LASER BEAM MELTING BOOSTS EFFICIENCY OF HOT SHEET METAL FORMING

Thomas Töppel
Fraunhofer Institute for Machine Tools and Forming Technology IWU

CONTENT

- The Fraunhofer IWU
- Hot Sheet Metal Forming
- Project “Resource Efficient Hot Sheet Metal Forming”

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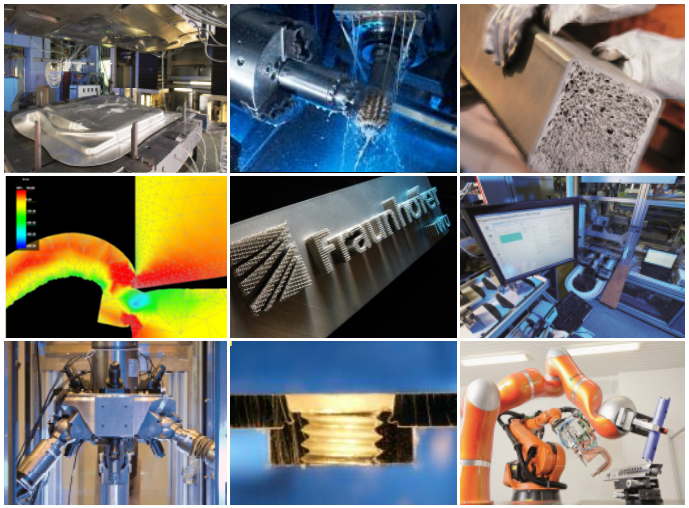
The Fraunhofer IWU

Profile

- Founded in 1991
- About 590 employees
- € 37.6 million annual budget
- Locations in Chemnitz (HQ), Dresden, Augsburg and Zittau

Research under the heading “Resource-efficient Production“



Scientific fields

- Mechatronics and lightweight structures
- Machine tools and production systems
- Forming technology and joining
- Machining

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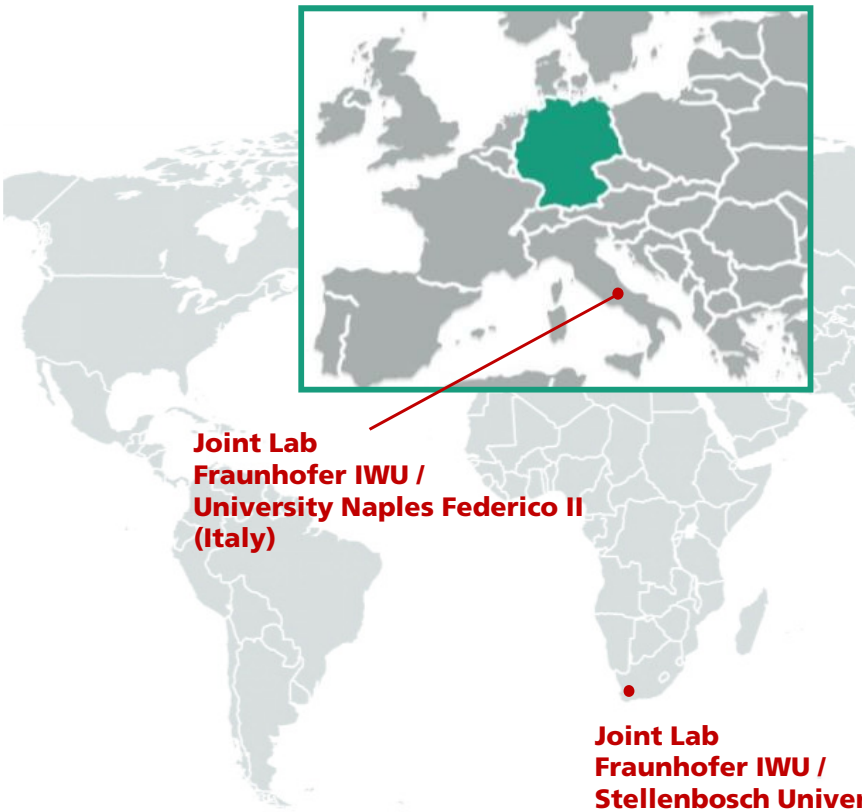
Research locations



Joint Lab Fraunhofer IWU / University Naples Federico II (Italy)

Joint Lab Fraunhofer IWU / Stellenbosch University (South Africa)

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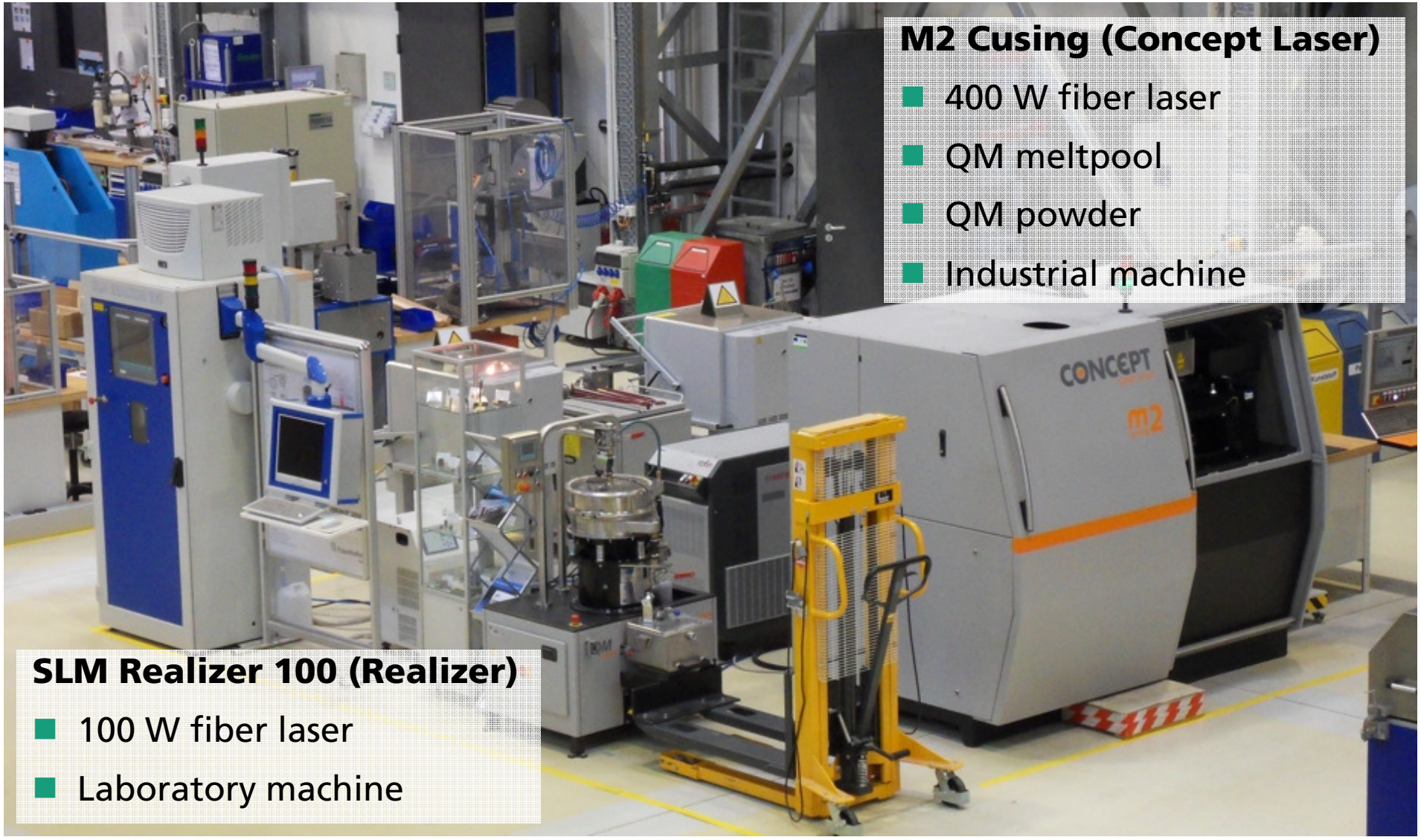
Laser Beam Melting Equipment at Fraunhofer IWU Dresden



M2 Cusing (Concept Laser)

- 400 W fiber laser
- QM meltpool
- QM powder
- Industrial machine

SLM Realizer 100 (Realizer)

- 100 W fiber laser
- Laboratory machine

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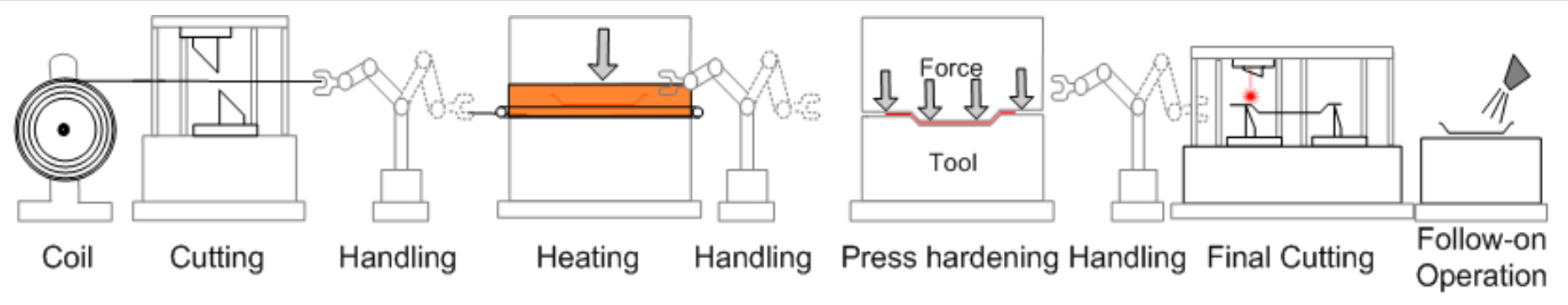
Hot Sheet Metal Forming

- Sheet metal is heated above the martensite finish temperature (around **950 °C**) and rapidly cooled down during the forming process below **200 °C**
  - Hard **martensitic** microstructure is created



Typical press hardening process chain

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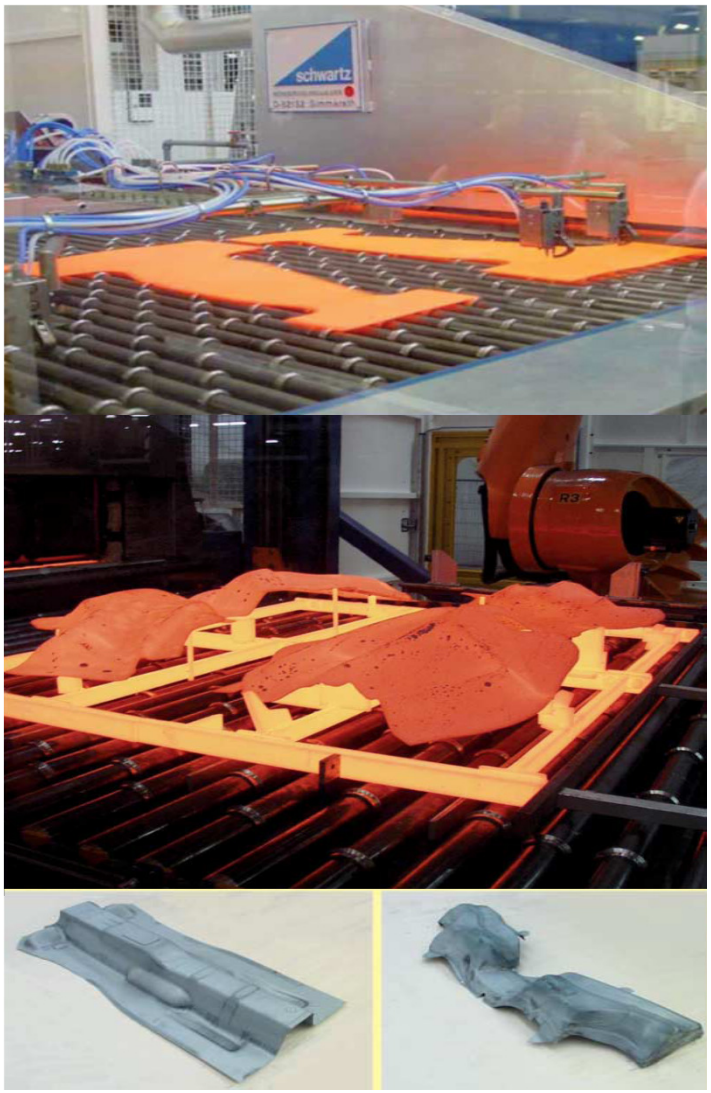
Hot Sheet Metal Forming

- Typical material: **22MnB5**
  - Yield strength ($R_{p0,2}$): 950 - 1250 MPa
  - Tensile strength (R_m): 1300 - 1650 MPa
  - Elongation (A_5): 6 %
  - Hardness (HV_{10}): 400 - 520
- **Tailored material properties** within one component become possible
  - areas of local strength and areas of high ductility
  - Typical application: **B pillar in car bodies**
    → component of high strength with high crash-absorbing capacity at the transitions to chassis and roof



Source: Volkswagen AG, Kassel

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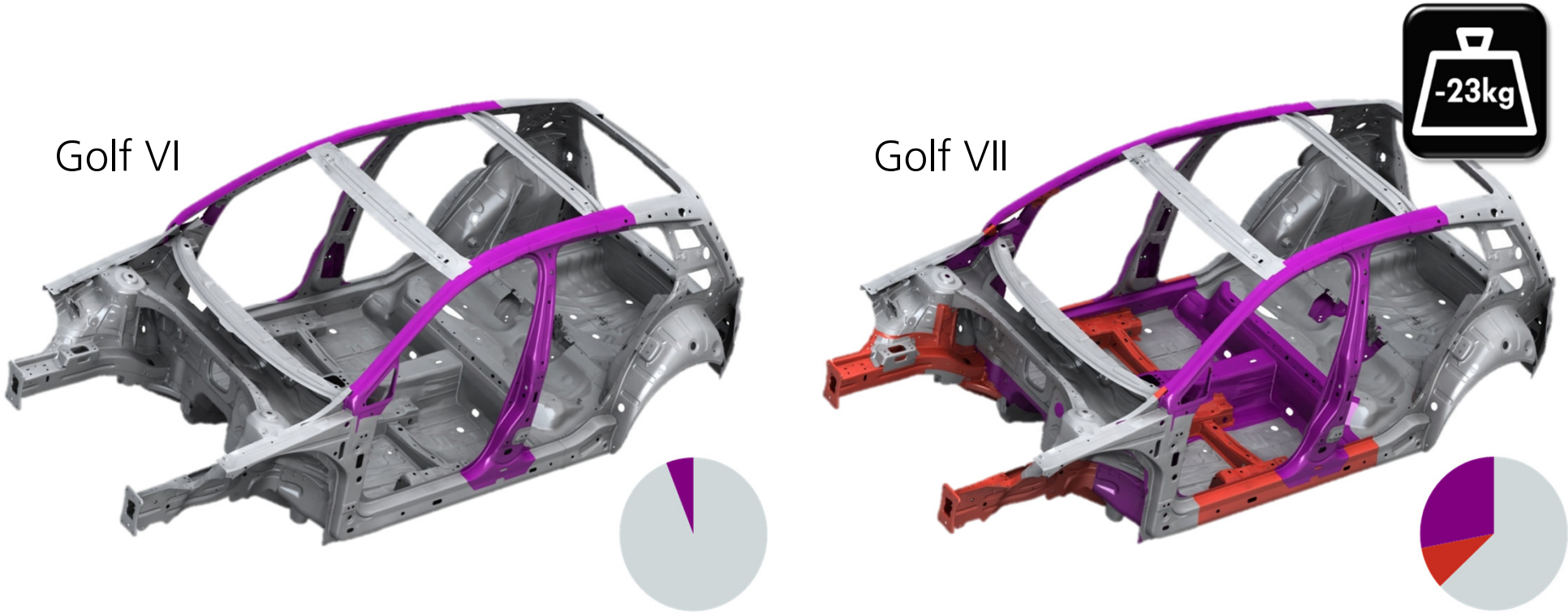
Hot Sheet Metal Forming

- Reduced amount of material due to **declined wall thickness** and therefore **reduced component weight** compared to conventional cold forming
- Reduction in component weight **without sacrificing strength**



Steel High-strength steel **Hot formed** ultra high-strength steel

Source: Volkswagen AG

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Project „Resource Efficient Hot Sheet Metal Forming“
Background

Innovation Alliace “Green Carbody Technologies” (InnoCaT®)

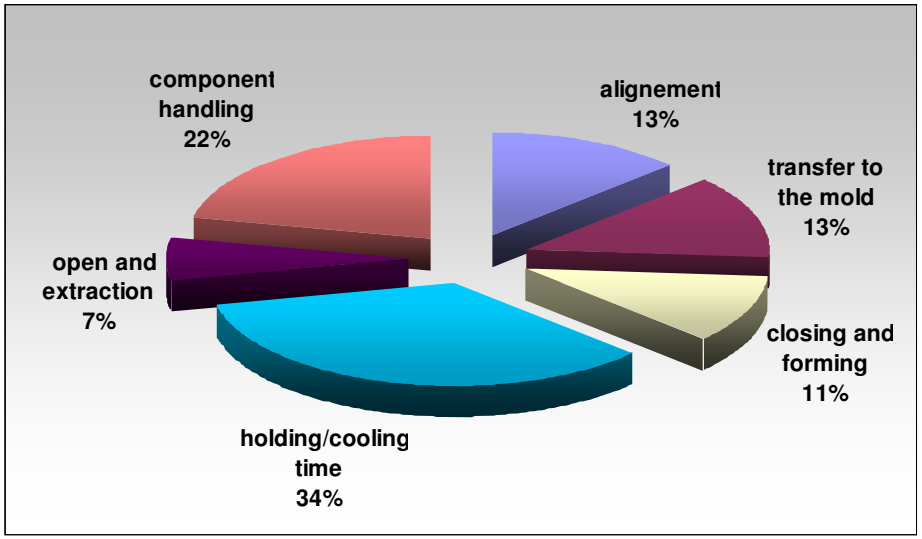
- Funded by the German Federal Ministry of Education and Research (BMBF): 03/2010 - 12/2012
- 60 companies and research institutes
- 5 collaborative projects and 30 subprojects
- Objective: increase resource efficiency along the entire car body production chain

Subproject “Resource Efficient Hot Sheet Metal Forming”

- Part of the collaborative project “Resource Efficient Tooling”
- Project team: Volkswagen AG
  BRAUN CarTec GmbH
  Fraunhofer IWU
  Concept Laser GmbH (associate partner)

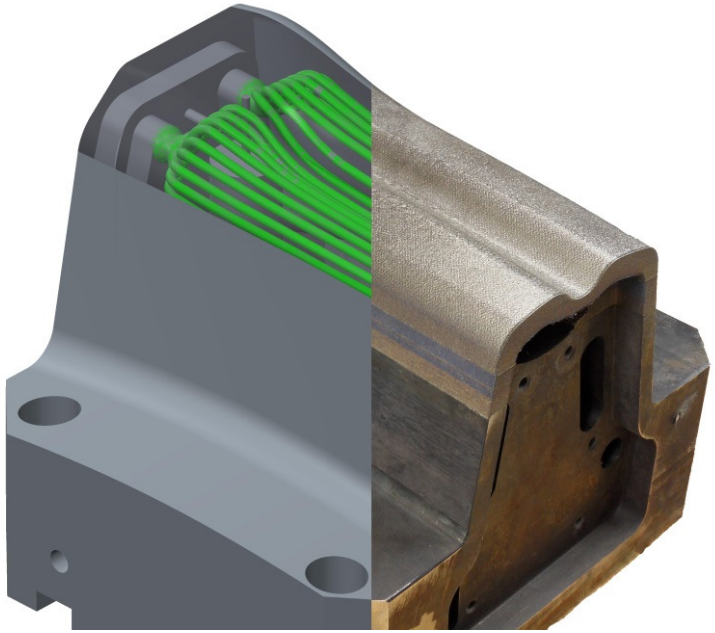
Project „Resource Efficient Hot Sheet Metal Forming“
Motivation

- **Cycle time** in hot forming process is determined to about **30 %** by **cooling time** (holding time)
- Currently **significant energy consumption** for operation of forming press and cooling system during holding
- **Selective and well controllable temperature adjustment** in particular die areas **not possible** or at least very limited
- Inadequacy in target temperature achievement and **insufficient heat conduction** in critical areas



Exemplary illustration of the cycle time in press hardening

Project „Resource Efficient Hot Sheet Metal Forming“
Approach

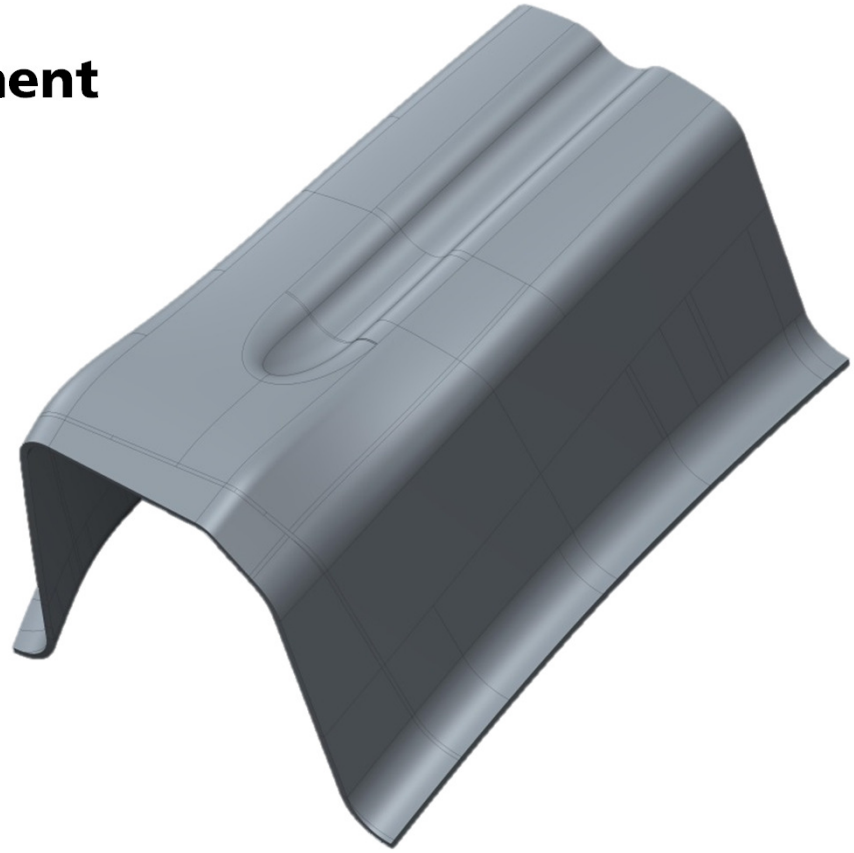


Tool insert (punch)
with conformal cooling system

- Best possible **temperature control** by a complex cooling channel design (large-scale net shaped system of cooling channels)
- Development and manufacturing of an innovative cooling system with surface compliant channels close to the cavity using the **freedom of design** given by the additive **laser beam melting** process
  - All channels with equally short distance to the tool cavity
  - Hybrid tooling (machined base body + additively applied tool geometry)

Project „Resource Efficient Hot Sheet Metal Forming“
Demonstrator Part

- Geometry **similar to a serial component** to enable easy transfer of the project’s results into series production
- Design reflects a **typical hot forming component** and its difficulties
  - Curved surfaces and cavities to demonstrate limitations of conventional deep hole drilled cooling channels
  - **High degree of deformation** in only one forming step (typical for hot forming)



Demonstrator part (CAD model)

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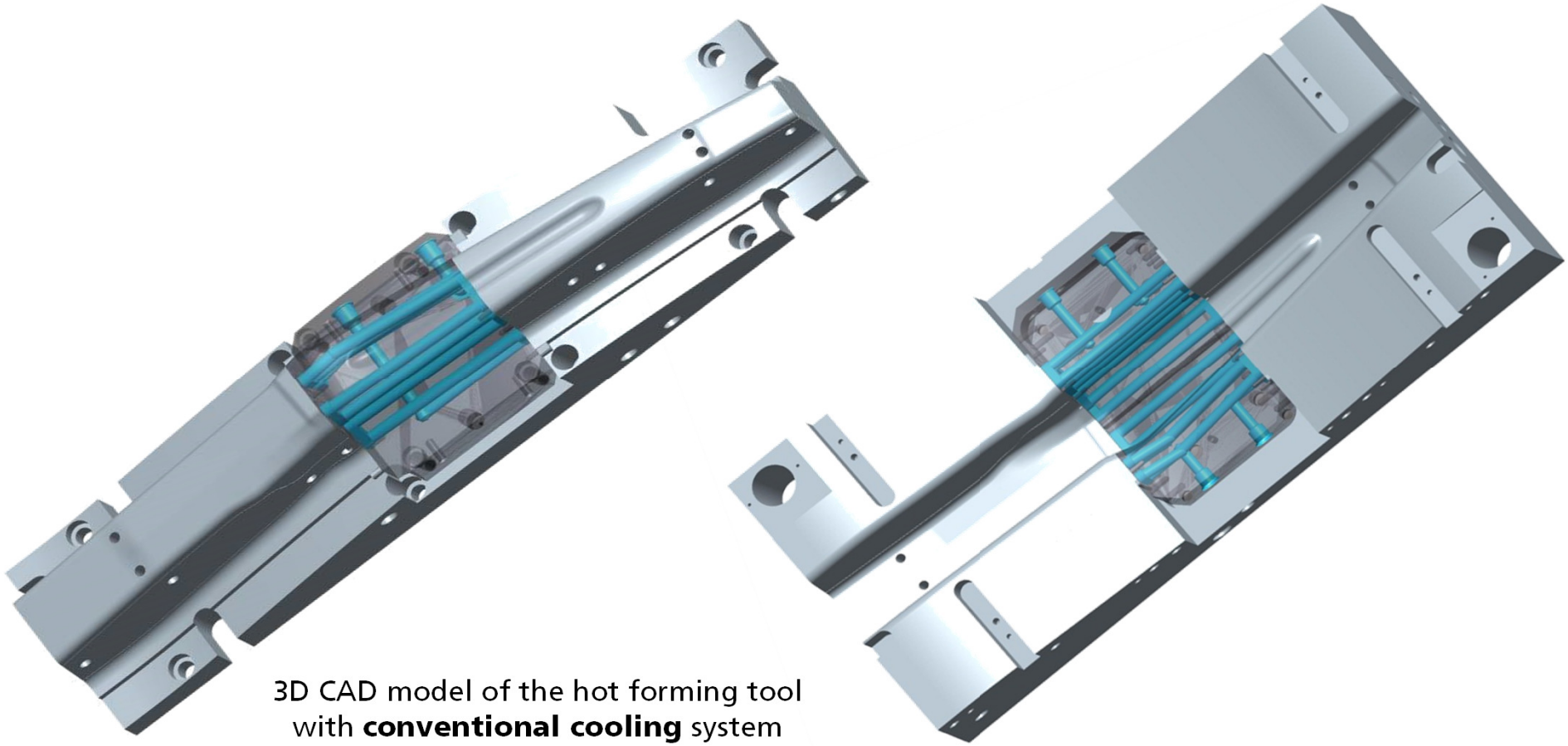
Project „Resource Efficient Hot Sheet Metal Forming“
Tool Design

- Tool and cooling system design based on conventional manufacturing methods (for benchmark purposes)



3D CAD model of the hot forming tool
with **conventional cooling** system

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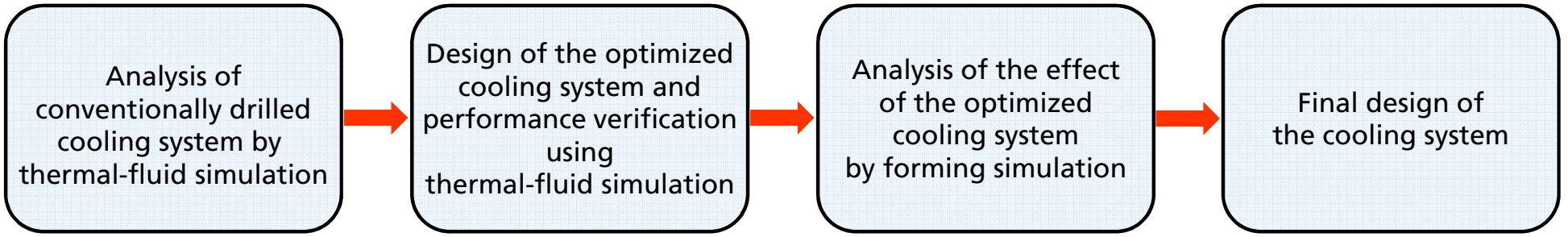
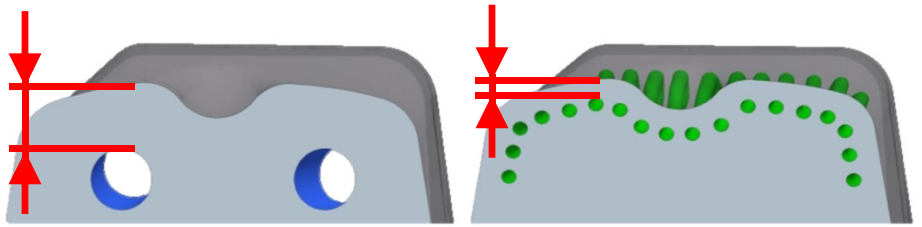
Project „Resource Efficient Hot Sheet Metal Forming“
Cooling System Design



- Optimized cooling system
  - Channels conform to the surface contour
  - Smallest possible distance from the tool surface
  - Wide area of net shaped channels



Conventional cooling system with deep-hole drilled channels

(Ø 16 mm)

Optimized cooling system for laser beam melting

(Ø 4 mm)

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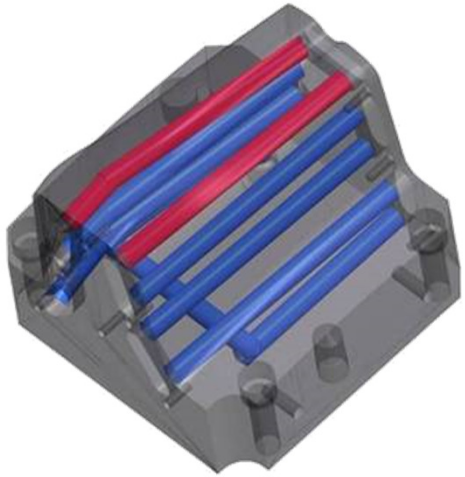
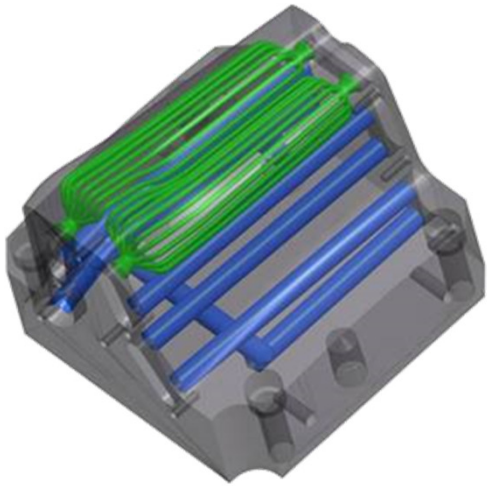
Project „Resource Efficient Hot Sheet Metal Forming“

Cooling System Design

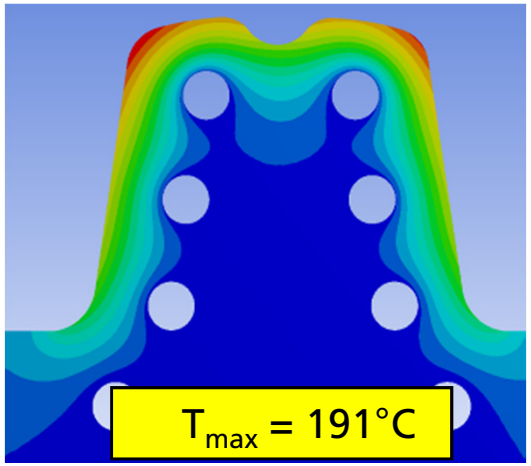
- Development of the innovative conformal cooling system with aid of numerical simulation
  - Various iterations designed and compared by simulation
  - Cooling efficiency could be constantly improved and resulted in a homogeneous temperature distribution at significantly lower level

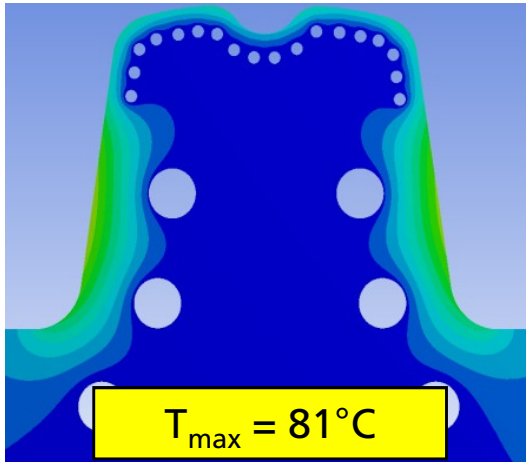


Tool insert (punch) with conventionally drilled cooling channels



Tool insert (punch) with conventionally and additively manufactured cooling system





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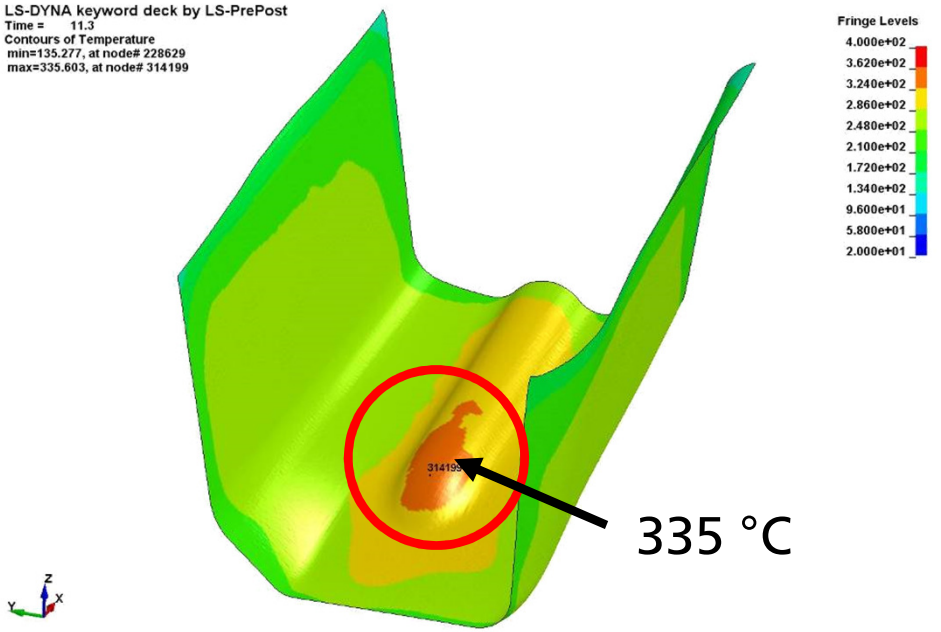
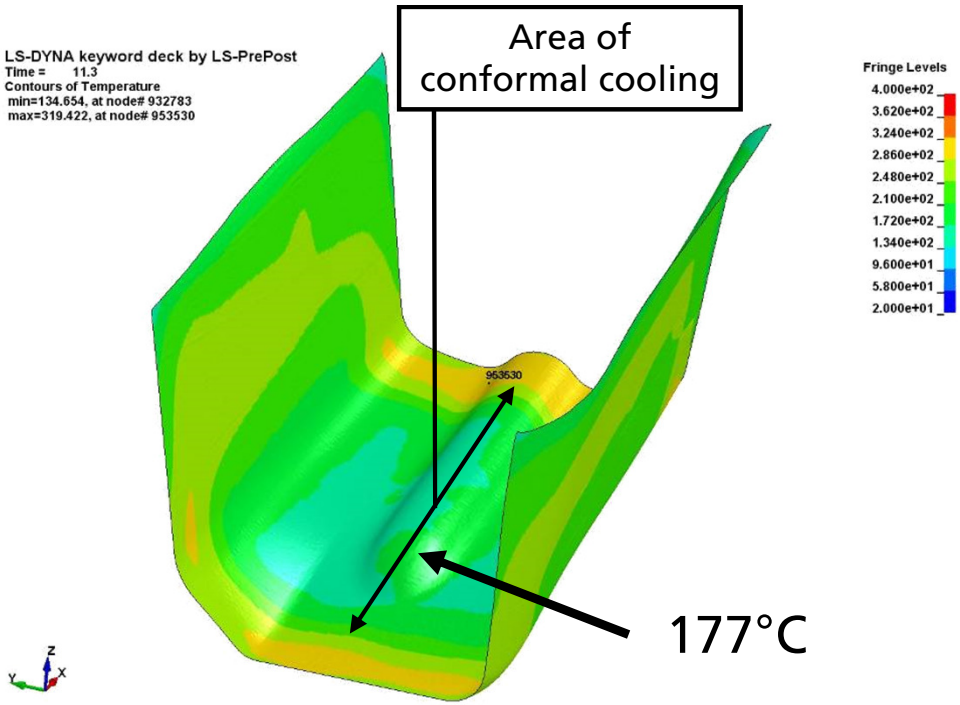
Project „Resource Efficient Hot Sheet Metal Forming“

Cooling System Design

- Most critical area localized in the die’s deepest cavity, where – due to limitations of conventional drilling – the standard cooling channels have the longest distance to the cavity surface



Temperature distribution in the component with **conventional cooling system**



Temperature distribution in the component with the **optimized cooling system**

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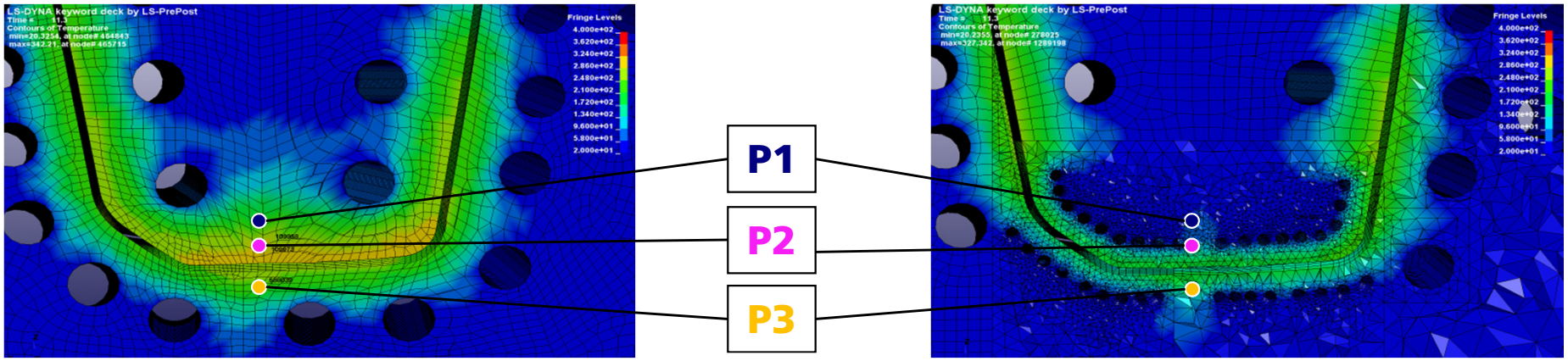
Project „Resource Efficient Hot Sheet Metal Forming“
Cooling System Design

- Simulations showed
  - Lower temperature and better heat distribution in the forming tool
  - Steady state of temperature is reached faster → within only 4 cycles
  - More rapid cooling and lower temperature of the component
  - Reduction of holding time by 47 % → reduction of total cycle time by 22%

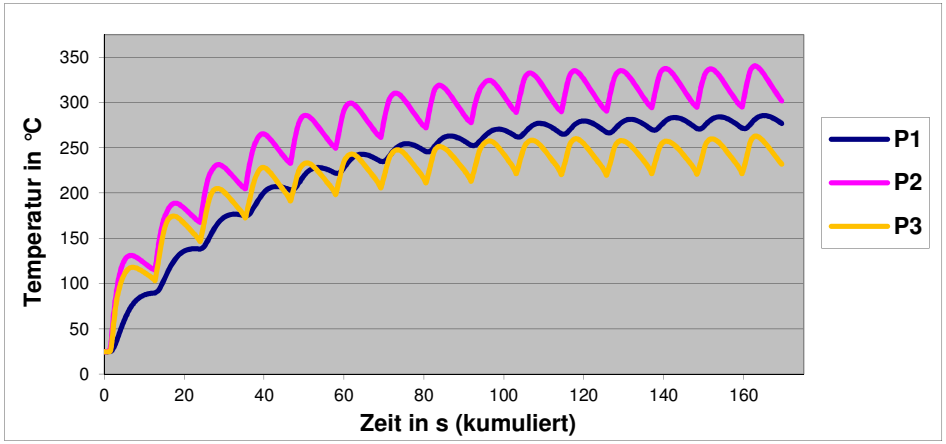


Temperature distribution in the tool with **conventional cooling system**

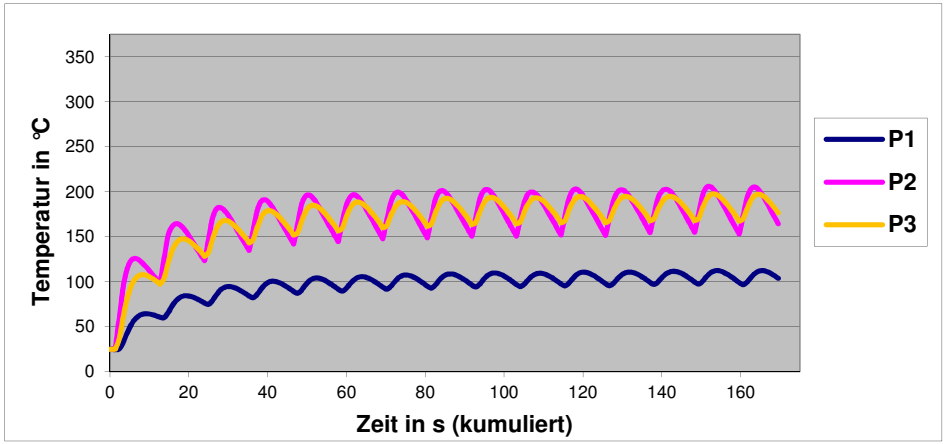
Temperature distribution in the tool with **optimized cooling system**

Project „Resource Efficient Hot Sheet Metal Forming“

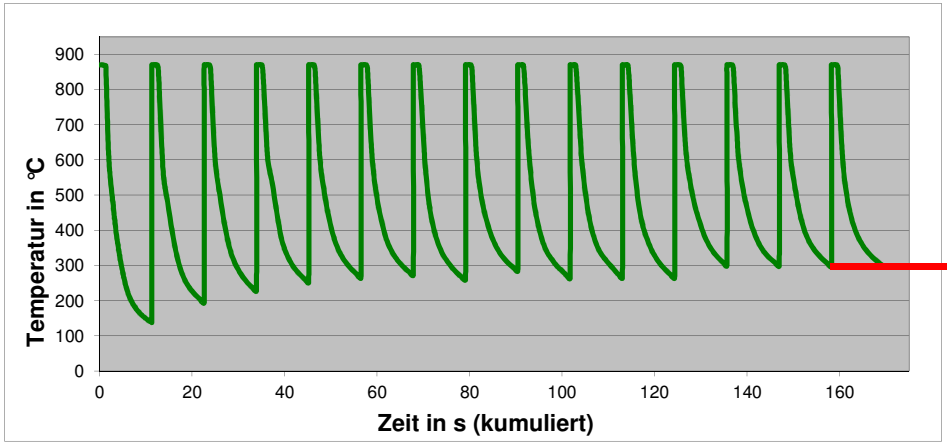
Cooling System Design



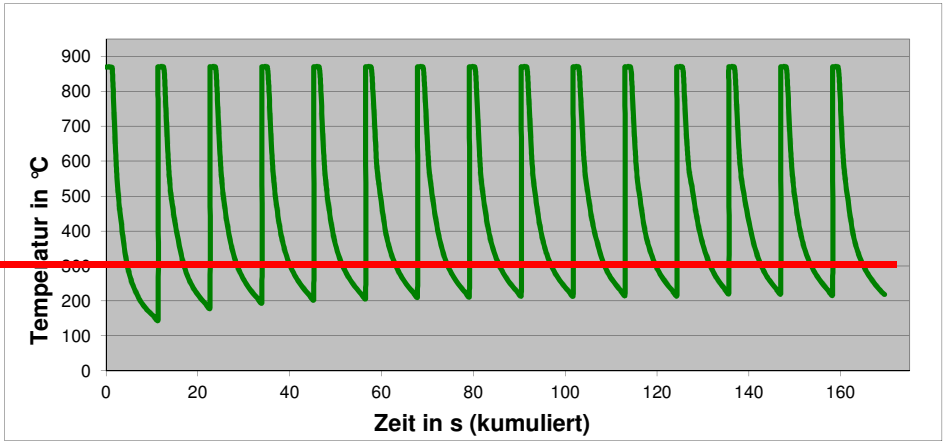
Tool temperature over 15 cycles/parts
with **conventional cooling system**



Tool temperature over 15 cycles/parts
with **optimized cooling system**



Component temperature over 15 cycles/parts
with **conventional cooling system**



Component temperature over 15 cycles/parts
with **optimized cooling system**

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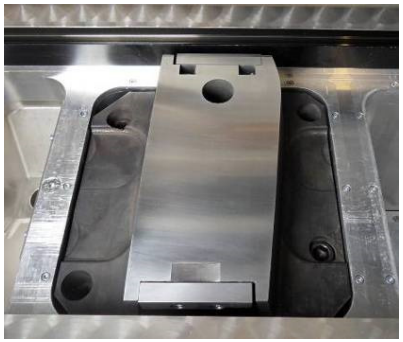
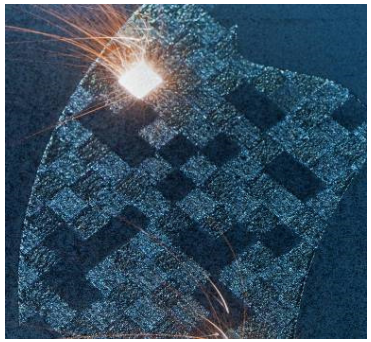
Project „Resource Efficient Hot Sheet Metal Forming“
Manufacturing of the Tool

- Manufacturing was done as so-called **hybrid tooling**
  - Combination of conventional manufacturing technologies like milling, drilling, turning with additive manufacturing like laser beam melting



Milled base body (punch) placed in the laser beam melting machine



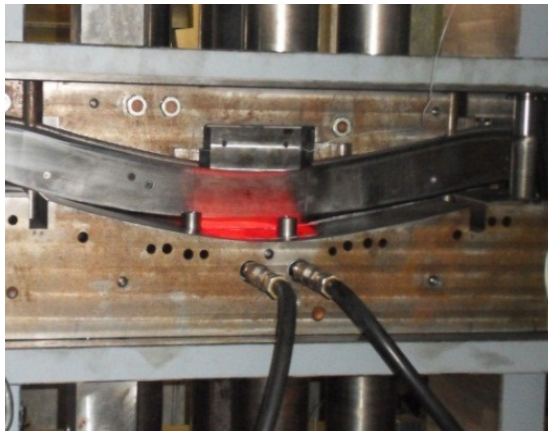
Laser beam melting process

Tool insert (punch) after laser beam melting, ready for heat treatment and finish-machining

Machined tool inserts (die)

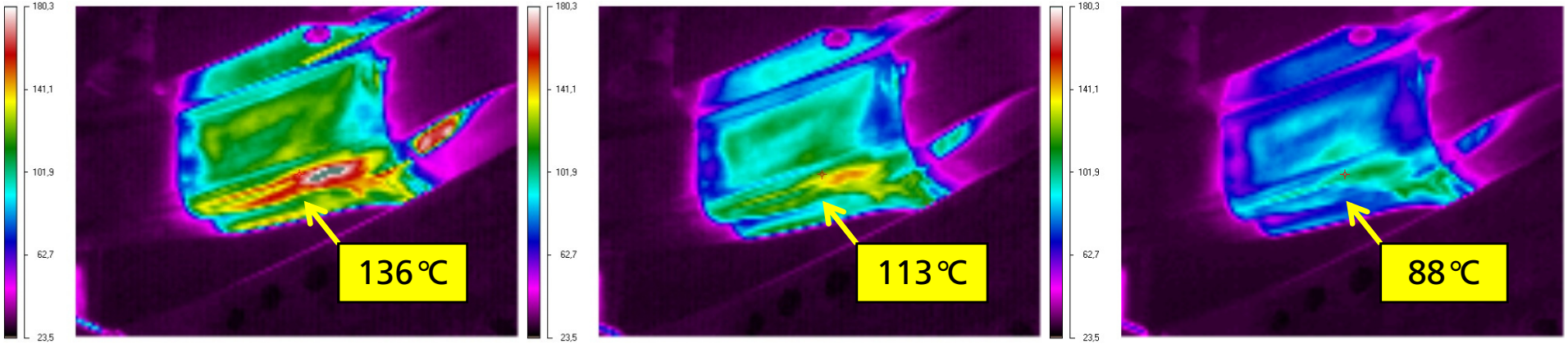
Project „Resource Efficient Hot Sheet Metal Forming“
Forming Trials

- Series of tests to determine the cooling rate:
  - Heating the tool without cooling
    → activating the cooling and measuring the temperature drop (thermography, thermocouples, pyrometers)
  - Several test cycles with different coolant flow rates (10 l/min, 20 l/min)
- Forming process:
  - Combinations of different holding times: (10 s, 5 s, 3 s) with different coolant flow rates (10 l/min, 20 l/min)
    → measurements using thermography (component + tool), pyrometer (component + tool), thermocouples (tool)



Project „Resource Efficient Hot Sheet Metal Forming“

Results - Punch



Conventional tooling

Temperature drop (punch) after 0 s

Conventional tooling

Temperature drop (punch) after 5 s

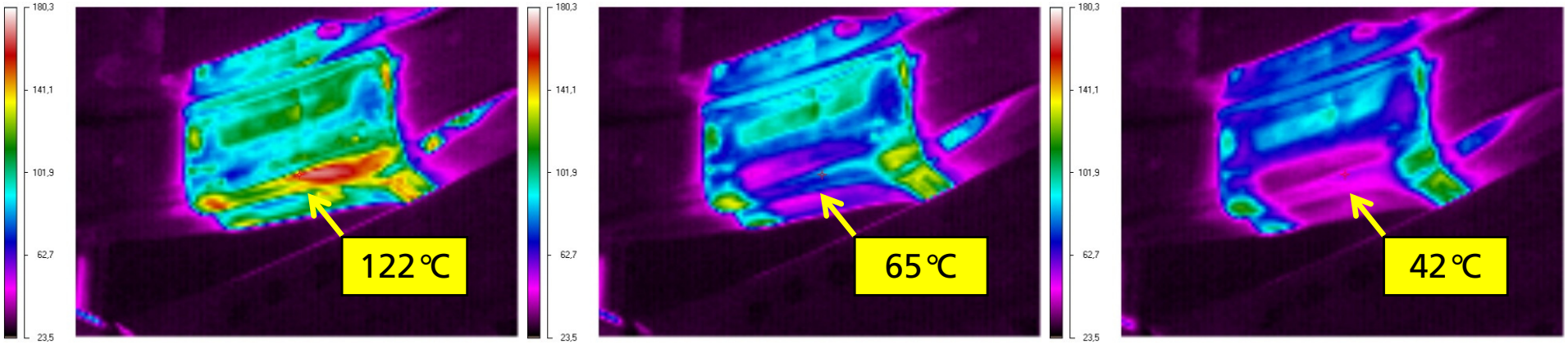
Conventional tooling

Temperature drop (punch) after 10 s

Optimized tooling

Optimized tooling

Optimized tooling



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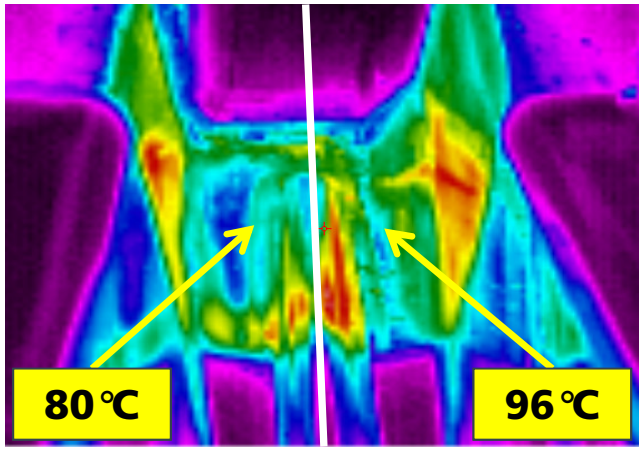
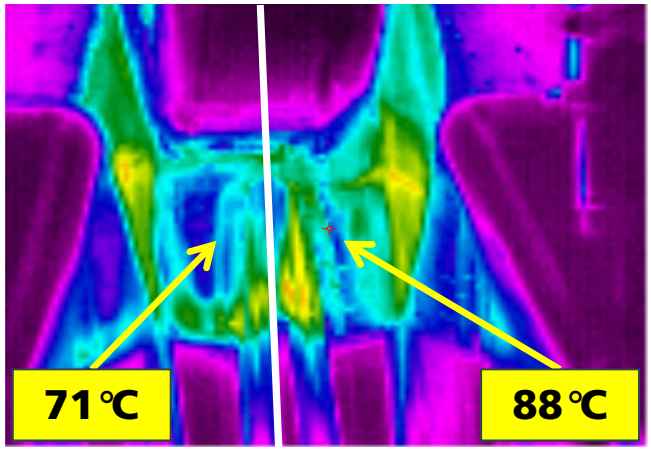
Project „Resource Efficient Hot Sheet Metal Forming“

Results - Die

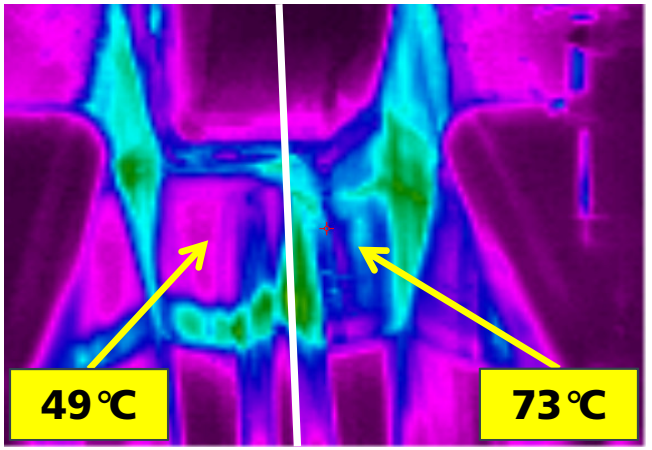
Temperature drop (die) after 0 s
optimized **conventional**
tooling



Temperature drop (die) after 5 s
optimized **conventional**
tooling



Temperature drop (die) after 10 s
optimized **conventional**
tooling



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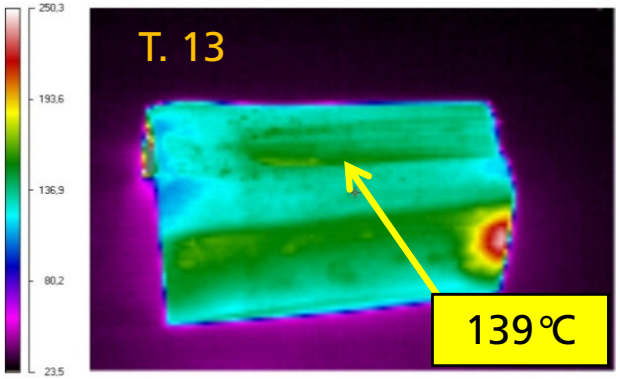
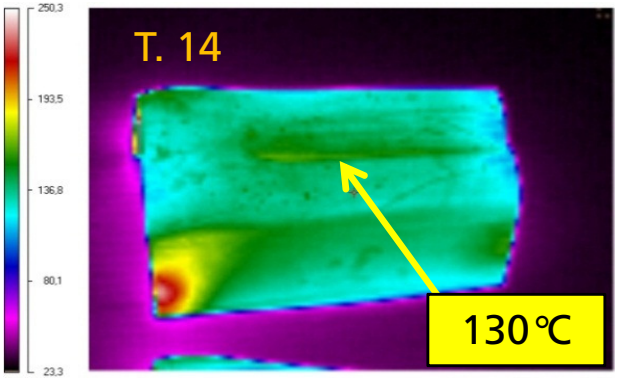
Project „Resource Efficient Hot Sheet Metal Forming“

Results - Demonstrator Part (3 different parts)



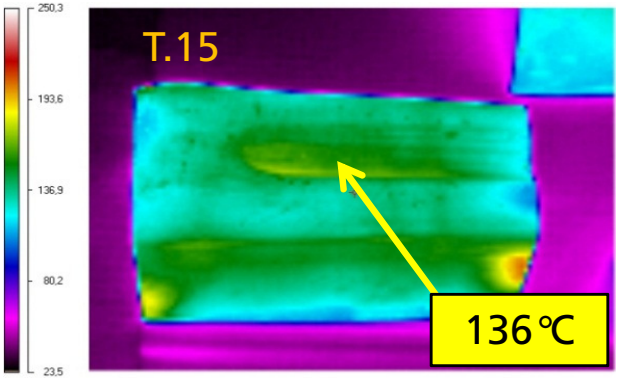
conventional

Part temperature
(10 s holding time 10 l/min)



conventional

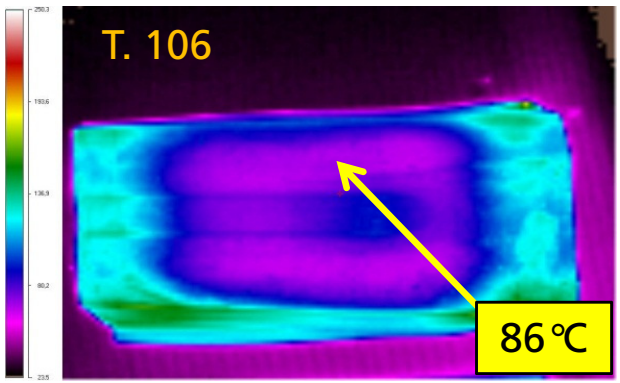
Part temperature
(10 s holding time 10 l/min)



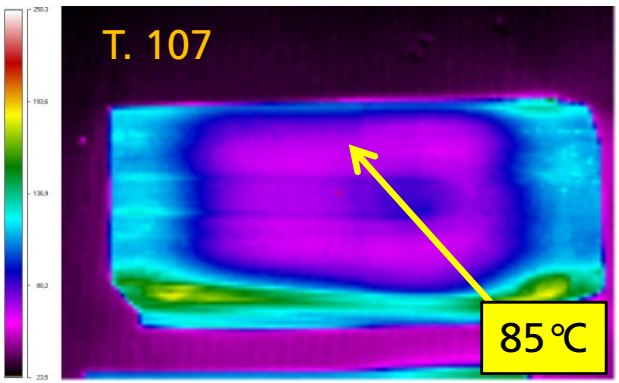
conventional

Part temperature
(10 s holding time 10 l/min)

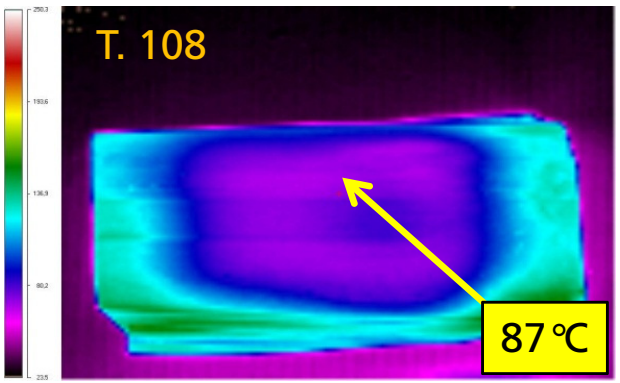
optimized



optimized



optimized



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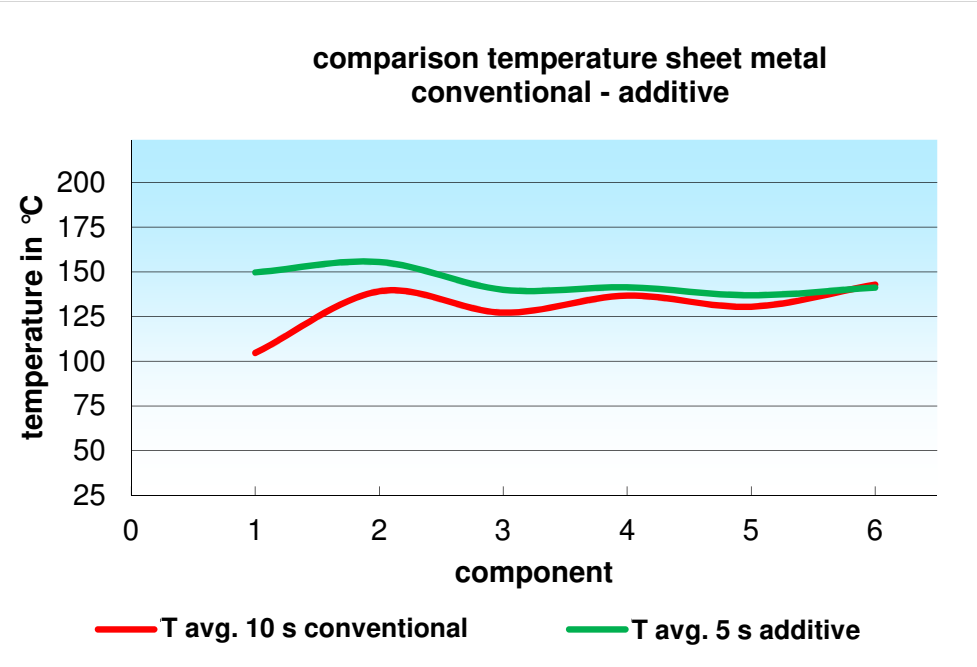
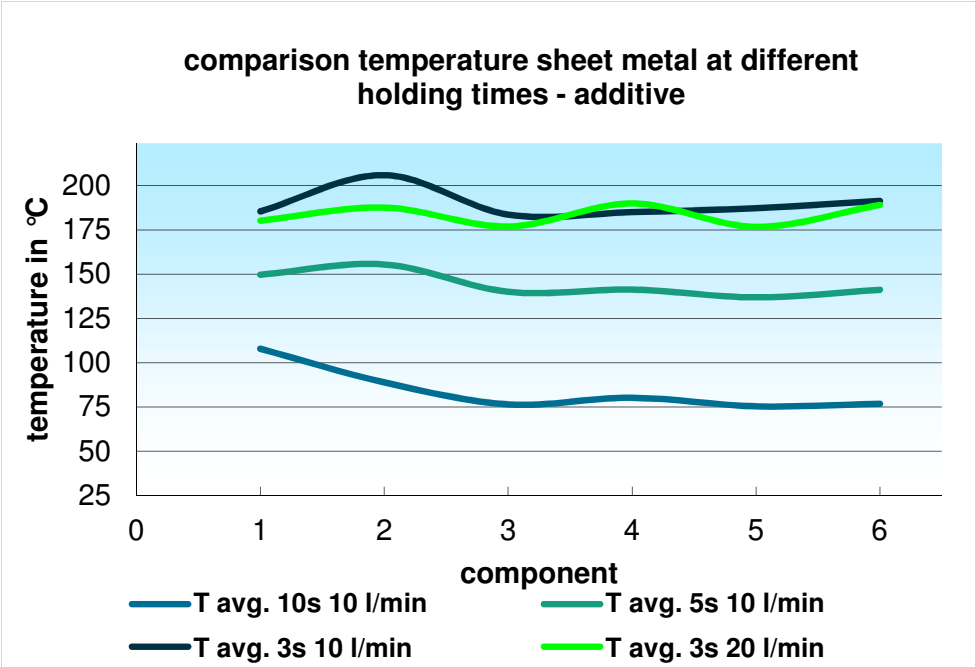
Project „Resource Efficient Hot Sheet Metal Forming“
Results

- reduction of holding time by **50 %** (from **10 s** to **5 s**) with additively manufactured tool inserts and therefore reduction of total cycle time by **20 %**





- analysis of mechanical properties (hardness testing) points out potential for further holding time reduction down to **3 s**

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Project „Resource Efficient Hot Sheet Metal Forming“
Conclusions

- Laser beam melting is a well-suited technology for manufacturing highly complex molds and tools which go beyond the limits of conventional production technologies
- Laser beam melting technology opens up ways for new design approaches of cooling systems in forming tools
- Enormous improvement of the temperature distribution can be achieved within the tool as well as in the sheet metal component
- Process cycle times in hot sheet metal forming can be reduced significantly by an innovative conformal cooling system
  → less energy consumption and carbon footprint (resource efficiency)
- **First application in series production by the end of 2014**

Thank you for your attention!

Questions?

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