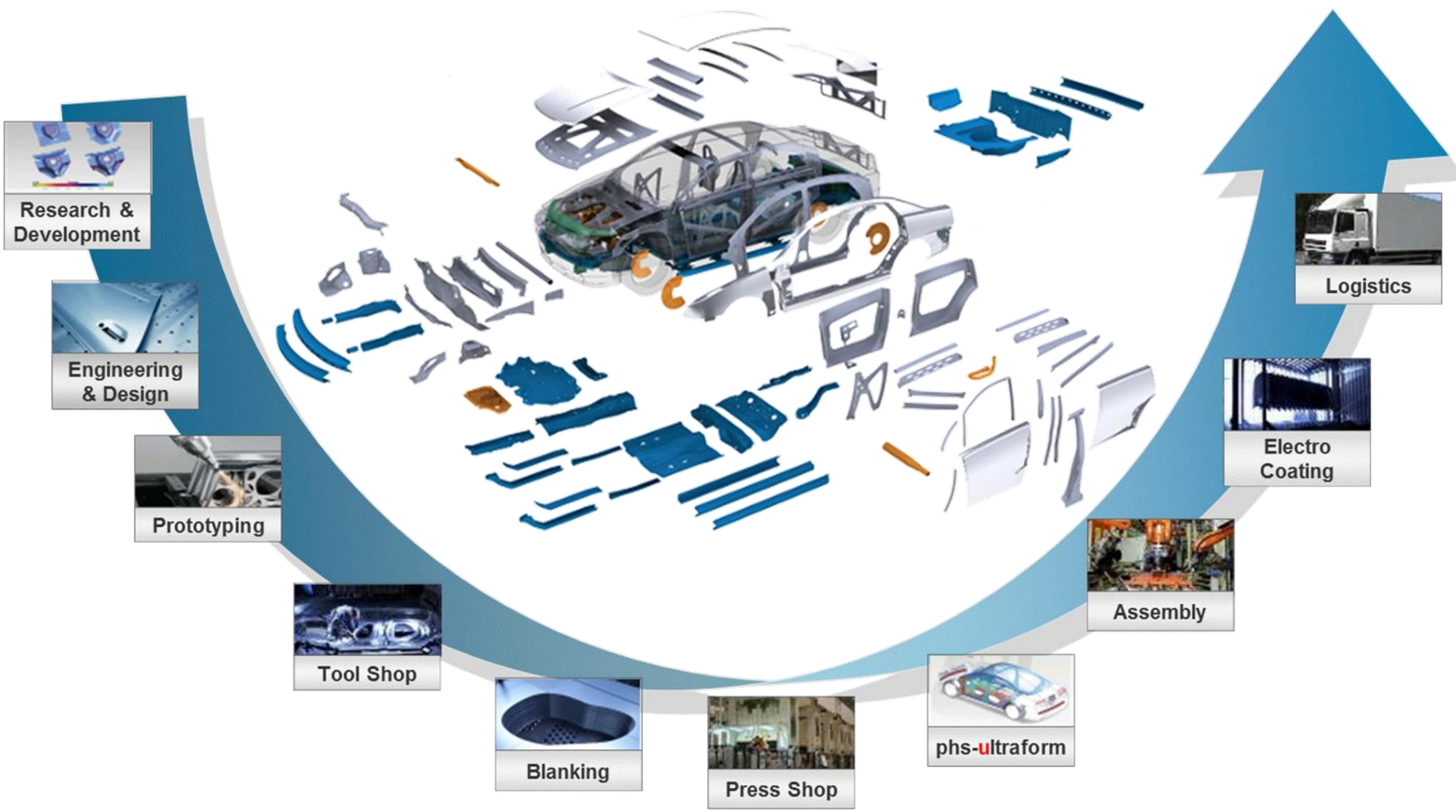
portfolio metal forming division

- all around Body in White



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voestalpine Automotive Components GmbH & Co. KG

voestalpine Automotive Components GmbH & Co. KG
Schwäbisch Gmünd (DE)

- employees: 650
- press lines: 2
- press hardening lines: 5

business areas:

- pressing / stamping / assembly
- press hardening (phs-ultraform)
- engineering / die making / tooling
- prototyping

Formation

- 1954 – startup priv. die making company

Growth and Acquisition

- 1997 – acquisition by Polynorm; first aluminium applications
- 2001 – opening of new plant in Schw. Gmünd
- 2002 – Polynorm became a voestalpine company

Development of phs-ultraform

phs-ultraform by voestalpine

- 2003 – start of development phs-ultraform
- 2008 – start of 1st series production
- 2010 – start of development phs-directform
- 2012 – global rollout
- 2016 – first series installation phs-directform

Development of aluminium warm forming

- 2007 – start of development of aluminium warm forming
- 2010 – development for high strength 7000 aloys
- 2014 – first series application semi hot forming of 7075 alloy

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agenda

- description of the problem
- thermal & ICFD Analysis in Hot-Forming
  - why ICFD Analysis
  - coupling of the problem
  - decoupling of the problem
- transfer of information for standalone solutions
  - ICFD Analysis steady state
  - export information from 2D to 3D mesh
  - thermal calculation
- results of the analyses
- conclusion

main chapter

DESCRIPTION OF THE PROBLEM

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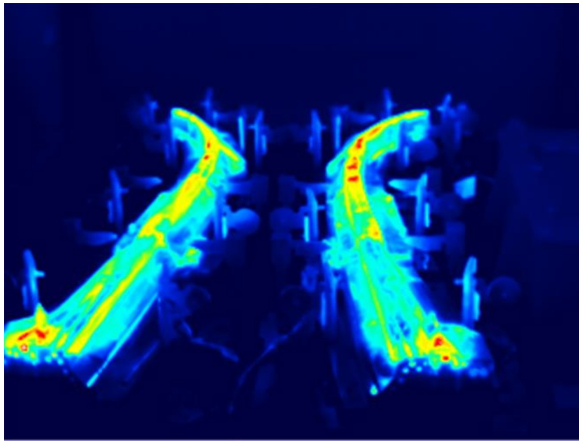
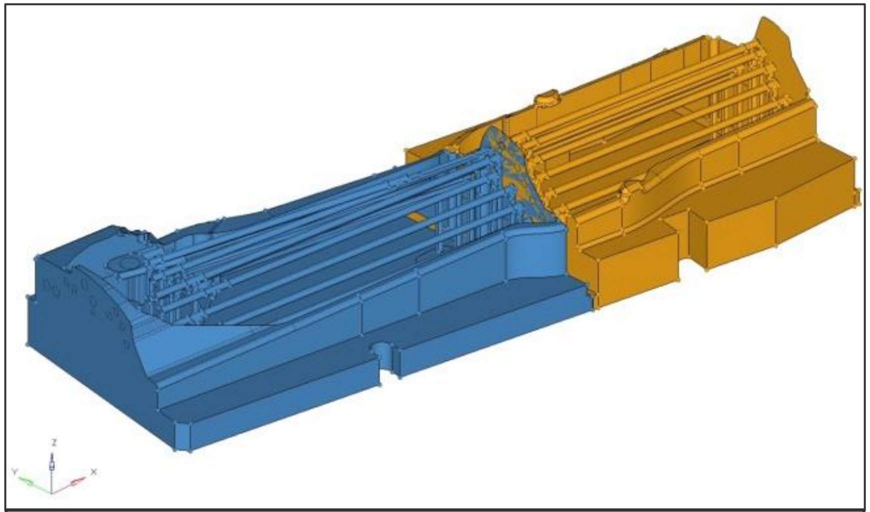
description of the problem

- is it possible to catch the effects from ICFD-Analysis for the heating up of the forming die?



  - considerations:
    - simulation time
    - cost
    - Know How
    - handling in pre- & post-processing



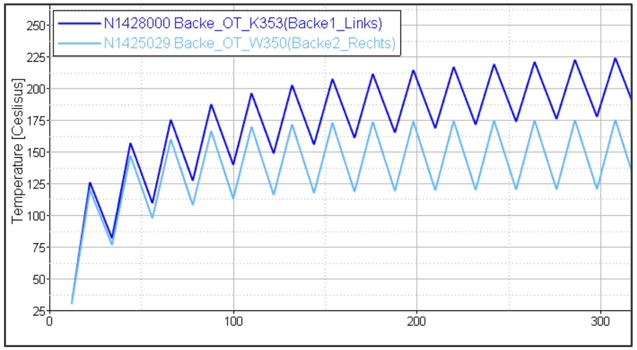
2 *from* 5 *Segments for the lower side of the forming tool*

- dimension of the tool:
  - original [mm]:
    - 2200 x 500 x 600
  - reduced [mm]:
    - 1000 x 500 x 600

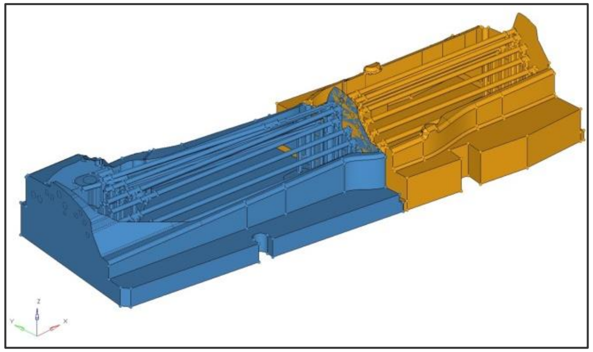
description of the problem

- system boundaries

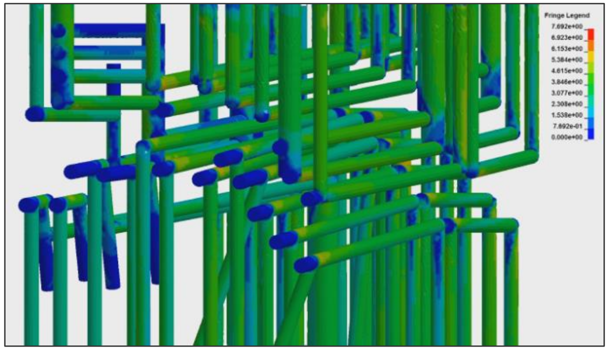
thermal transient Analysis
(29 cycles)



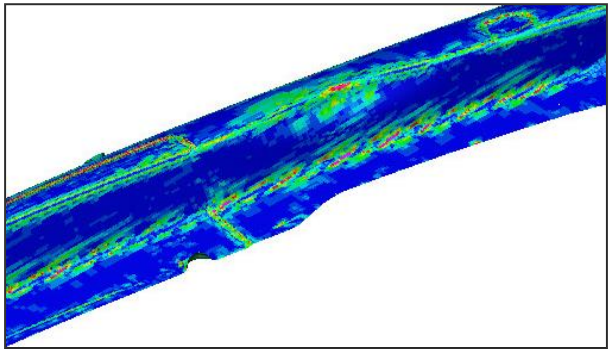
only considering a section
of the tool (~40%)



full ICFD-Analysis



no mechanical component



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THERMAL & ICFD ANALYSIS IN HOT-FORMING

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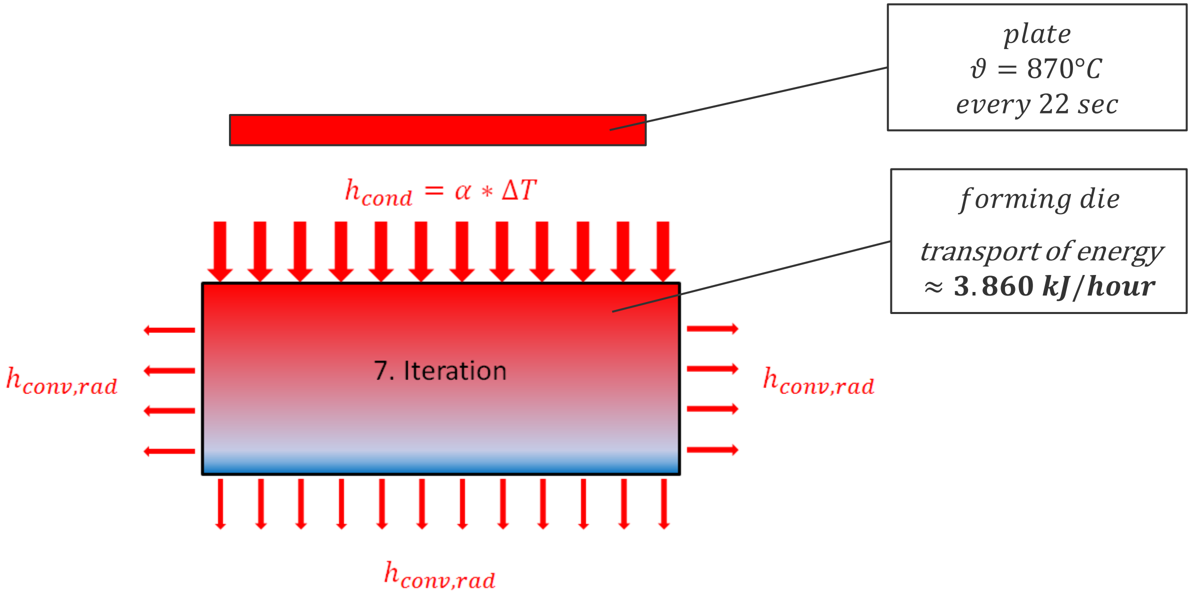
why ICFD Analysis

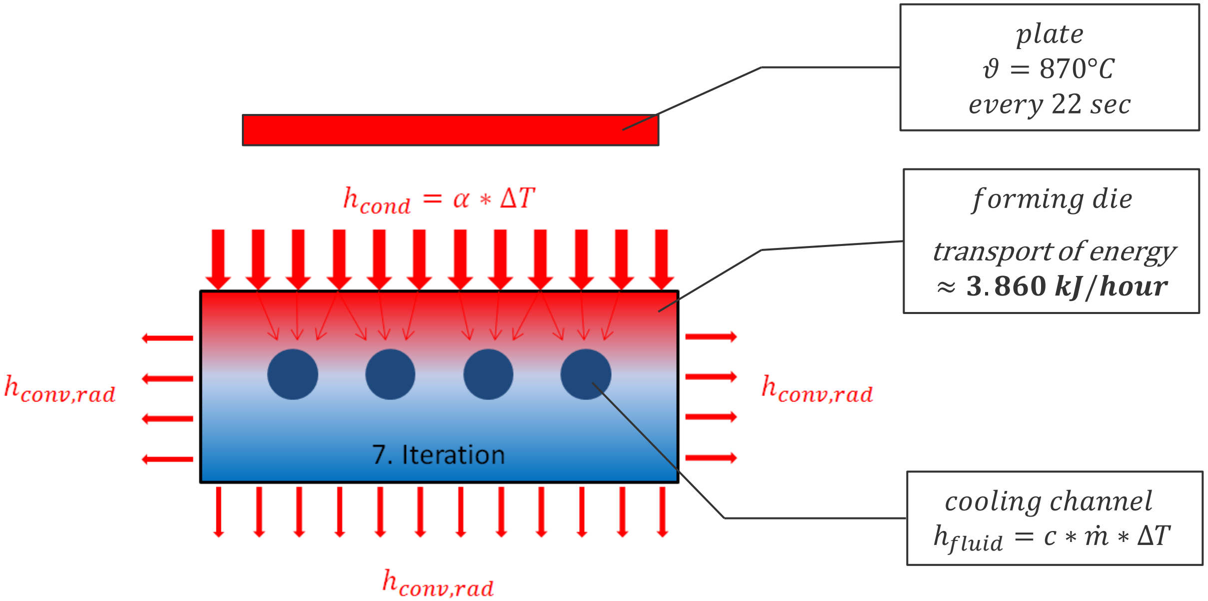
- hot-forming for press-hardening parts need high cooling rate (≥27 K/s) for full martensite conversion [1]



- with out various mechanisms the die get to hot and the temperature difference get to low
- full martensite conversion can no longer be provided

why ICFD Analysis

- to increase heat transport in the die, cooling channel are necessary

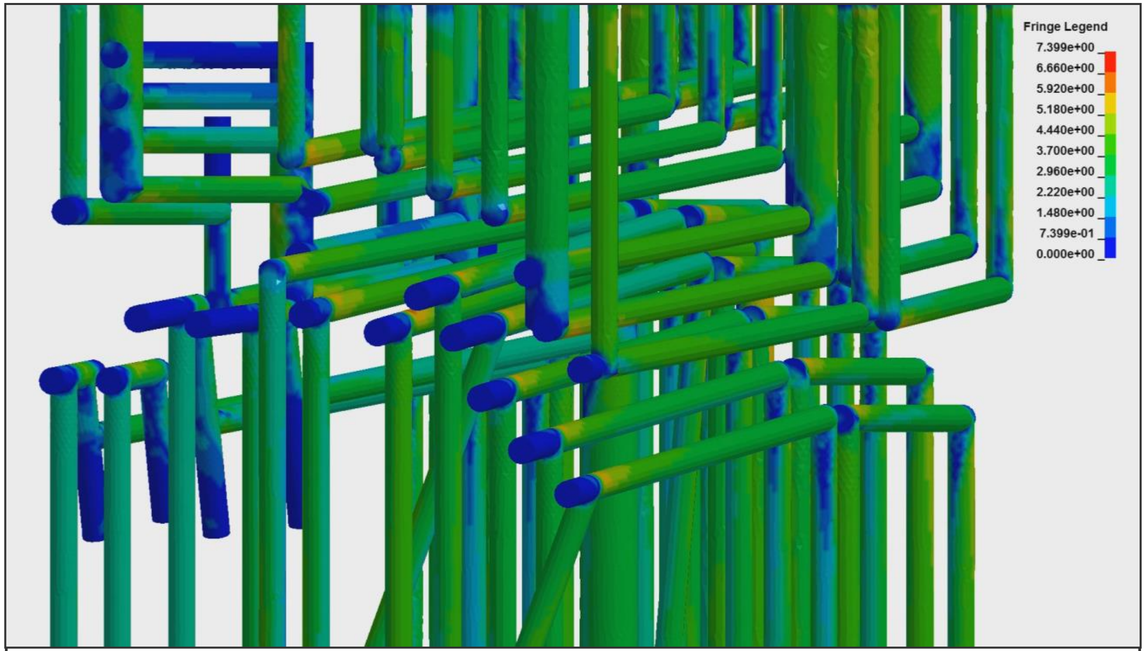


- keep the die on an acceptable level for the heating up over time
- $h_{fluid} \approx 580 + 2100 * v^{0,5}$

What is the value of v? And is it constant?

why ICFD Analysis

- complex cooling channels in the Hot-forming tool result in different pressure drops and lead to various velocity profiles



velocity magnitude [m/s] for the cooling pipes in the die

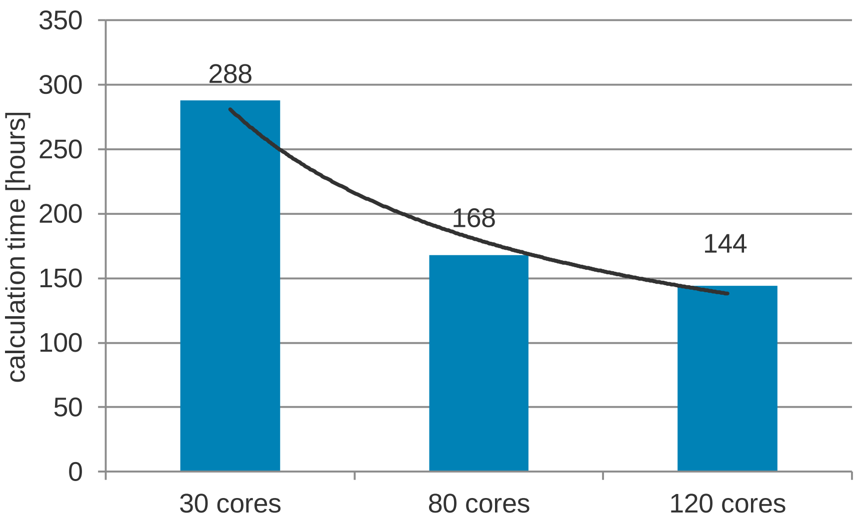
tetraeder mehs with *boundary layers* $(n = 3)$
6.000.000 elements
only modeling
round about 40% of
the cooling geometrie

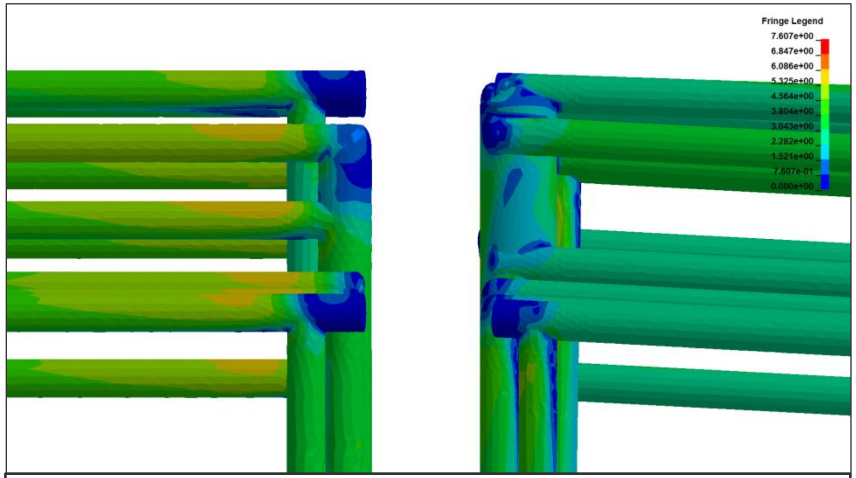
- the ICFD Analysis can capture these kind of effects
- compressibility can be neglected (ma<0.3, fluid water)
- high hardware requirements for the ICFD Analysis

coupling of the problem

- transient ICFD calculation:
  - 6,000,000 elements
  - k-epsilon model
  - 3 boundary layers
  - automatic time step
  - 32 cpu's // 80GB RAM

- **12 days** of calculation time
- catching **4 second** real time
- no big changes in velocity
- heating up on low velocity areas need a lot of real time

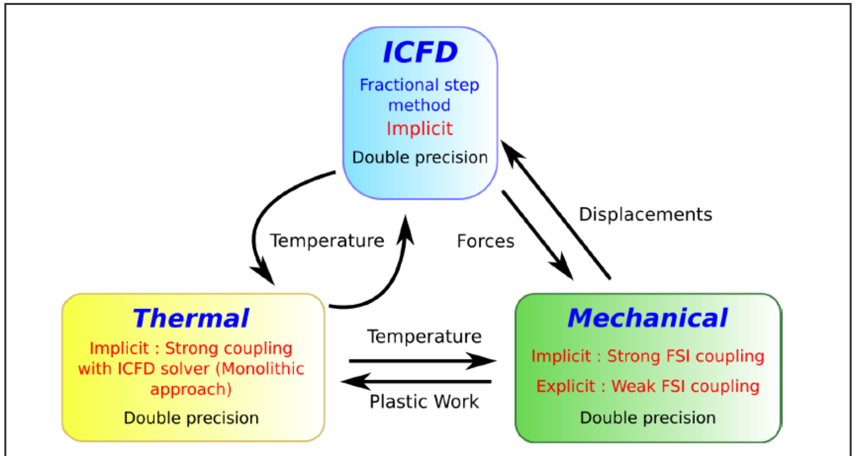




low velocity areas in the cooling system

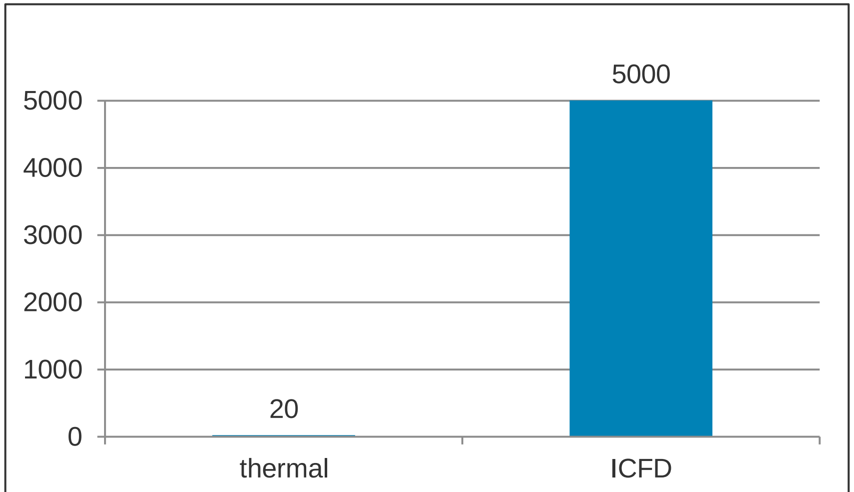
coupling of the problem

- time steps for calculation:
  - $dt_{ICFD} \approx 2.0 * 10^{-4}s$
  - $dt_{thermal} \approx 5.0 * 10^{-2}s$
  - $dt_{thermal}/dt_{ICFD} = 250$



Multiphysics workflow for thermal, ICFD and mechanical [2]

- strong coupling of the problem
  - $dt_{thermal} = dt_{ICFD}$
  - Increase of thermal calculation time
  - old calculation time ≈ 10 min
  - new calculation time ≈ **41 hours**



time steps for one second of real time in simulation

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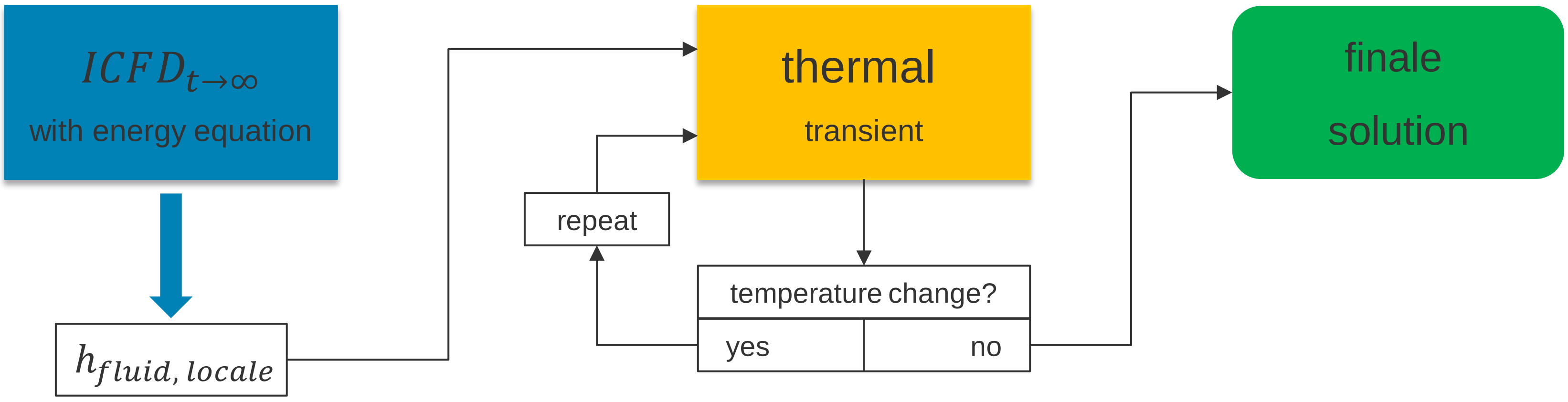
coupling of the problem

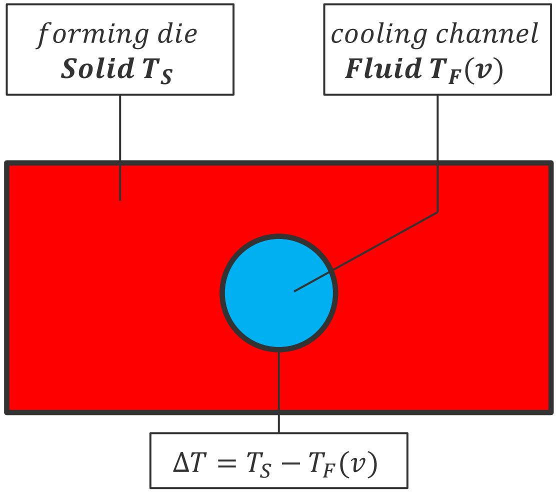
- conclusions of the data generated by now:
  - small dt_{ICFD}
  - large $dt_{thermal}$
  - different velocities in the cooling channels
  - no big changes of velocity on the single elements (local)
  - high times for the heating up process

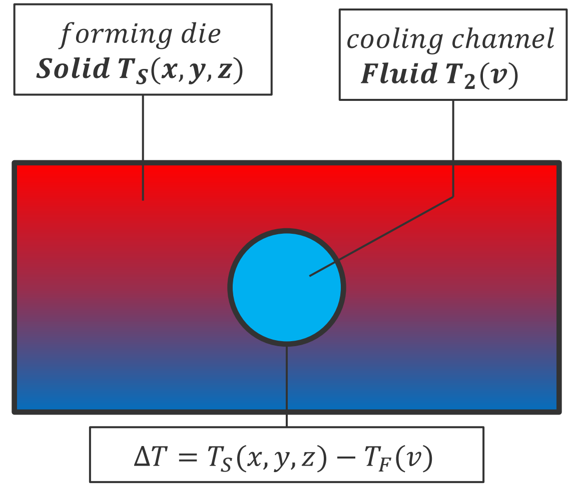
- decoupling of the solution:



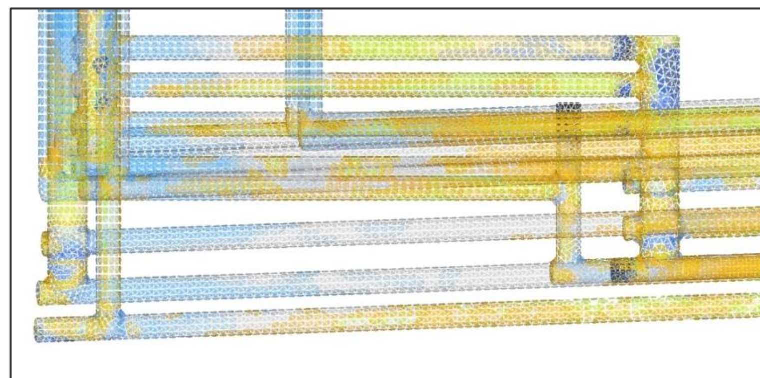
decoupling of the problem

- ΔT in $ICFD_{t \to \infty}$





- transfer of set’s for heat transfer
  - define sectors for h_{fluid}
  - manual mapping difficult
  - export of 2D surface mesh
  - 3D solid mesh for thermal calculation



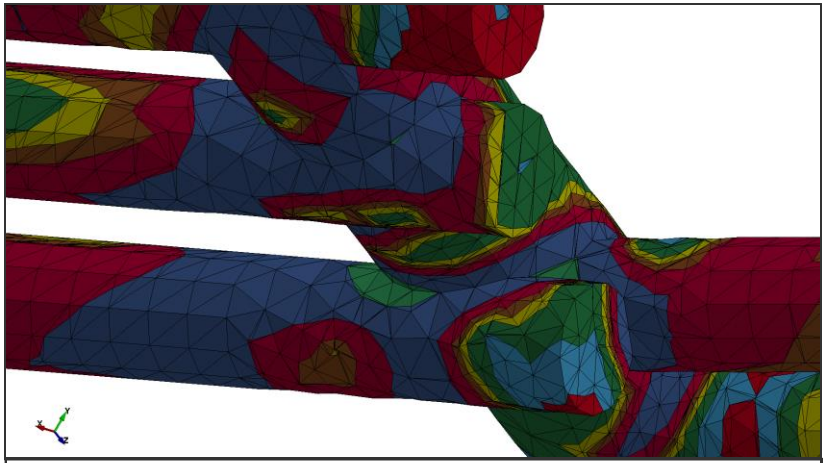
sectors for h_{fluid} from the ICFD Analysis

main chapter

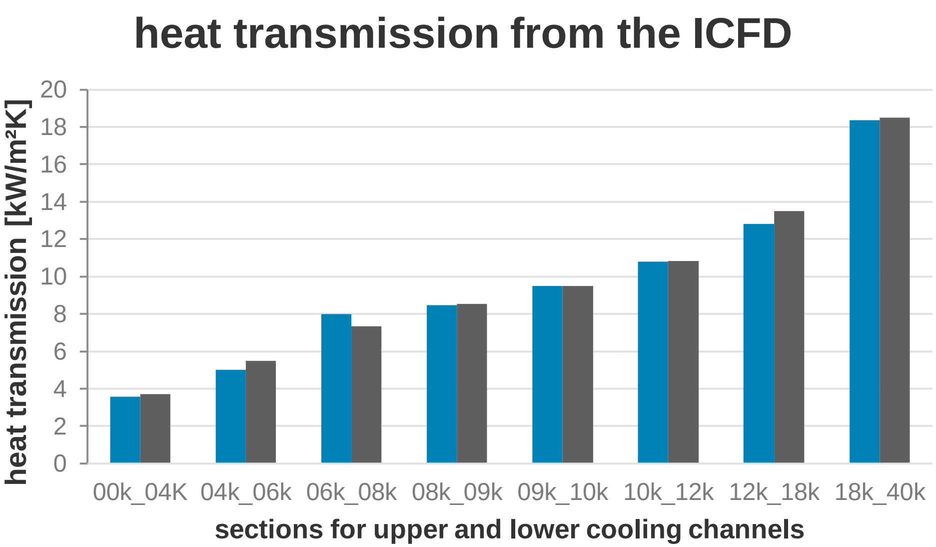
TRANSFER OF INFORMATION FOR STANDALONE SOLUTIONS

ICFD Analysis steady state

- sections for the heat transmission h_{fluid}
  - conventional estimate for $h_{fluid} \sim 5\ kW/m^2K$
  - calculated sections from $h_{fluid} \sim 0 - 40\ kW/m^2K$
  - interpolation of 2D mesh in the export file (mesh modifications)

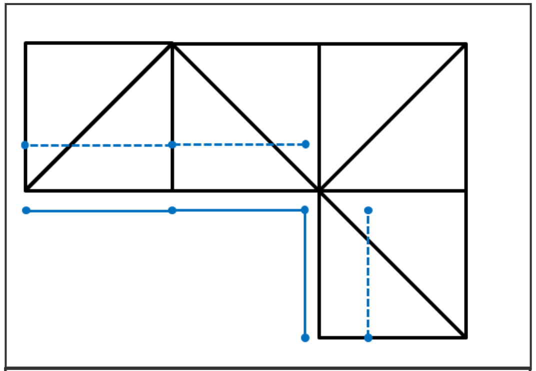


2D meshes from the export file

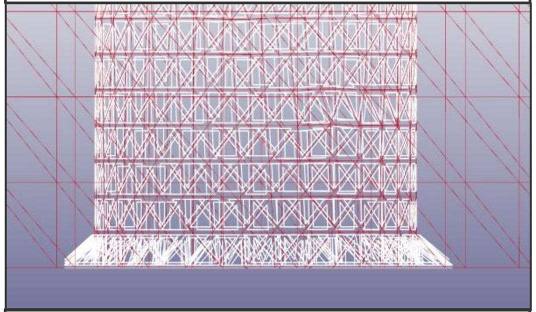


transfer of information 2D to 3D

- how to get information from 2D to 3D mesh?
  - use wall mesh from ICFD for 3D mesh generation
  - save nodes on the cooling channels
  - use penetration/intersection tool to identify solid faces on the 3D mesh in combination with the nodes
  - create your segment sets for h_{fluid}
  - export mesh and import to LS-PrePost
  - save segment sets to file
  - remove element faces with double function
  - save a segment set for the complete wall
  - add attach faces for the wall segment (2-3 times)
  - remove faces in the solid
  - use *Boundary_Convection to define the different heat transfers



ICFD 2D mesh with virtual thickness and 3D solid mesh



wrong element faces at edge regions

a lot of handwork, high error rate,

high temporal expenditure which rise with more sections

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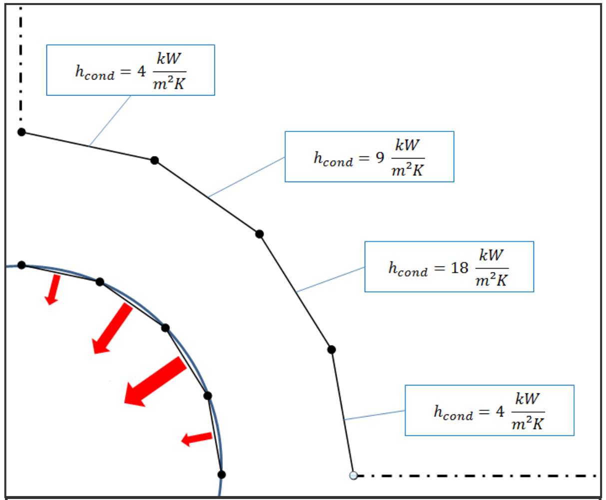
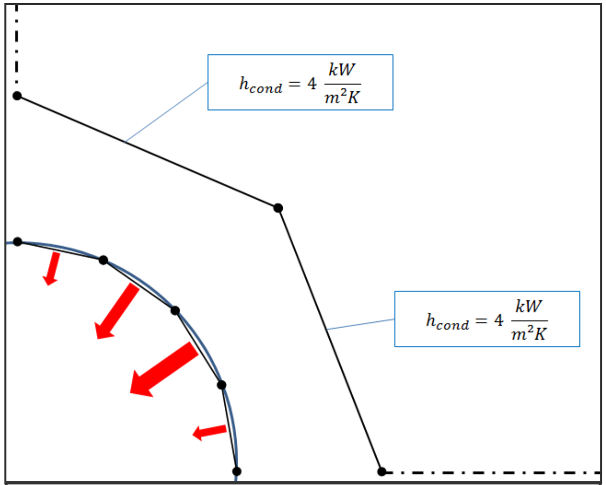
transfer of information 2D to 3D

- wall mesh near cooling regions for the thermal calculation
  - ICFD & thermal mesh with same element length
    - high element intensity near cooling areas
    - full transfer of information
    - ICFD heat transfer coefficients equal to the thermal calculations
  - ICFD & thermal mesh with different element length
    - significant reduction of the element number
    - different heat transfer for same element face
    - only the lowest heat transfer coefficient for the thermal calculation

by using a coarse mesh for thermal calculation most of the information from ICFD will get **lost**!



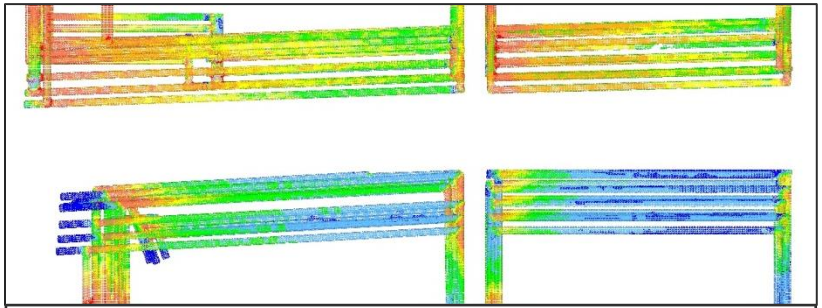
fine mesh in areas of cooling channel



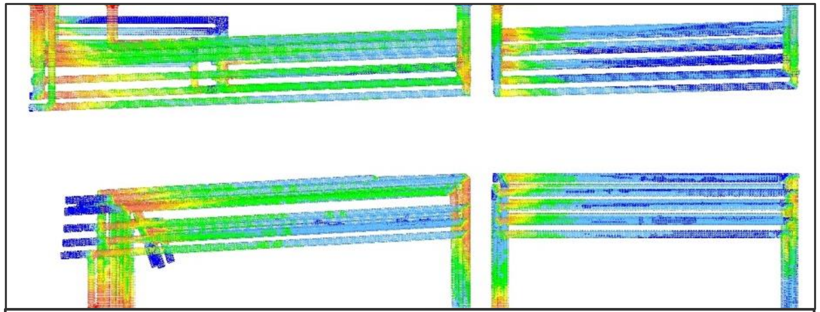
coarse mesh in areas of cooling channel

transfer of information 2D to 3D

- heat transmission and first cell height in k-epsilon-model

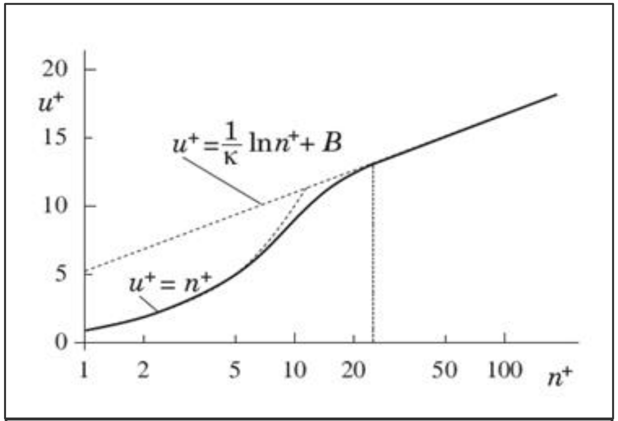


$h_{fluid}\ for\ y^{+} \sim 1\ (upper\ Tool)$



$h_{fluid}\ for\ y^{+} \sim 30 - 45$

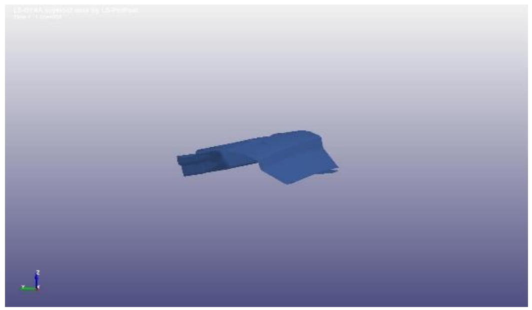
- influence of first panel thickness
  - undersize y^{+} value
  - high velocity in wall proximity
  - strongly increasing of h_{fluid}

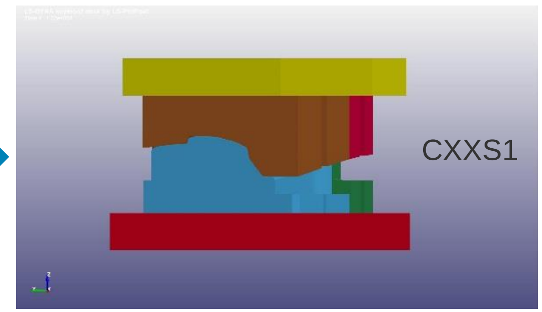


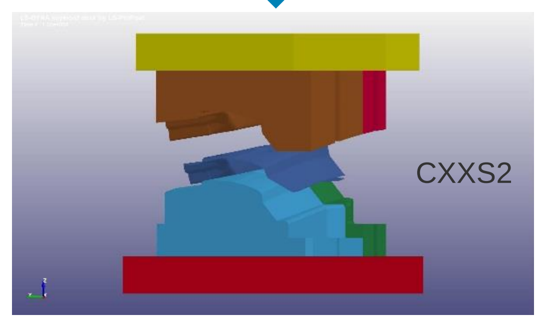
$(n^{+} = y^{+})\ law\ of\ the\ wall$ [4]

thermal calculation

- overview for the thermal calculation







- every picture is a separate calculation
- C = Cycle   S = Step
- every cycle hast two steps
  - S1: Holding (heating up of the tool)
  - S2: Recovery (cool down of the tool)

abort calculation

start of documentation

changes in the solution

no

yes

thermal calculation

- unique calculation for the plate
  - transfer from furnace to the forming die
  - use thick shell definition for the plate
  - convection & **<u>radiation</u>**
  - different convection for top & bottom surface
  - use interface_springback to save temperature profile

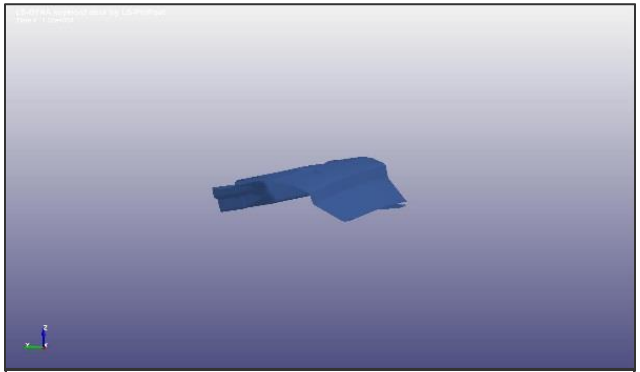
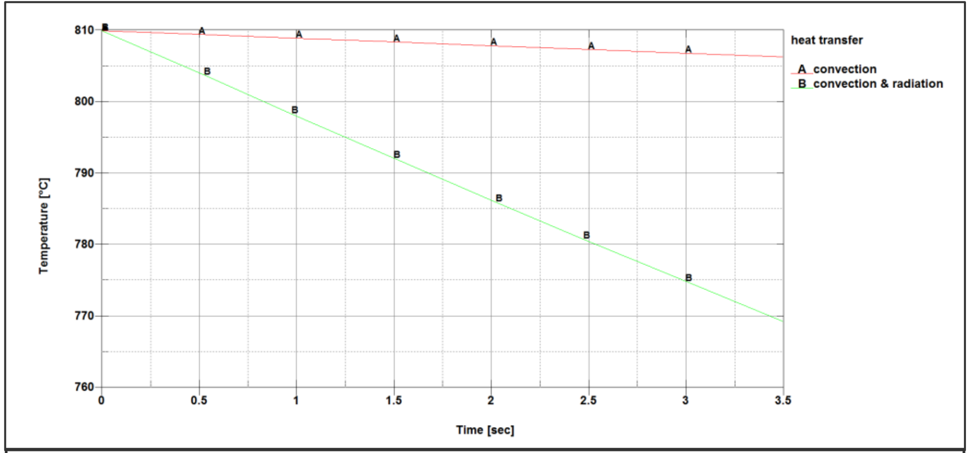
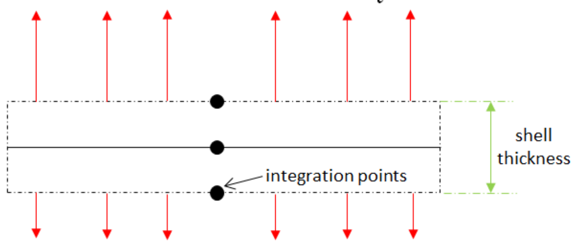


plate for the hot forming process



heat transfer with & with out radiation

$$h_{top} = [0.14(Gr * Pr)]^{0.33}\frac{k}{l}$$



$$h_{bot} = [0.27(Gr * Pr)]^{0.25}\frac{k}{l}$$

thick shell for convection definition [3]

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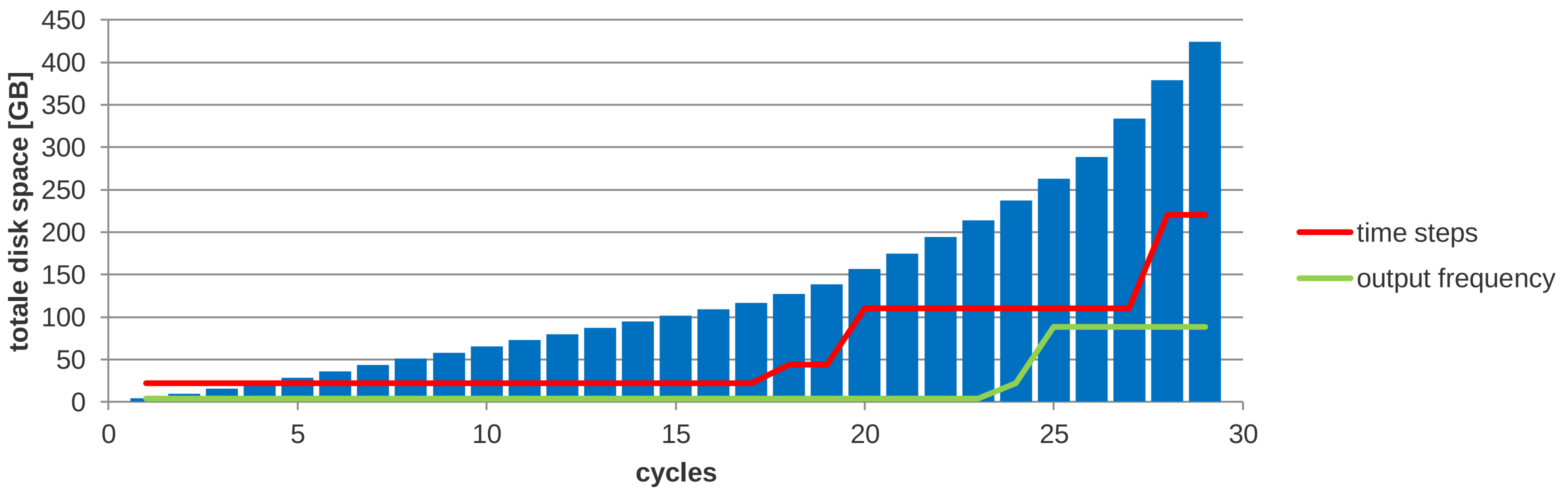
thermal calculation

- 29 cycle with 2 steps in thermal calculation
  - without any mechanical calculation penetration problems in the contact will occur (*control_contact)
  - deactivate restart file (SMP d=nodump) in the execution line to reduce required disk space
  - start with large time steps $\left(dt_{thermal} \gg dt_{explicit}\right)$
  - only plot the files that are necessary
  - use *interface_springback to save temperature profile for next step/cycle
  - use “LS-Run” to define your job list (58 jobs for calculation!)

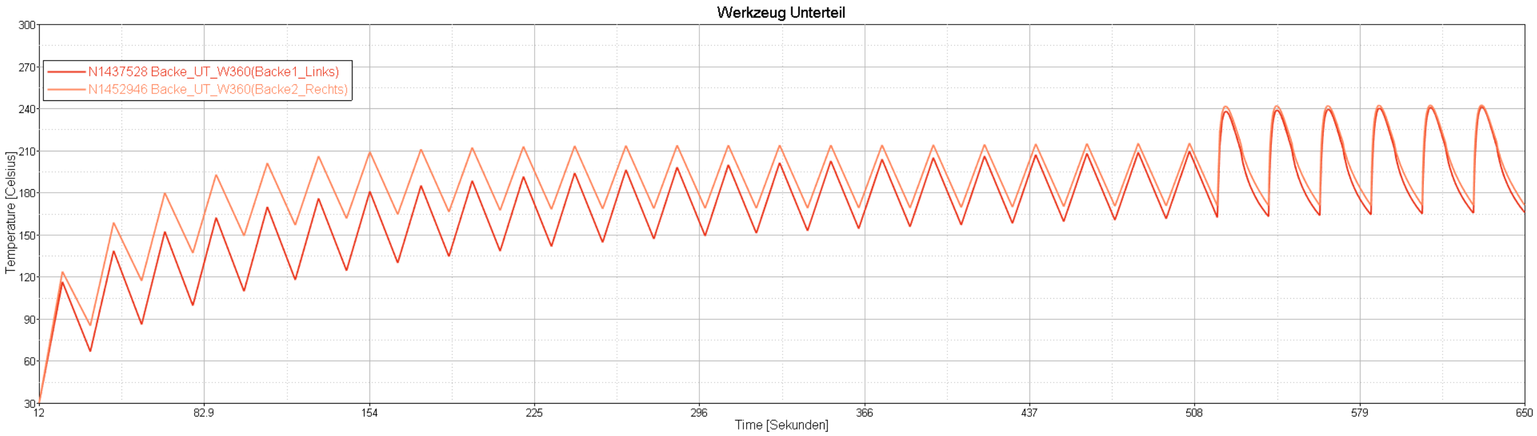


main chapter

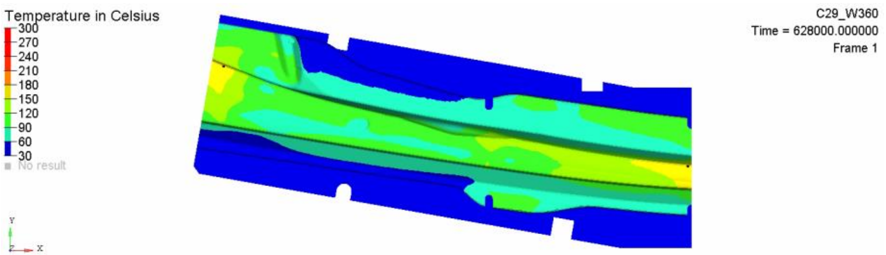
RESULTS OF ANALYSES

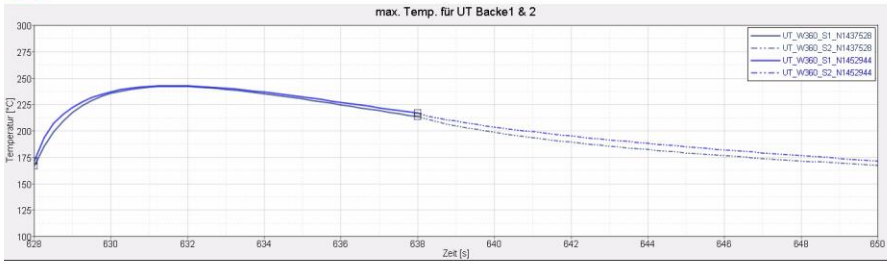
results of analyses

- steady state vibration



  - hottest temperature shortly after beginning of the holding time
  - changes in the graph result from t_{plot} and not from the time step
  - only little changes for $dt_{thermal} \sim dt_{explicit}$





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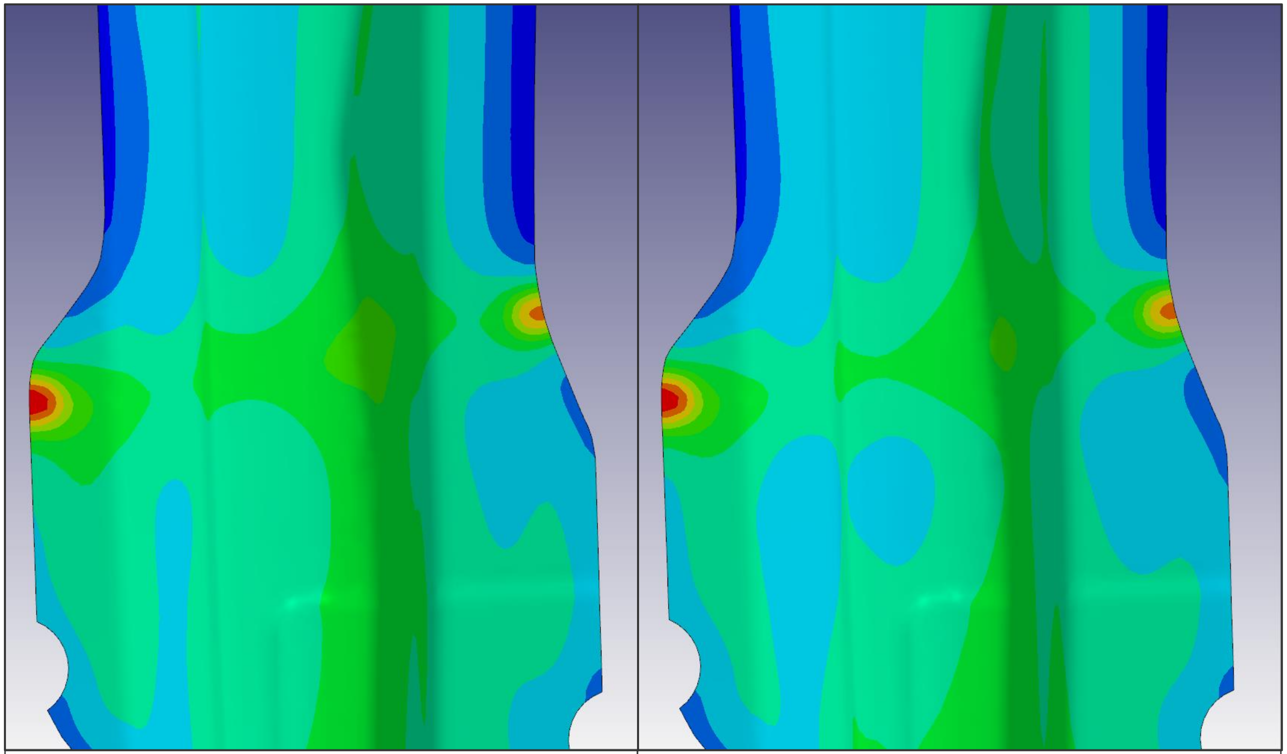
results of analyses

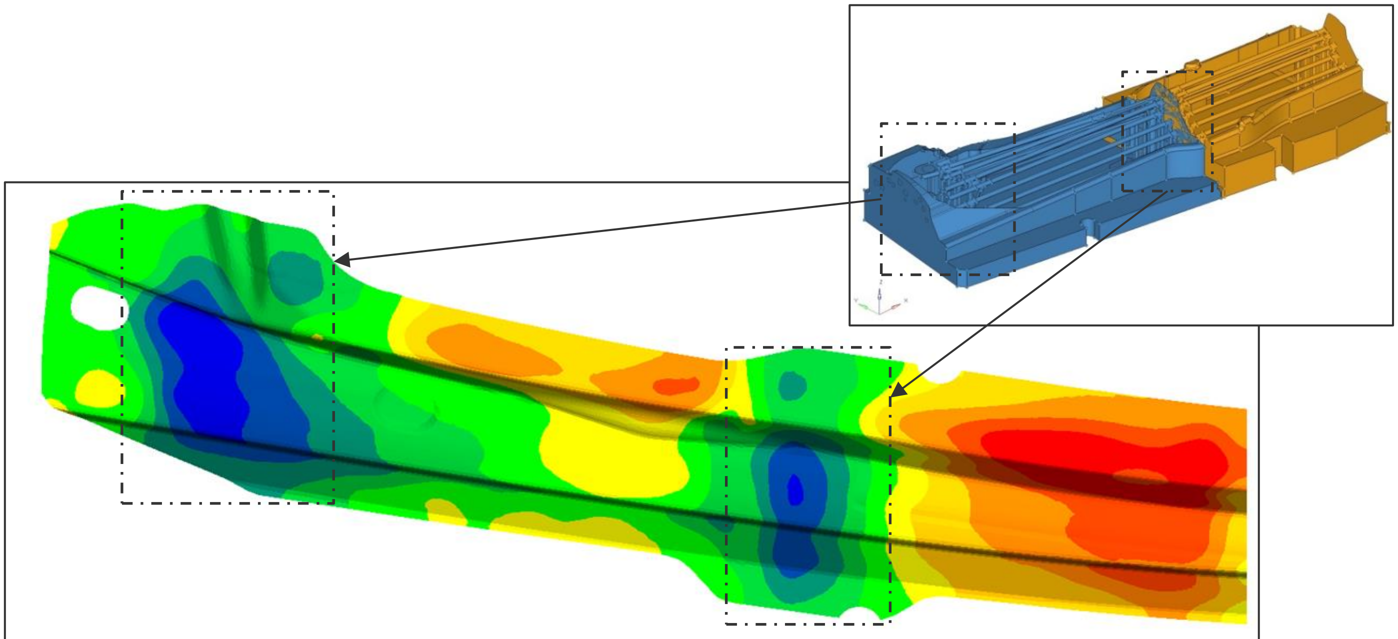
- temperature profile of the plate with constant and ICFD cooling
  - the considered area at the tool side is where horizontal und vertical cooling channels meet together
  - increase of cooling performance in areas with high velocity profiles (pressure drops)



temperature profile with constant cooling	temperatur profile with icfd cooling

results of analyses

- superposition for the results of the different cooling system
  - the results with constant cooling gets factor (-1)
  - the results with ICFD cooling gets factor (+1)
  - blue to green regions have lower temperatures with the ICFD results
  - red to yellow regions have higher temperatures with the ICFD results



$Temperature\ differences\ for\ the\ different\ cooling\ definitions\ (ICFD + 1\ //\ constant - 1)$

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CONCLUSION

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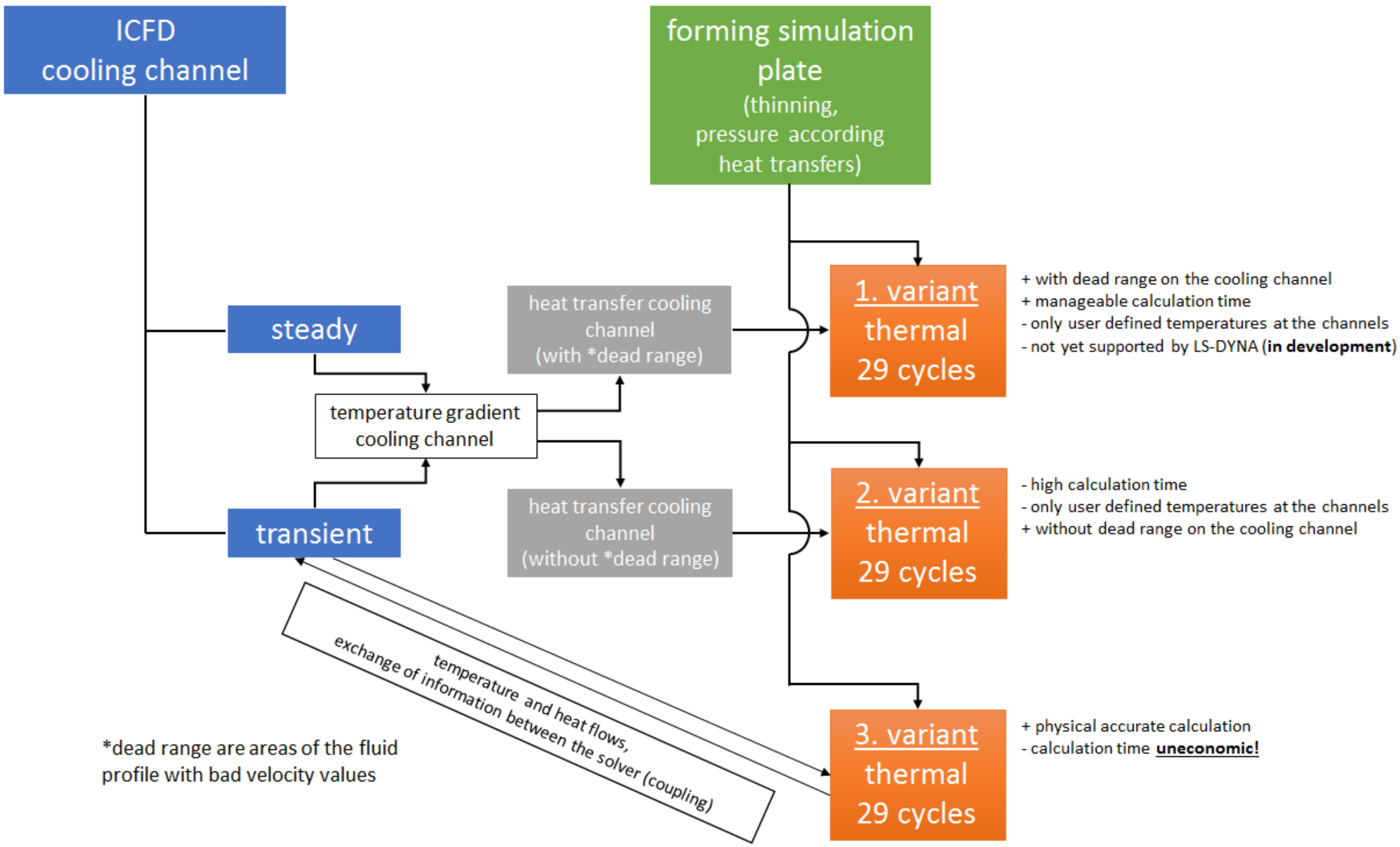
summary

- ways to solve the different disciplines

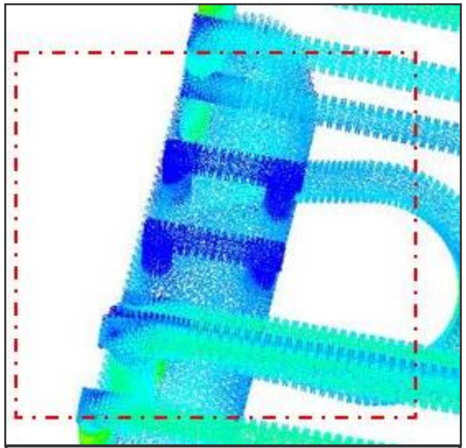


summary

- is the ICFD-Analysis helpful in the area of hot-forming?

  - effort:
    - experienced engineers in the area of CFD-Analysis
      - transient or steady state?
      - turbulence model?
    - separate tool for fluid mesh generation

  - benefit:
    - better prediction of cooling performance
    - local effects can be captured (dead range)
    - mistakes in the cooling system can be recognized and corrected in the digital product development



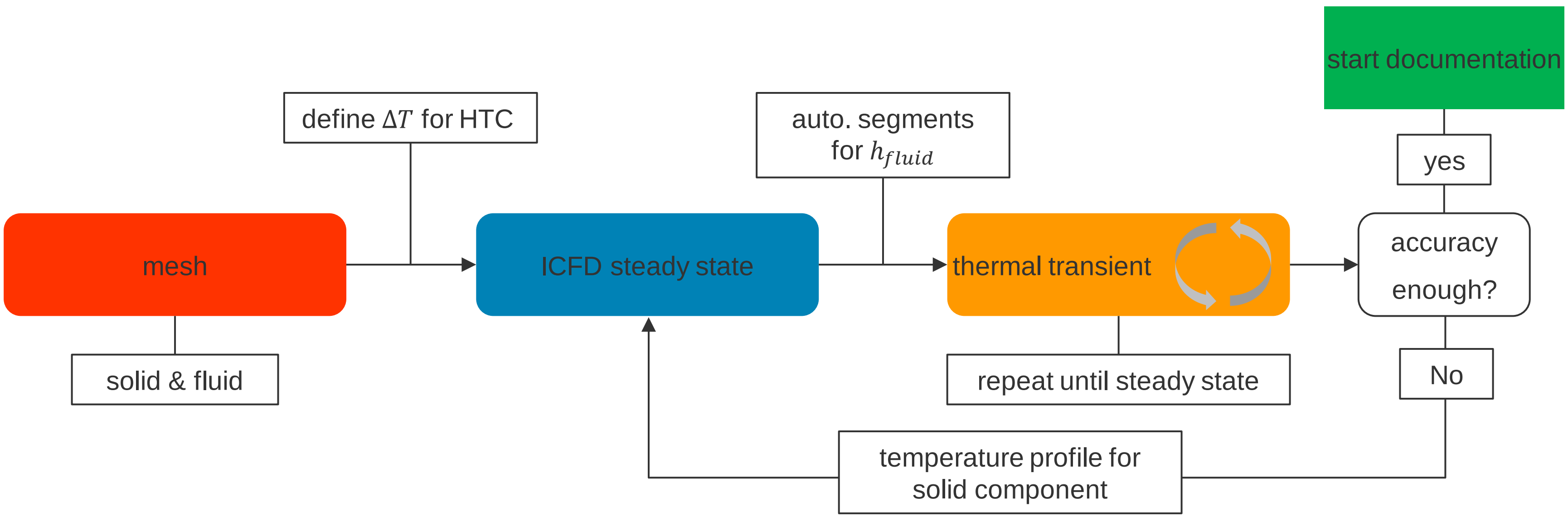
example for an construction mistake that can be captured with the ICFD – Analysis

outlook

- Thermal & ICFD-Analyses in future
  - ICFD steady state
  - ICFD_DATABASE_HTC
    - need of solid and fluid component
    - different options for the balk temperature
      - solver based calculation
      - user based definition
    - auto segment for HTC in solid component

Card 1	1	2	3
Variable	OUT	HTC	TB
Type	I	I	F
Default	0	0.	0.

keyword card for the ICFD_DATABASE_HTC



literature

- [1] Arndt R. Birkert, “Umformtechnische Herstellung komplexer Karosserieteile”, Springer-Verlag, 2013, p. 287
- [2] ICFD Theory Manual, “Incompressible fluid solver in LS-DYNA”, DYNAmore 2014, p. 27
- [3] Arthur B. Shapiro, “Using LS-DYNA for Hot Forming”, LSTC, 2007, p. 3
- [4] Joel H. Ferziger, “Computational Methods for Fluid Dynamics”, Springer-Verlag, 2002, p. 352

Thank you for your attention

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