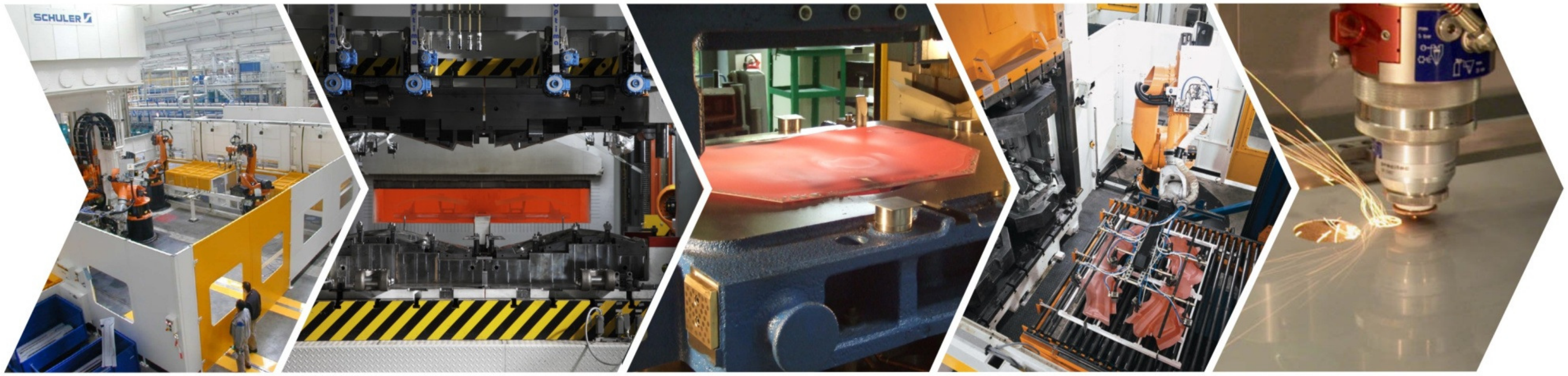
New Approaches for Improved Efficiency and Flexibility in Process Chains of Press Hardening

Frank Schieck, Fraunhofer IWU



ASME 2015 International Mechanical Engineering Congress & Exposition
IMECE2015
November 13-19, 2015, Houston, Texas, USA

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New Approaches for Improved Efficiency and Flexibility in Process Chains of Press Hardening

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1st Challenge: CO_2 Emission

2014 world wide CO_2 emission

by burning fossil fuels

37 Billion Tons CO_2

picture source: lateinamerika-blog.de

Request of climate researcher

to limit global warming at 2°C

2,5 t CO_2 Per Head and Year

picture source: www.planet-wissen.de

Impact by Car Industry

to worldwide CO_2 emission

67,5 Mio new cars in 2014

picture source www.spiegel.de

CO_2 emission by production of a:

- **Small car** — **4,1 Tons**
- **Midsize car:** — **4,9..5,4 Tons**
- **Large car:** — **6,3..7,1 Tons**

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2^{nd} Challenge: Shortage of Resources

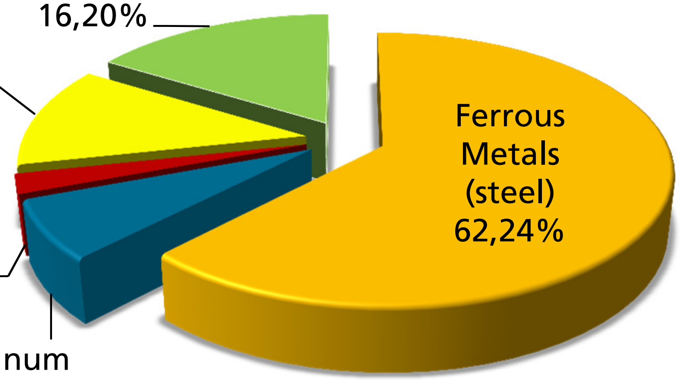
2014 world wide production – automotive main materials

1 662 Mio. t	steel
53 Mio. t	aluminum
19 Mio. t	copper
303 Mio. t	polymer*

*** at about 4 402 Mio t mineral oil production → 7 %**


picture source: www.faz.net

average passenger car material mix



source: Habermacher

2014 share of passenger cars production: 67,5 Mio.

average kerb weight per car: 1.37 t

→ 57,6 Mio. t	steel (3,5%)
→ 6,5 Mio. t	aluminum (12,3%)
→ 0,9 Mio. t	copper (4,8%)
→ 11,3 Mio. t	polymer (3,7%)

resources consumption per car: 70 t

4 725 Mio. t

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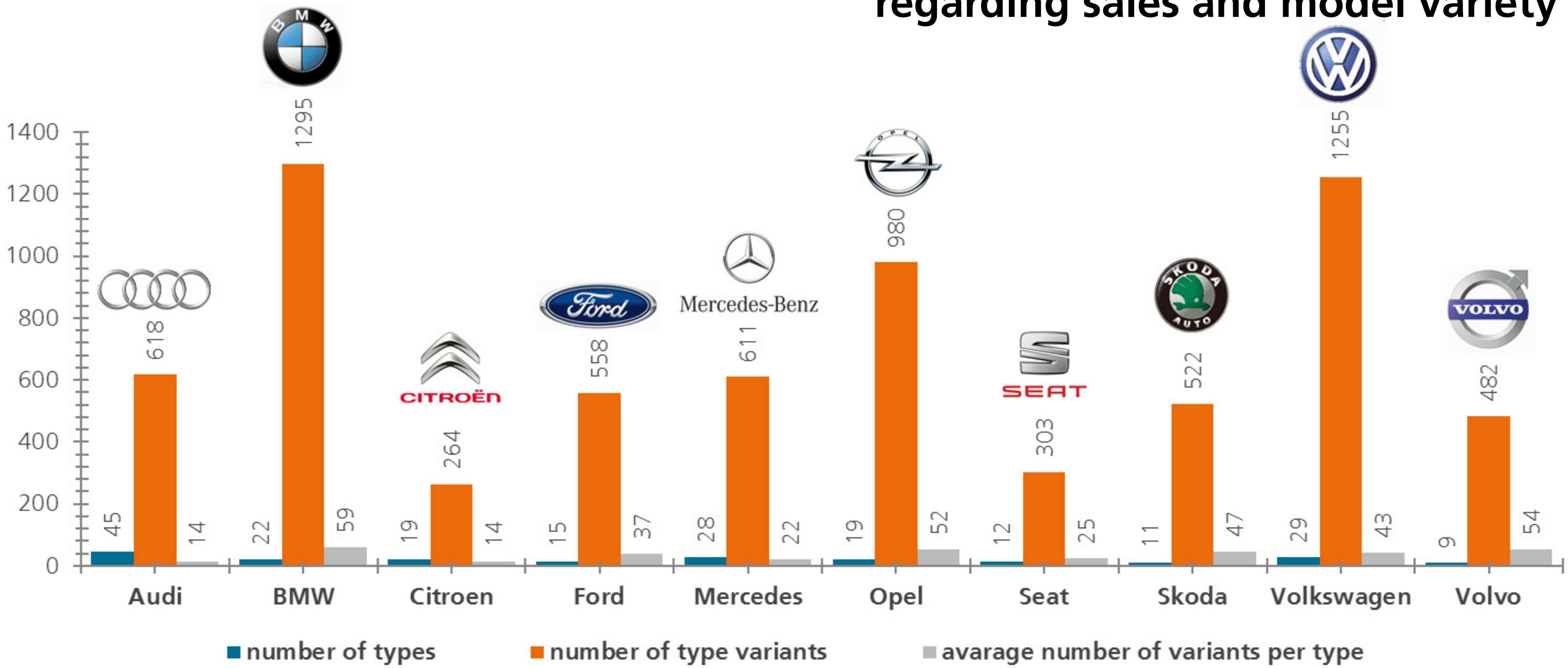
3rd Challenge: Growing Individualism

2013 top 10 car manufacturer at German market

regarding sales and model variety



source: statista GmbH, meinauto.de, status 8/2013

Future Trends:

- mass customization
- rising number of variants
- reduced model cycle periods
- reduced development and cash recovery periods

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Challenges in Press Hardening Technology

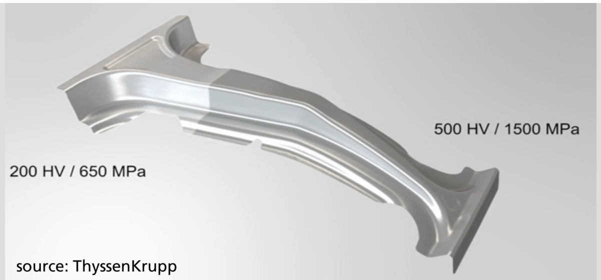
balancing of energy- and material streams

➔ detecting of weak points, increasing of **energy and material efficiency**

increasing of component complexity

➔ **tailored properties** with diversity in strength and ductility

➔ Target: weight- and cost optimization

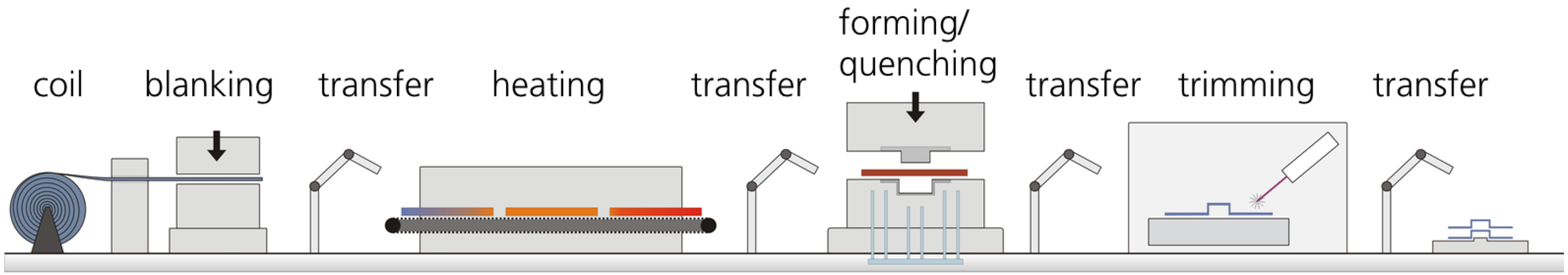


increasing of component quality

➔ vision of **zero defect manufacturing** by **intelligent process control**

increasing of production flexibility

➔ short **retooling cycles** and modular **production devices**



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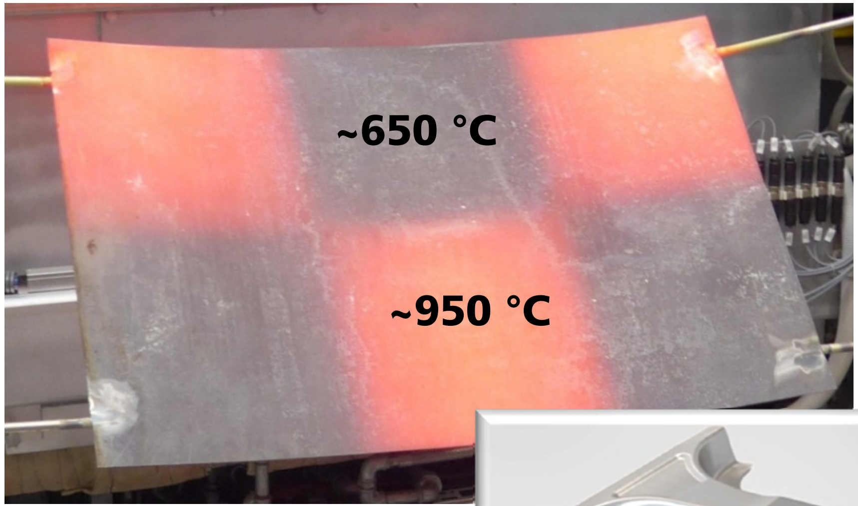
Heat Treatment Strategies

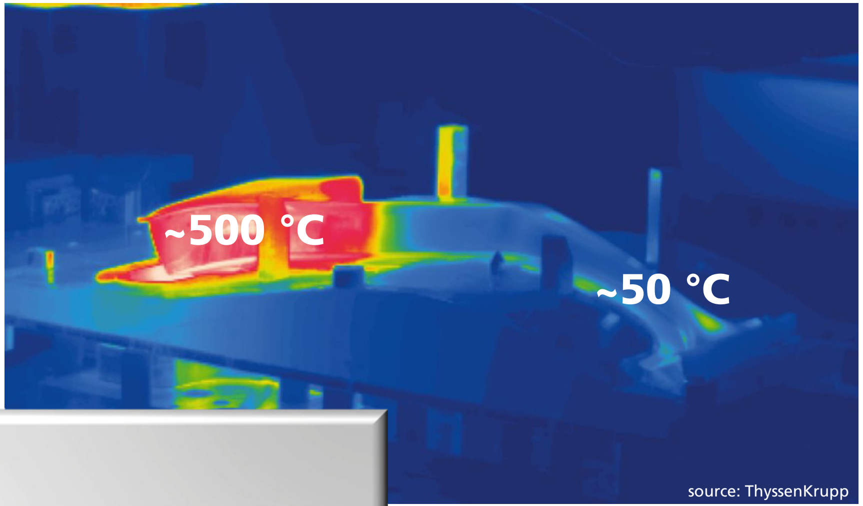
by adaptive heating:

various temperature zones in heating device
→ avoidance of austenitization
= avoidance of Martensite

by adaptive quenching:

various temperature zones in tool
→ reduction of cooling rate below 27°C/s
= avoidance of Martensite





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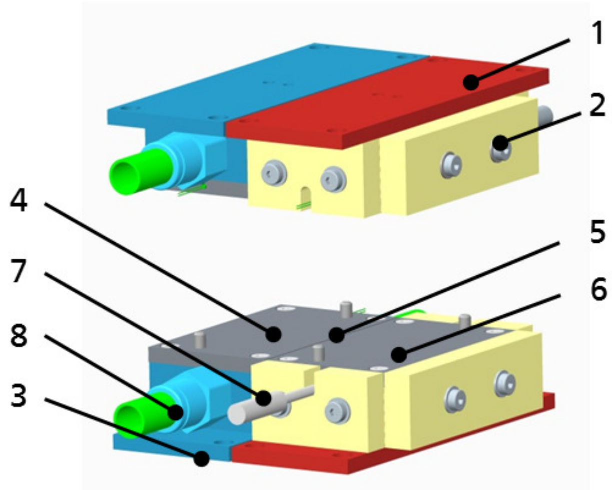
2. Tailored Tempering

Adaptive Quenching

Basic investigations

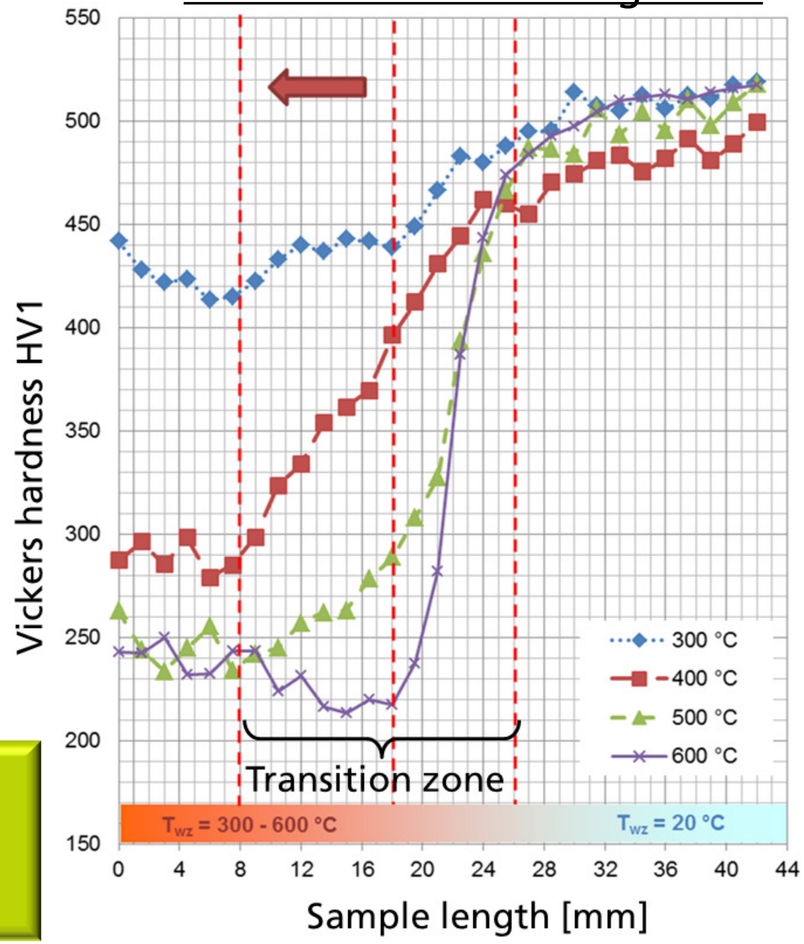
<u>experimental setup (schematic)</u>



1 upper mounting plate
2 heat insulation plate
3 lower mounting plate
4 cooled tool segment WZ1
5 heat insulation plate
6 heated tool segment WZ2
7 heating cartridge
8 cooling channels

Increased tool temperature:
micro hardness ⇩
transition zone width ⇧

<u>results of basic investigations</u>

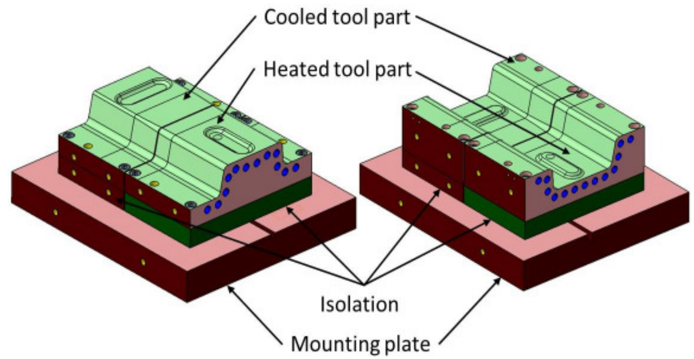


2. Tailored Tempering

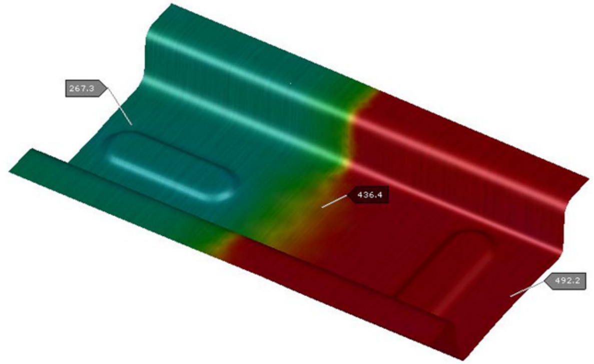
Adaptive Quenching

Application at a sill geometry

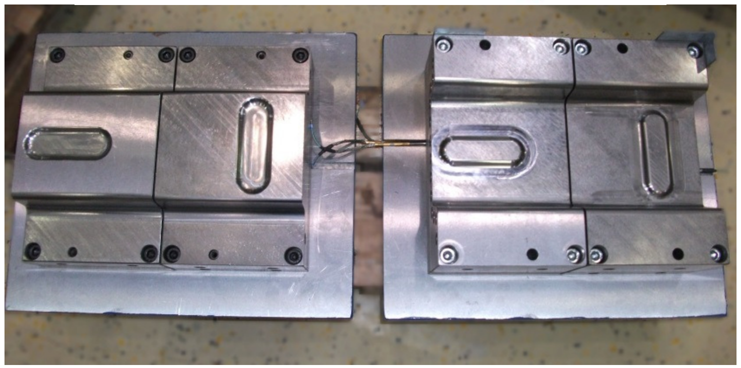
- **design** of a testing tool:
  side sill with two different zones



- **FE-simulation** & estimation of reachable local properties



- **tool manufacturing** &
  experimental verification of simulation results



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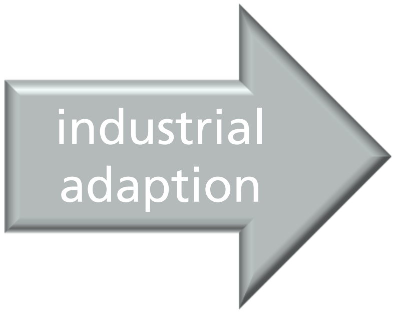
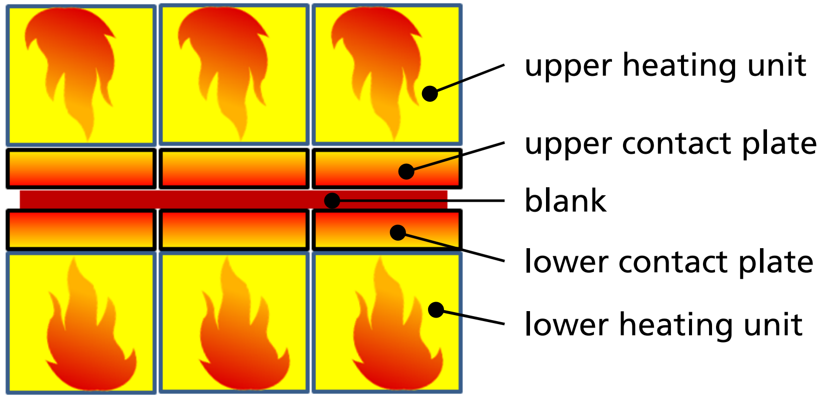
2. Tailored Tempering

Adaptive Heating

Function principle contact heating and basic investigations

function principle: „Flat Iron“

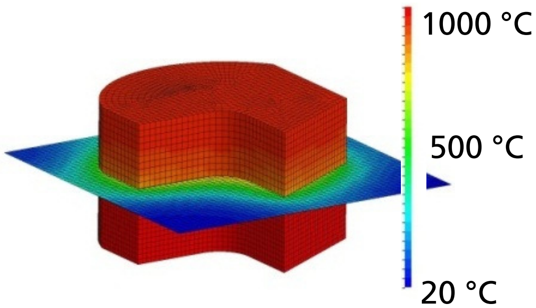




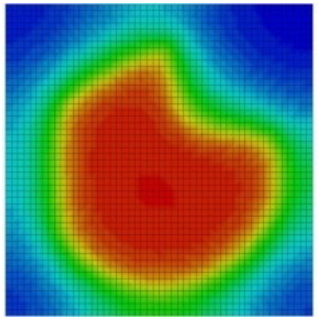
basic investigations

contact pressure: 15 MPa
heat contact coefficient: 4000 W/(m²*K)
heat contact coefficient : 28 W/(m*K)
(ceramic contact plate)

Thermal FE-simulation



test tool



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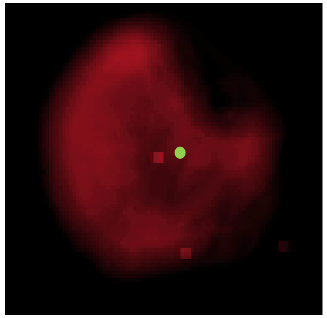
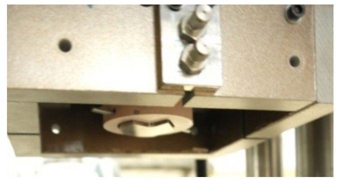
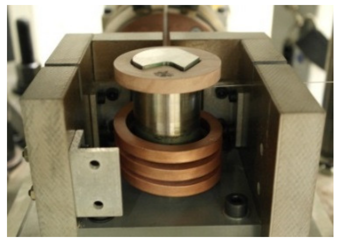


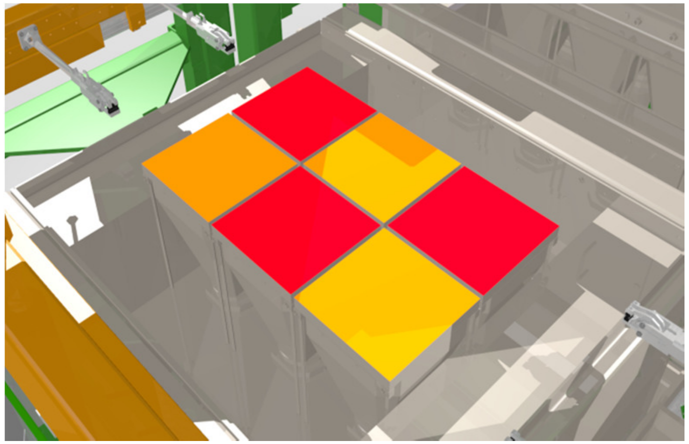




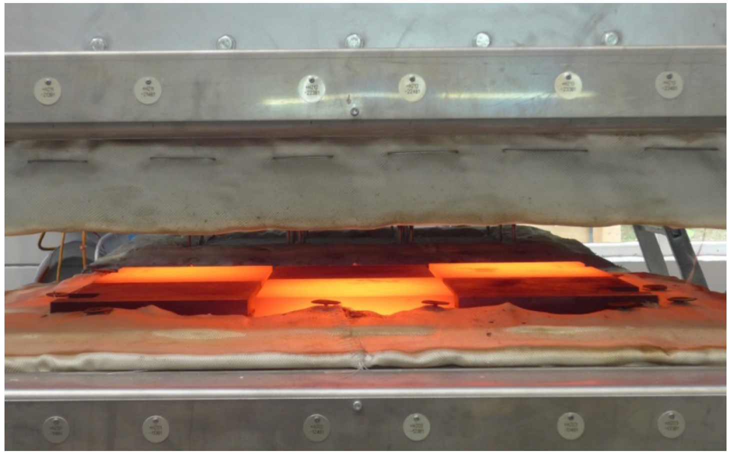
thermal camera image - 5 s after part remove from tool

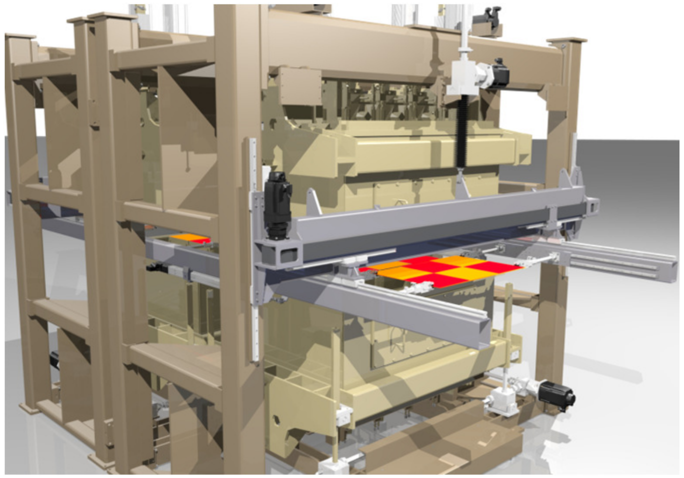
Contact Heating – Fast and Efficient

Testing device at Fraunhofer IWU

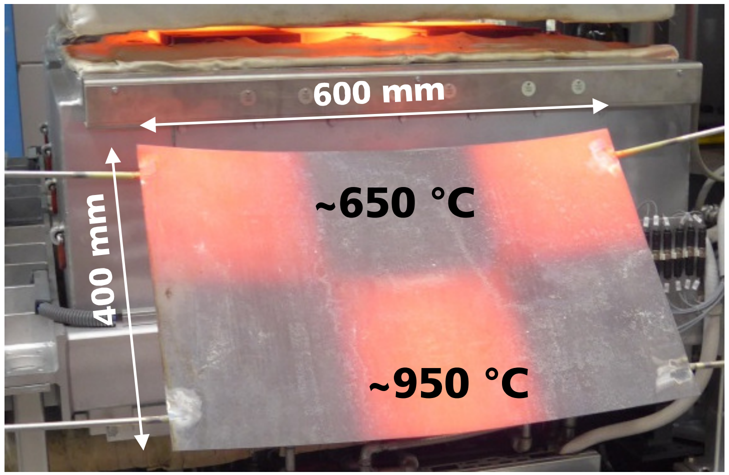


contact plates





blank, adaptive heated



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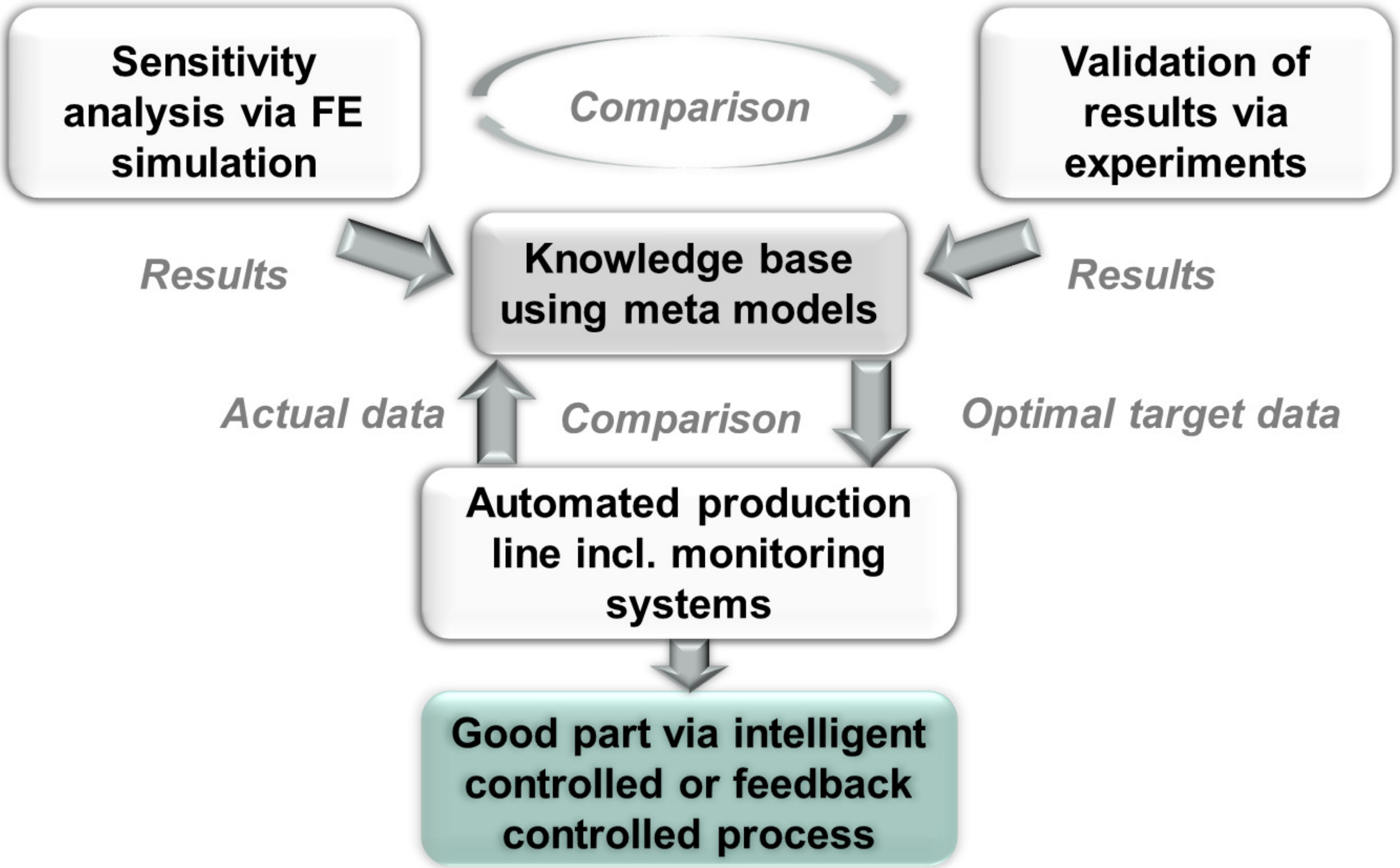
Control loop for a press hardening process

Development of the knowledge base

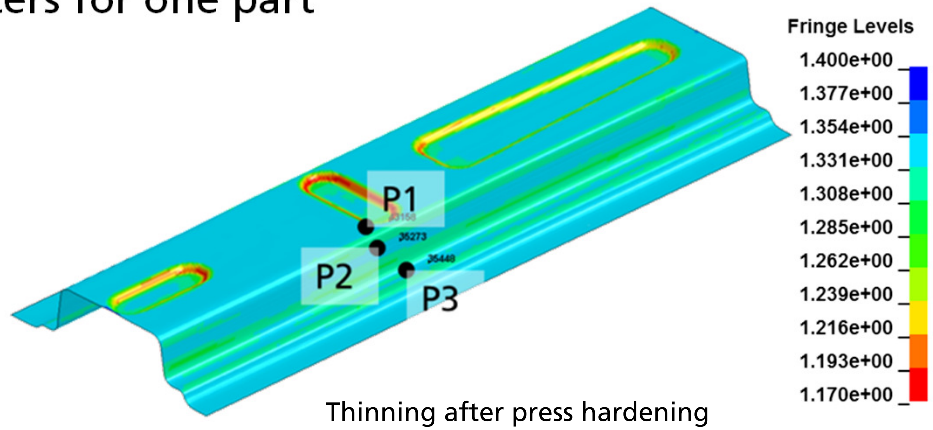


Sensitivity Analysis via FE Simulation

- Simulating the press hardening process with variation of the input variables in a low range considering deviation of series production
- Identification of significant parameters for one part

Aim

- Creation of a process model
- Definition of a process window for producing good parts with defined quality criteria



Thinning after press hardening with evaluation points (LSDyna)

Example sill geometry

Process parameters

- Initial sheet temperature
- Punch force and velocity
- Sheet thickness
- Tool temperature

Significant influence on

Quality criteria

- Thinning
- Hardness
- Spring back

Experiments, Tool and Monitoring Technology

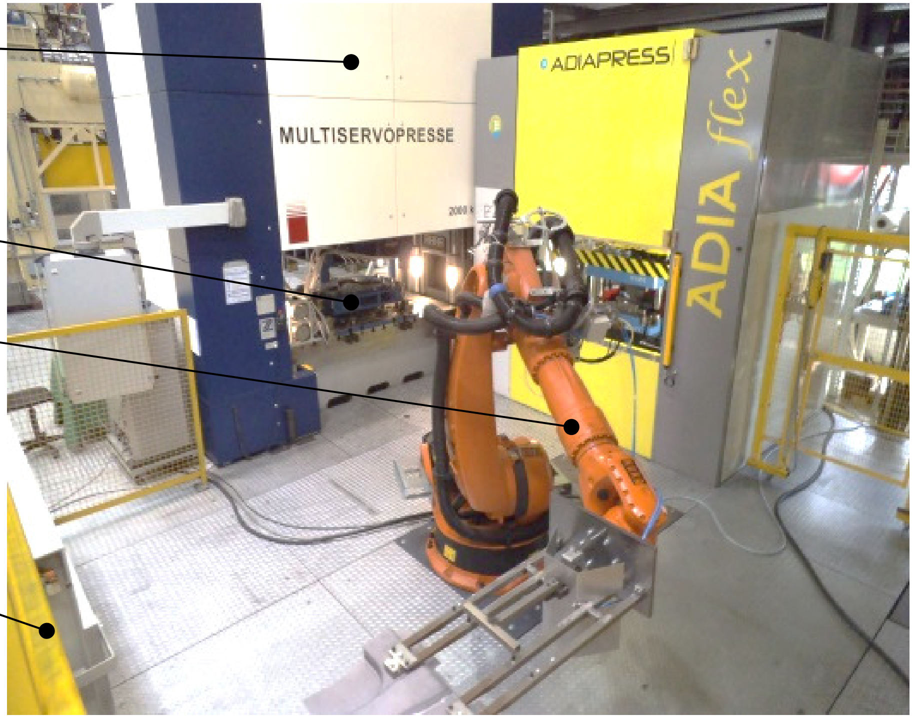
Fully automated test set up for press hardening of car body parts

Multi-servo press

Press hardening tool

Robot with work piece handling

Chamber furnace



Fully automated test set up at Fraunhofer IWU

Aim

- Creation of reproducible test conditions for generating a comprehensive data base
- Experimental verification respectively extension of the FEM generated process model

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Experiments, Tool and Monitoring Technology

Fully automated test set up for press hardening of car body parts

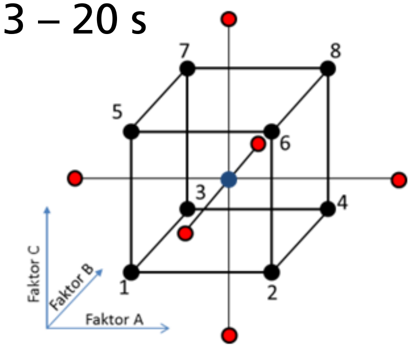
Experiments, Tool and Monitoring Technology

Process parameters (input variables)

- Material: 22MnB5, 1.5 mm
- Closure time (quenching): 3 – 7 s
- Blank holder distance: 0.5 – 2.0 mm
- Press force: 1250 – 1400 kN
- Tool temperature: 70 °C
- Transfer time: 13 – 20 s

Experiments

- Central composite circumscribed experimental design
- 10 factor level combinations, 42 experiments

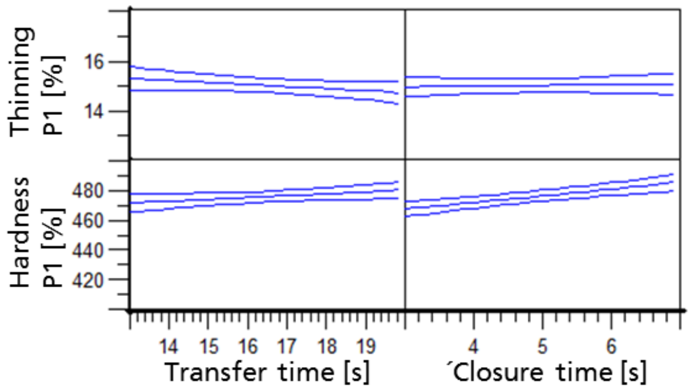


CCC design for 4 factors

Results

- Database describing the dependencies between process parameters and quality criteria
- E.g.: significant influence of transfer time and Closure time on hardness

Predicted response graphs (excerpt)



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Knowledge Base

Applied models

Model A:
Offline Control

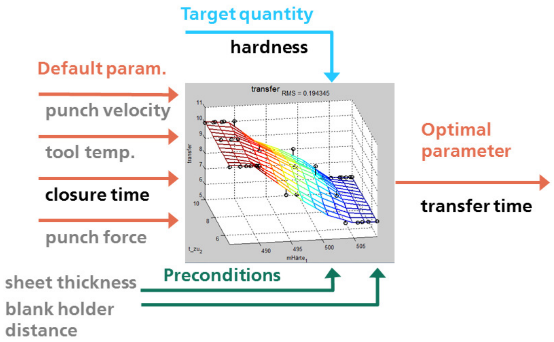
- uses knowledge base
- offline (process control)
- e.g. calculation of transfer time to reach a certain hardness

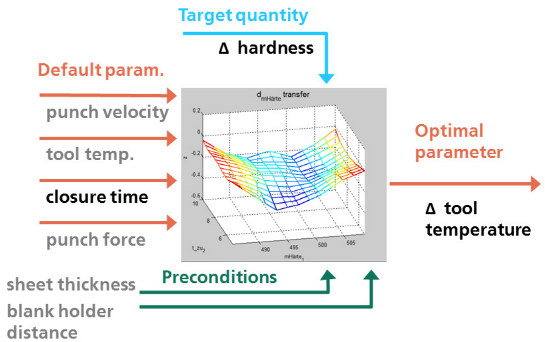
Model H:
Online, Long Term Control

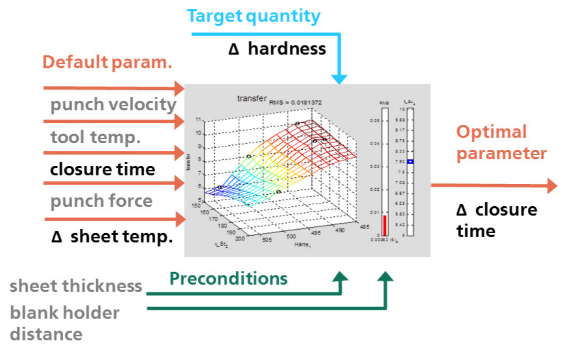
- uses knowledge base
- online, extended process control
- e.g. regulates the tool temperature in case of deviations in part hardness

Model O:
Online, Short Term Control

- uses knowledge base
- online, feedback control
- e.g. regulates closure time considering the current part temperature







relevant for — **Process planning**

relevant for — **Batch optimization**

relevant for — **In-process control**

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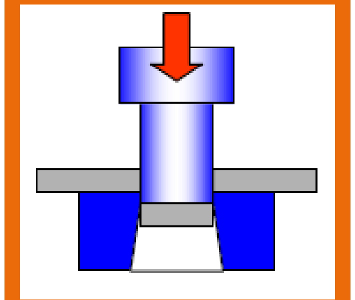
Application of High Speed Impact Cutting (HSCI)

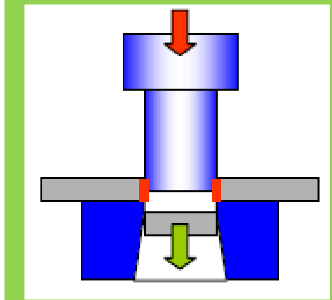
Function principle

Shear cutting



v_s ~ 0,1 m/s

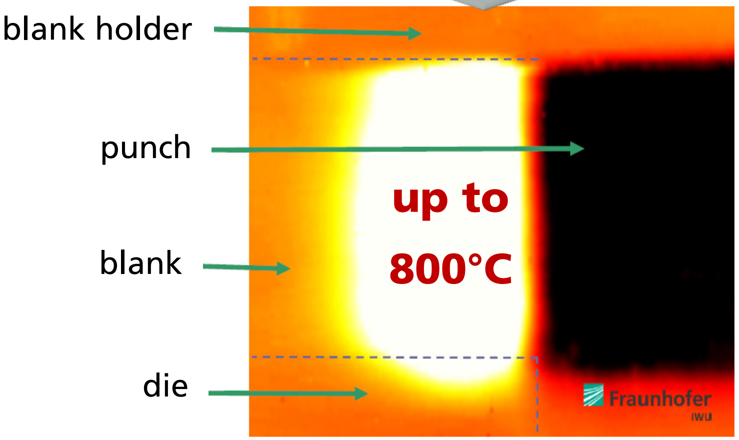
HSCI



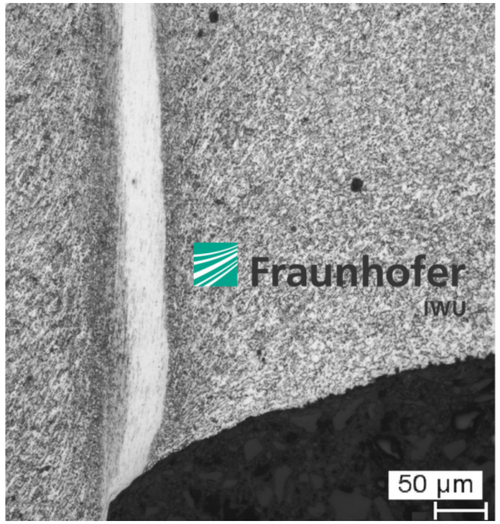
v_s = 10 m/s

Application of physical effect of shear band

- High **temperature increase** (some hundreds of grad within shortest time (< 100 µs)
- Limited of a very small **volume of material** (< 100 µm)
  - extremely short cycle time
  - no heat transfer between heating zone and remaining material – adiabatic weakening
  - sharp separation of material results in high cutting edge quality



Shear band



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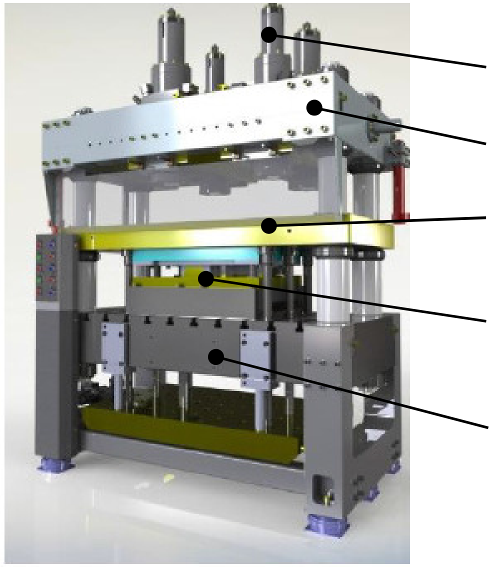
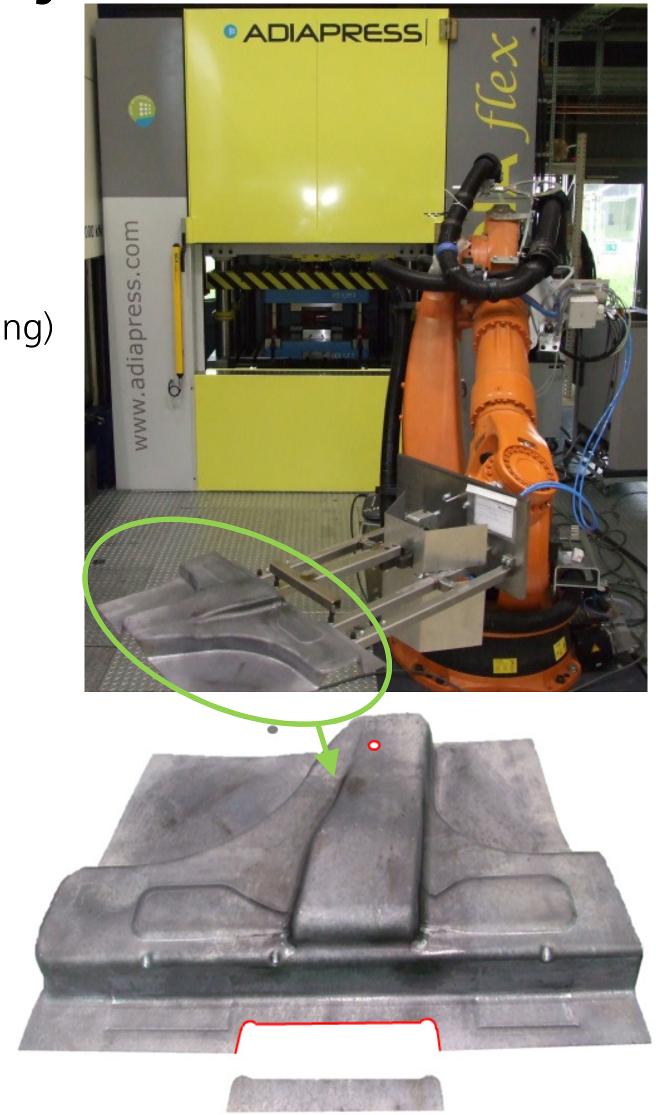
Trimming of Press Hardened Blanks by HSCI

ADIA*flex*® testing device





<u>Technical parameters „AdiaFlex“®:</u>

energy level :	**2 x 1,0 kJ and 2 x 2,0 kJ** (4 independent punching units)
velocity range:	**3 to 10 m/s**
table size:	**1500 x 800 mm**

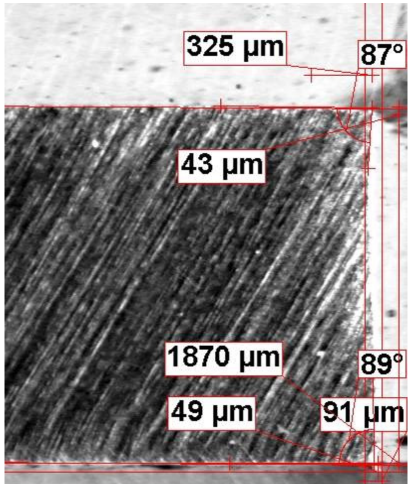
power generation by high speed hydraulic

Trimming of Press Hardened Blanks by HSCI

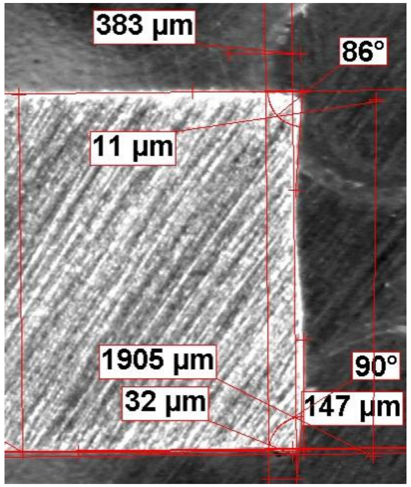
Effects for press hardened steel - Cutting quality

Material: 22MnB5, R_m= 1500 MPa, sheet thickness 2,0 mm, die clearance **3%**

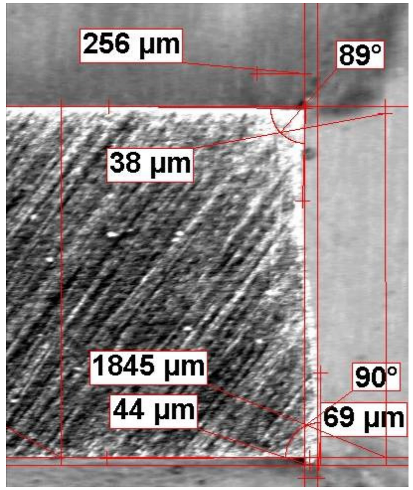
HSIC



E = 1700 J (v = 4,7 m/s)



E = 4000 J (v = 7,2 m/s)

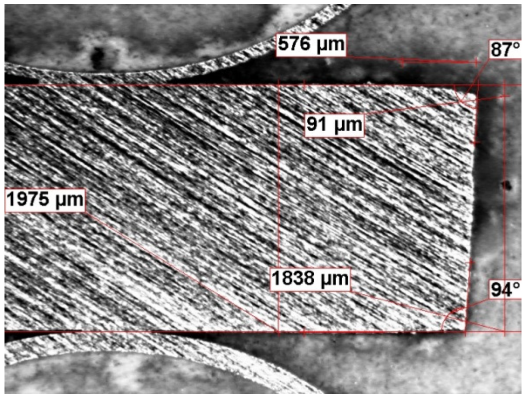


E = 7000 J (v = 9,6 m/s)

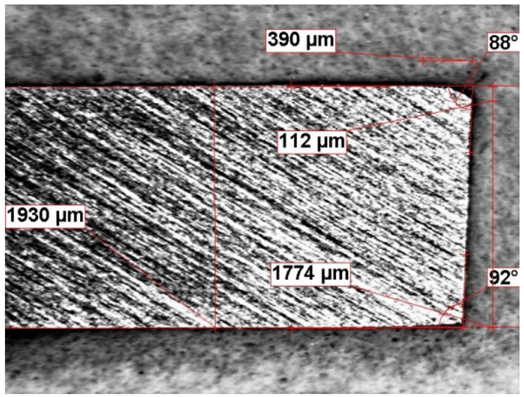
Shearing

(reference)

v_S = 25 mm/s



v_S = 100 mm/s



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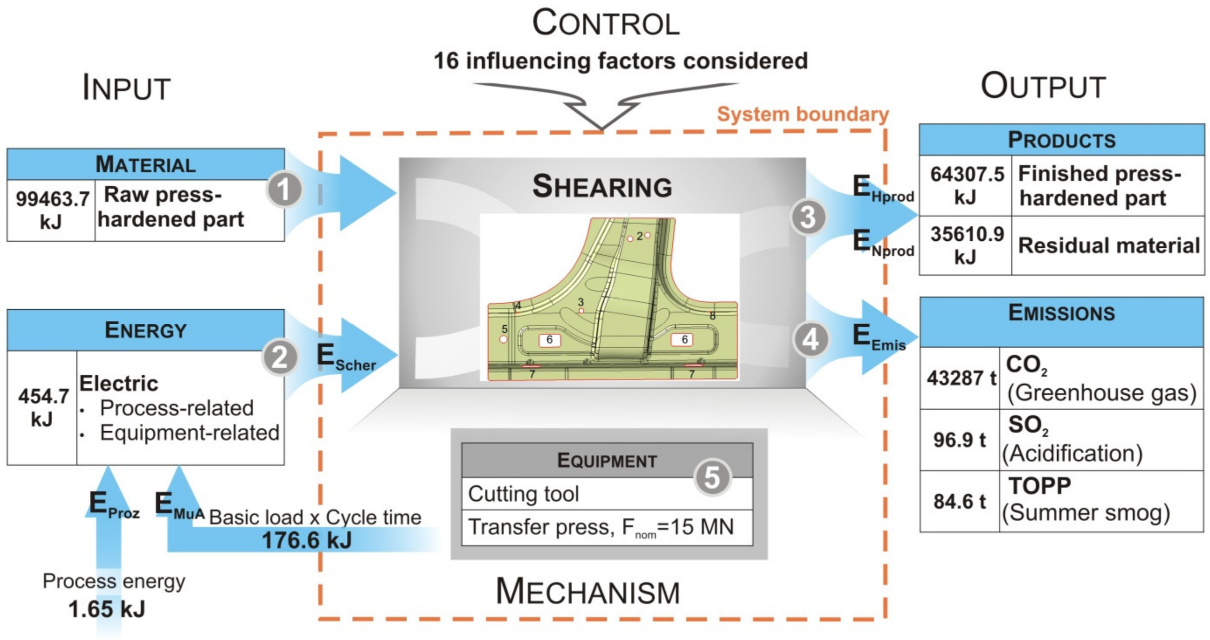
4. Trimming of Press Hardened Blanks

Mechanical vs. Laser Cutting

Balancing of process energy consumption



comparison of technologies

Process-Efficiency-Rate

$$\eta_{Proz} = \left(\frac{E_{Proz,\ ideell}}{E_{Proz,\ tat}} \right) \cdot 100\%$$

$\eta_{Proz,\ HSIC} = 91\ \%$

$\eta_{Proz,\ Laser} = 42\ \%$

comparison to laser cutting

→ better process efficiency rate

→ significant lower energy consumption

→ no additional process medias necessary

HSCI = resource-efficient!

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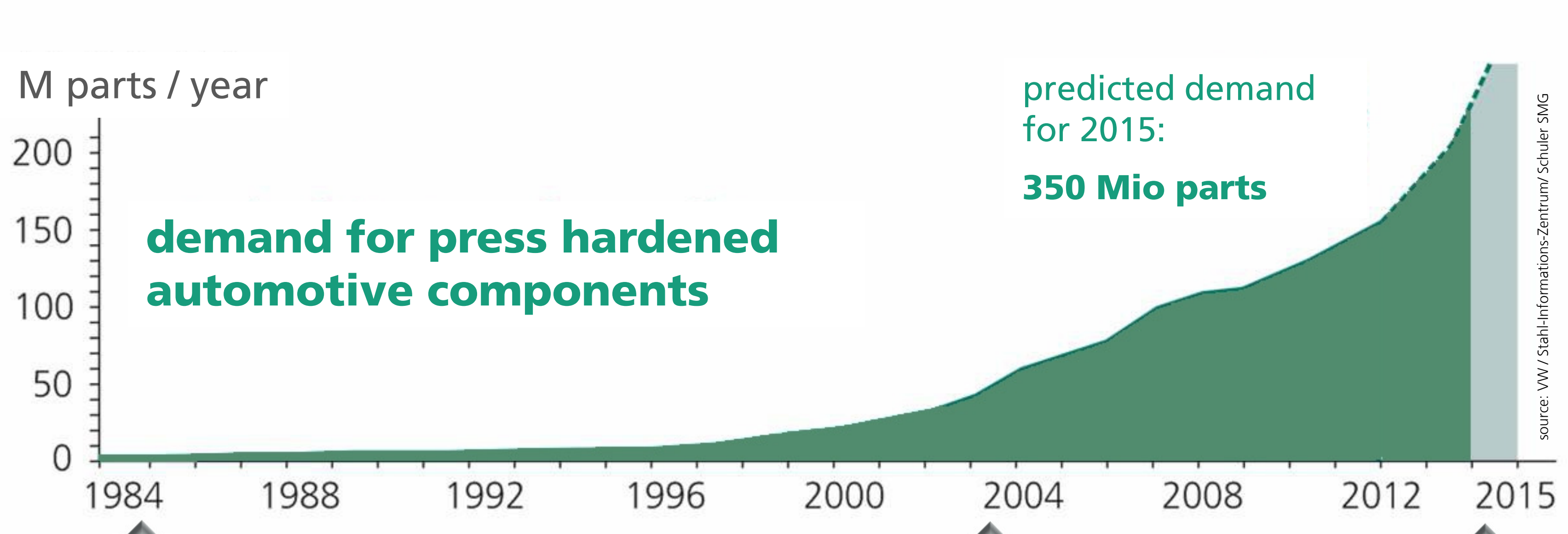
5. Conclusion and Outlook

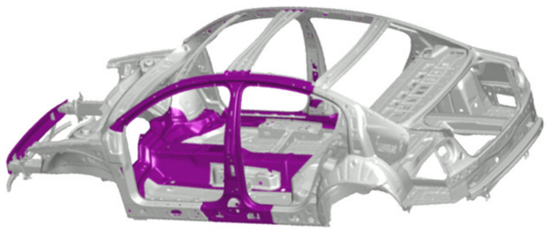
Commercial Development of Press Hardening



first application
door impact beam
SAAB 9000

breakthrough
body in white
VW Passat B6

current state
body in white
2015 Volvo XC 90



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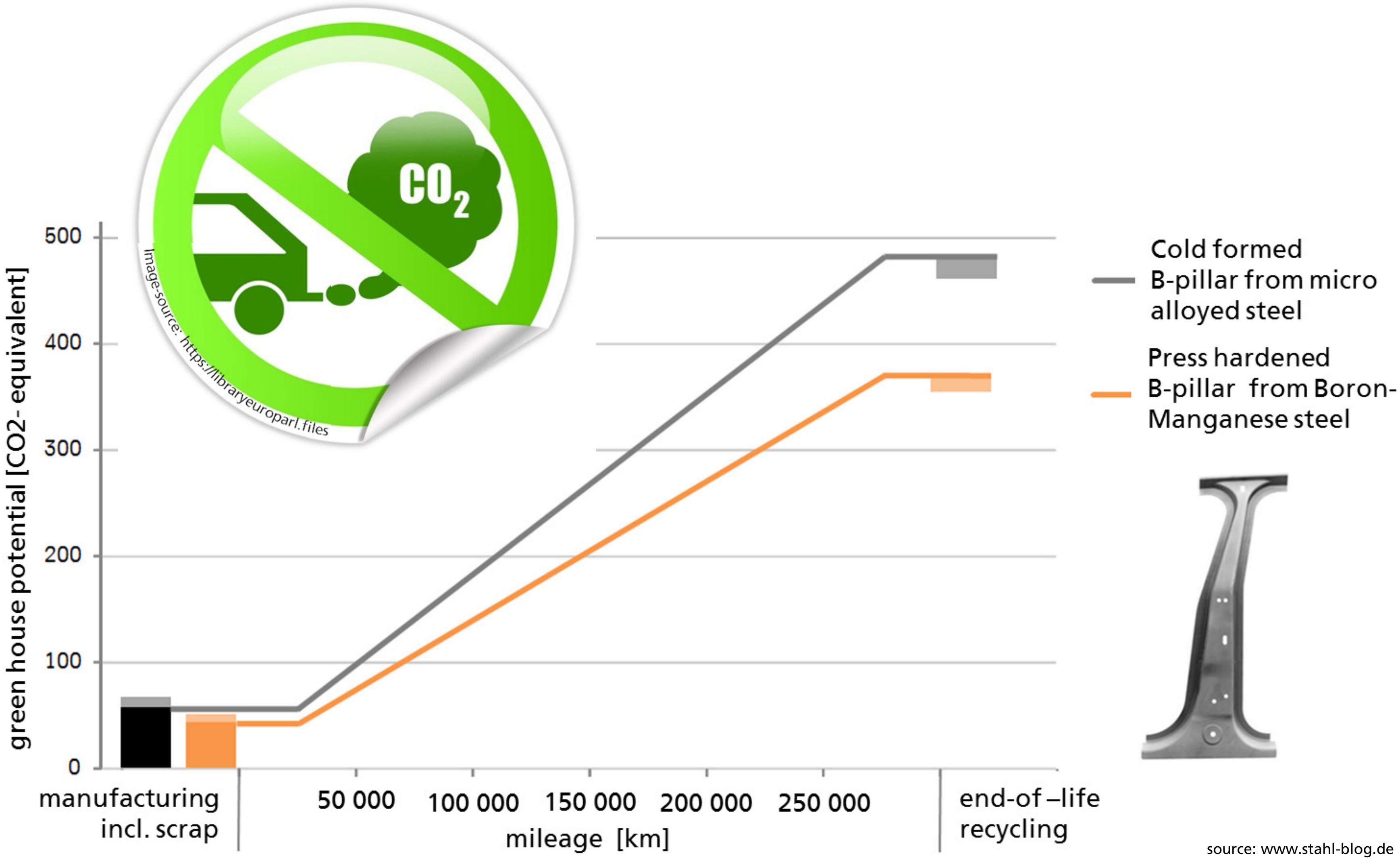
Green House Potential for Press Hardening Parts



source: www.stahl-blog.de

Optimization Potential for Press Hardening Technology

Press hardening

Product optimization	Process optimization
improvement of product properties for more efficiency, safety and performance during car operational phase	improvement of energy and resources efficiency as well as flexibility during the production phase

- increased strength
- improved elongation at fracture
- increased size and part complexity
- multiple tailored properties
- application at small series cars
- …

- zero defect manufacturing
- degreased scrap value
- alternative scale protection
- optimized heating technologies
- modular production cells
- quantity optimized process chains
- …

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Thank You for Your Kind Attention!