Innovative Forming Technologies for Efficient Light Weight Design in Car Body Structures

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1. Introduction

1st Challenge: CO_2 Emission

2014 world wide CO_2 emission

by burning fossil fuels

37 Billion Tons CO_2

Request of climate researcher

to limit global warming at 2°C

2,5 t CO_2 Per Head and Year

Impact by Car Industry

to worldwide CO_2 emission

67,5 Mio new cars in 2014

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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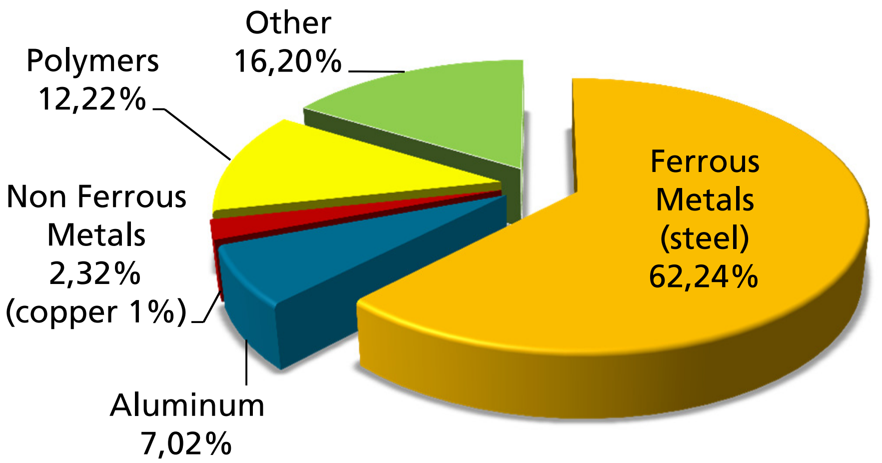
2nd Challenge: Shortage of Resources

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 %**

average passenger car material mix



source: Habermacher

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

average kerb weight per car: 1.37 t

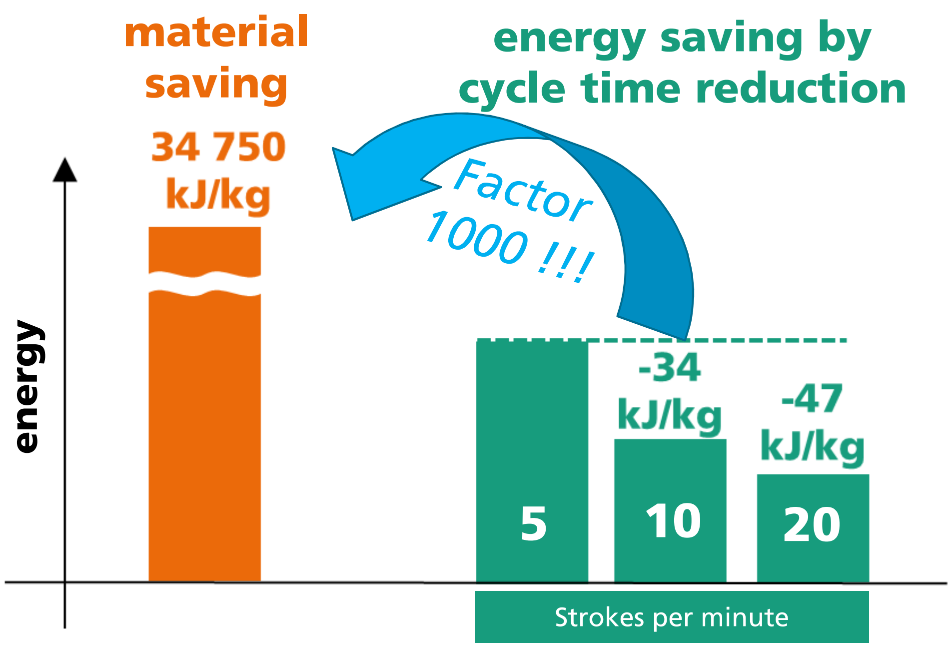
→ 57,6 Mio. t	steel (3,5%)
→ 6,5 Mio. t	aluminum (12,3%)
→ 0,9 Mio. t	copper (4,8%)
→ 11,3 Mio. t	polymer (3,7%)

resources consumption per car: 70 t

4 725 Mio. t

3rd Challenge: Energy Efficiency in Production

Material savings versus Productivity



* Cumulated energy consumption (KEA) incl. all process steps to manufacture zinc-coated steel blanks, 2010 (source: ProBas-Datenbank des Umweltbundesamtes)

Constraints :

mech. transfer press , 15 000 kN nominal force, max. strokes of 22 [1/min].
reference part: lower B-pillar of 2,33 kg

High material usage rate

=

High Energy efficiency

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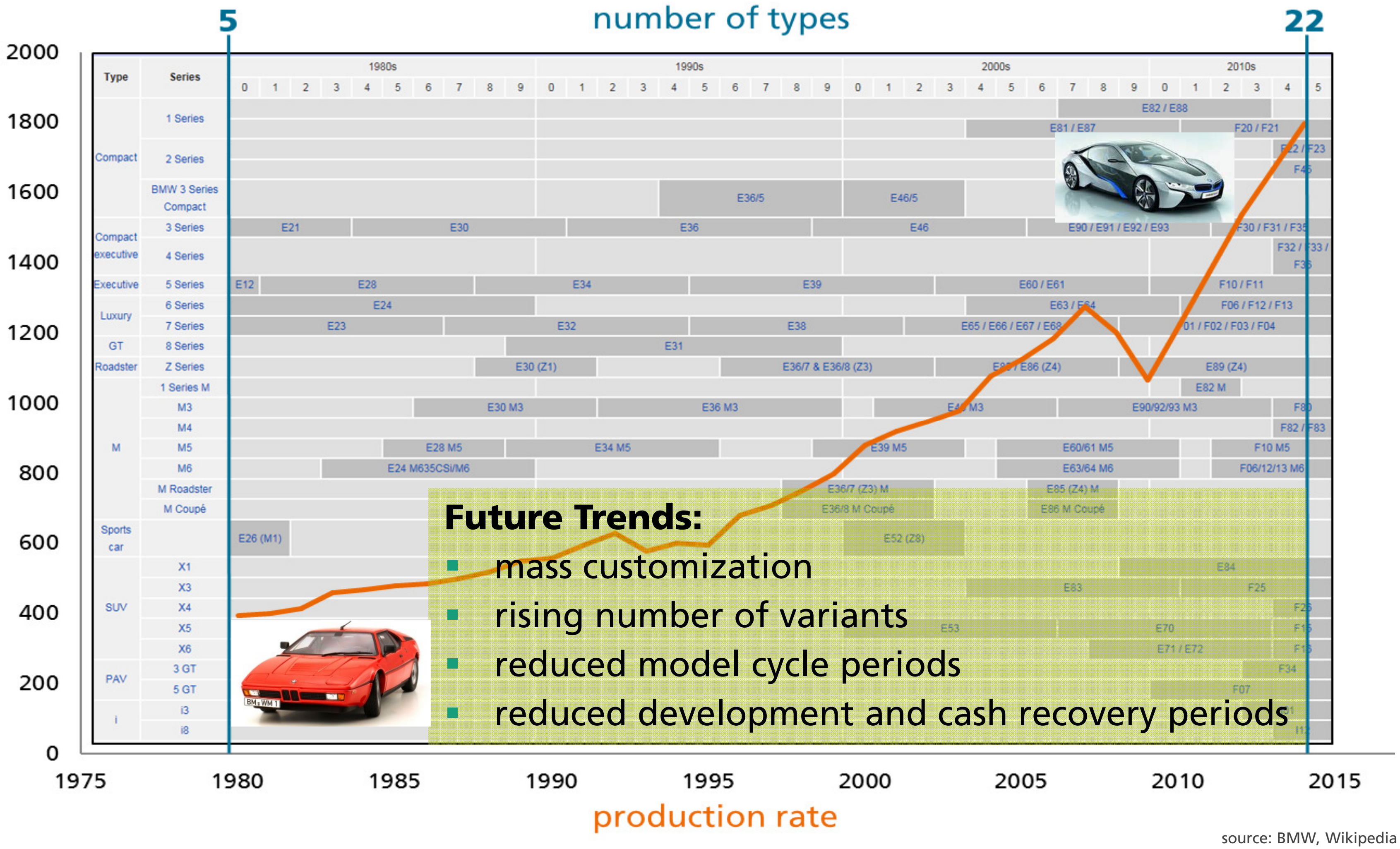
4rd Challenge: Growing Individualism

Evolution of product variety: example BMW



Future Trends:

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

source: BMW, Wikipedia

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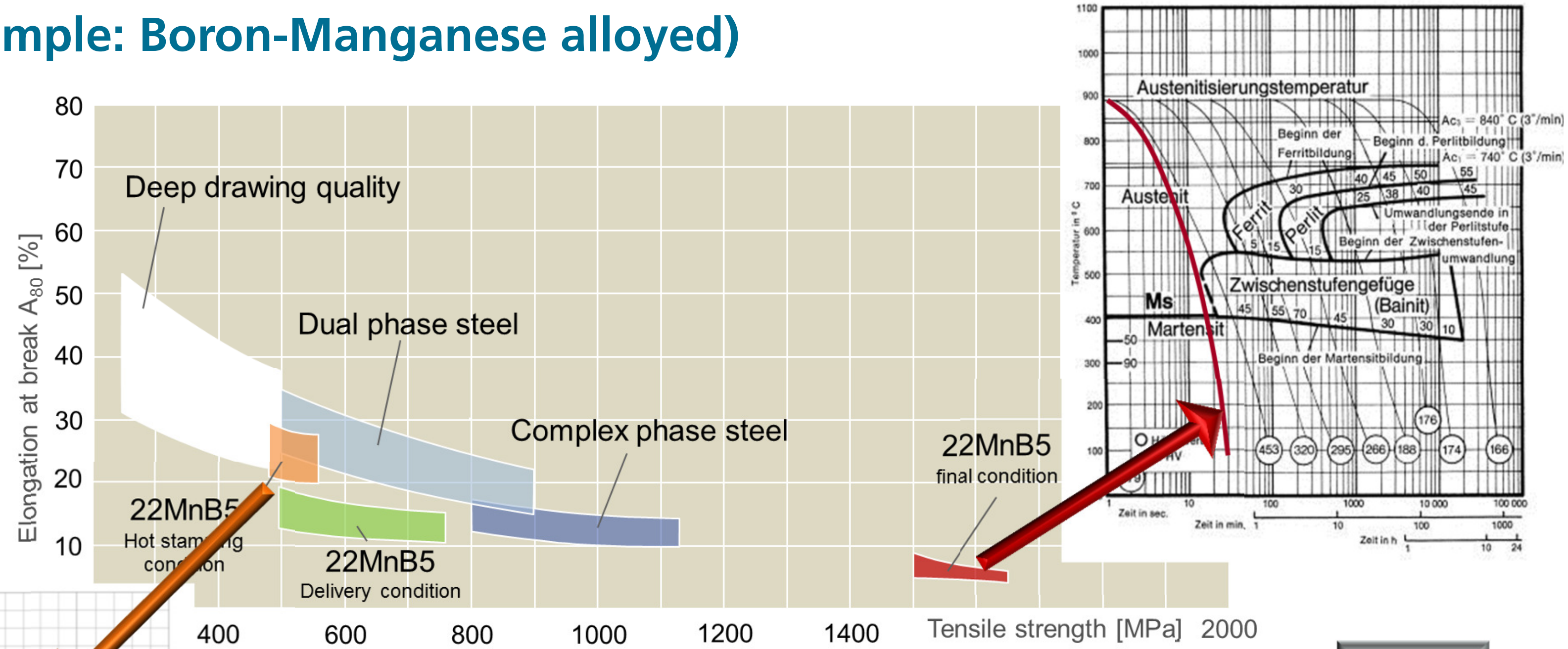
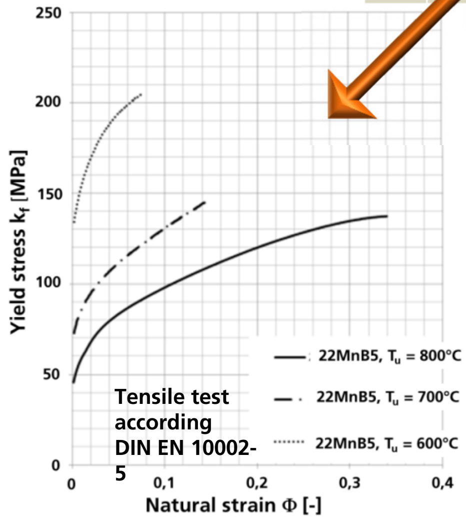
2. Pre-Processing

Effects by Temperature Support at Lightweight Materials

Steel (example: Boron-Manganese alloyed)





thermal related effects:

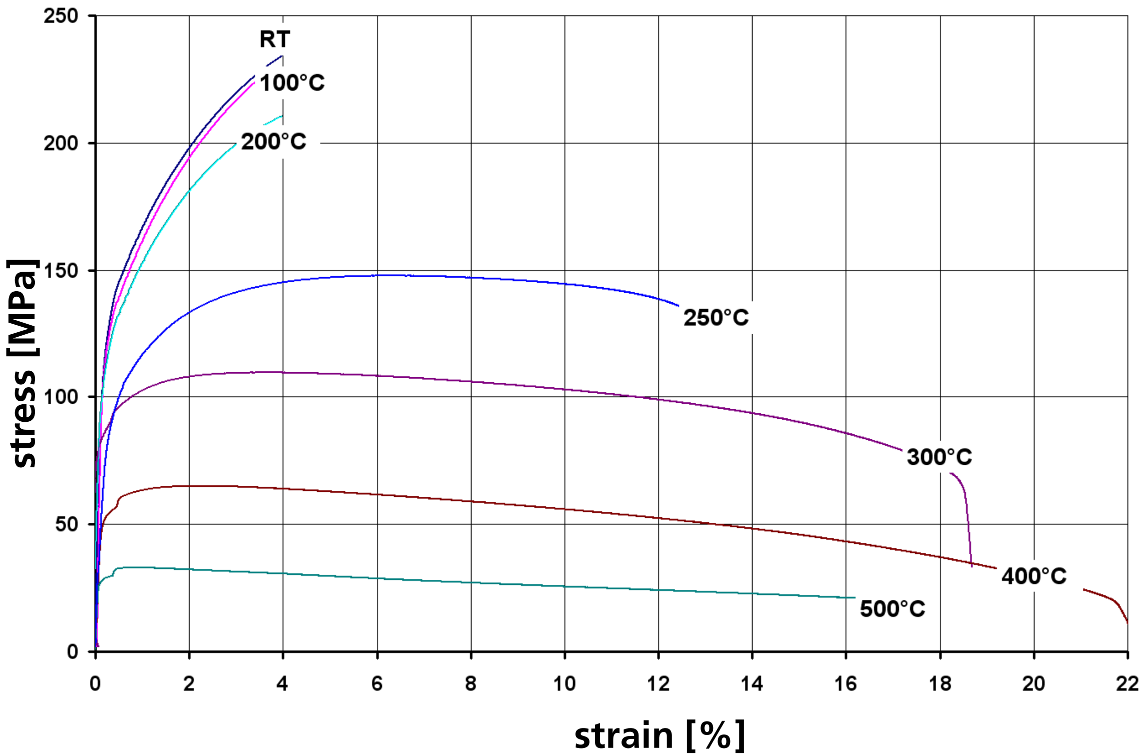
- ➔ formability ⇧
- ➔ forming forces ⇩
- ➔ spring back ⇩
- ➔ part strength ⇧

Effects by Temperature Support at Lightweight Materials

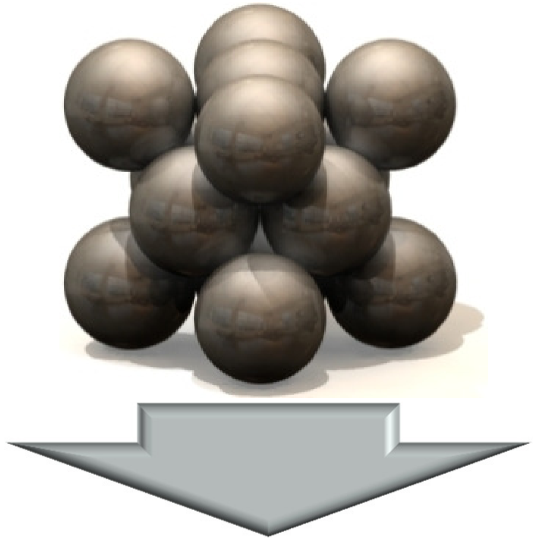
Aluminum

Influence of temperature support at A6061; s_0 = 1,3 mm;

Tensile test according DIN EN 10002-5



face centered cubic grid



thermal related effects:

- ➔ annealing
- ➔ recrystallization
- ➔ diffusion
- ➔ reduction of internal tensions

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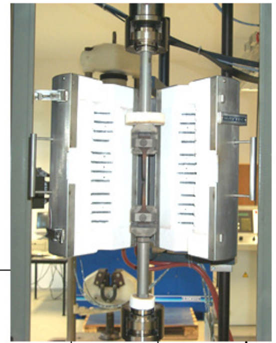
Effects by Temperature Support at Lightweight Materials

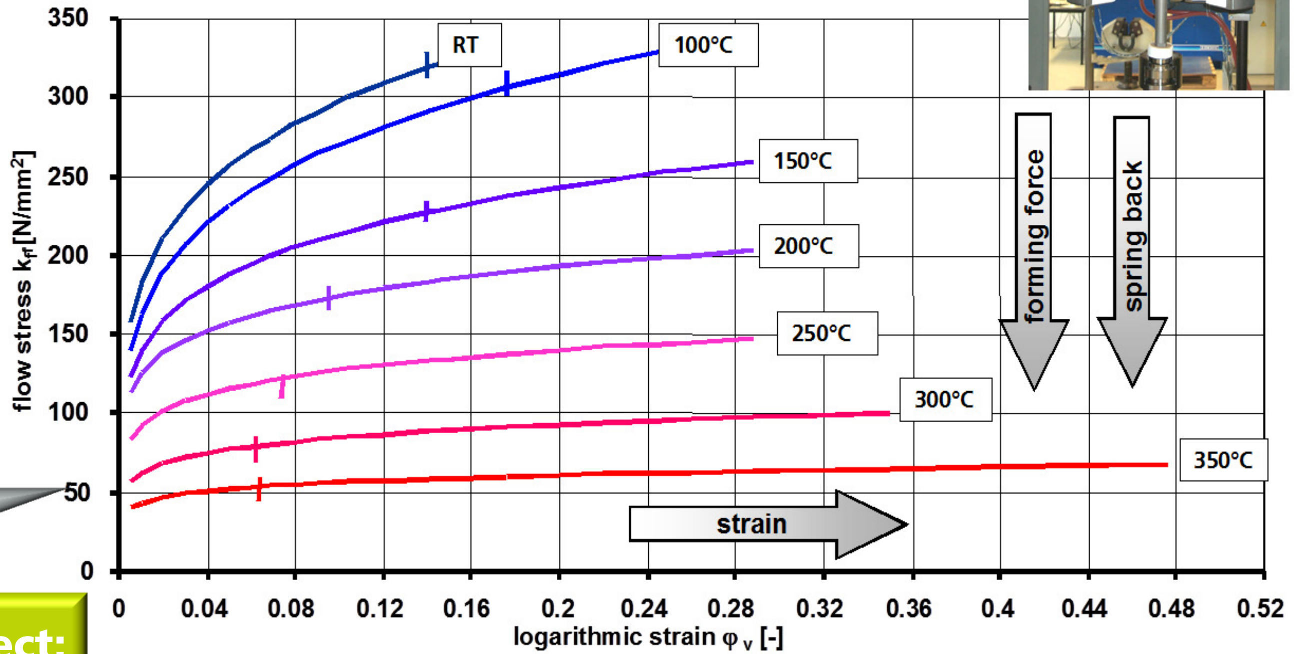
Magnesium

Influence of temperature support at AZ 31B; s_0 = 1,3 mm;

hexagonal structure of Magnesium

tensile tester
ϑ_{max} = 1200°C





Tensile tests conducted regarding DIN EN10002-5

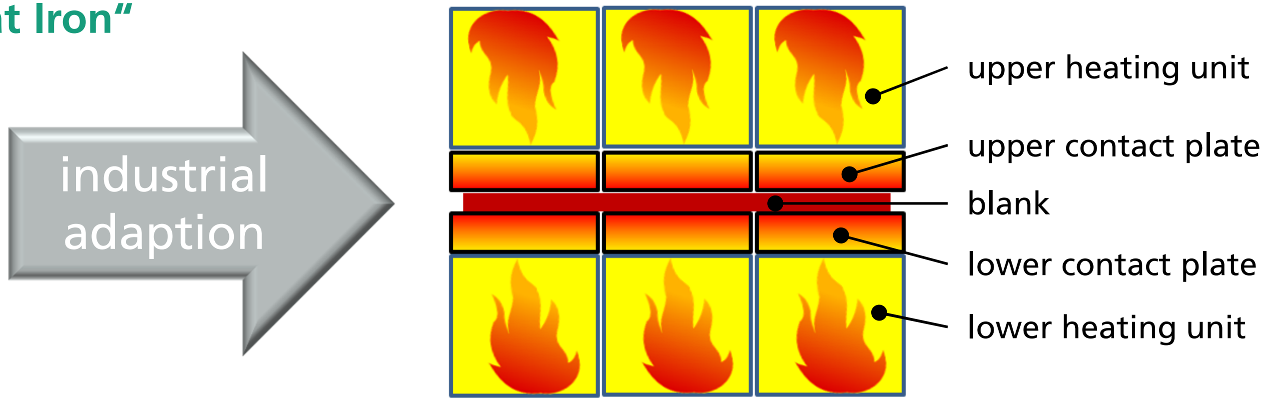
thermal related effect:

→ activating of additionally sliding planes

Contact Heating – Fast and Efficient

Function principle and basic investigations

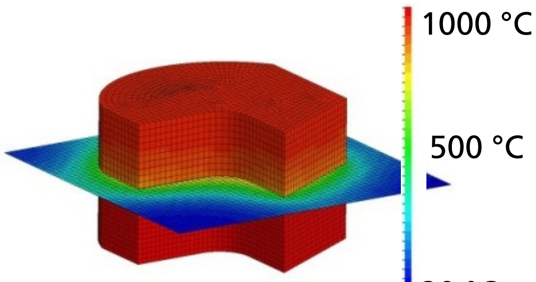
function principle: „Flat Iron“



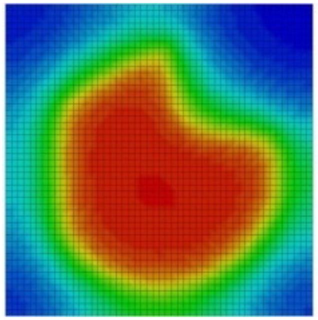
basic investigations

Thermal FE-simulation

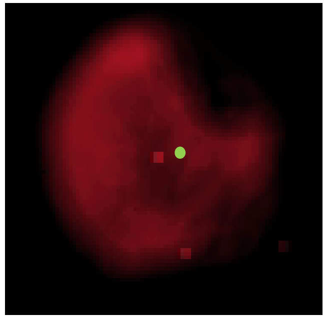
contact pressure: 15 MPa
heat contact coefficient: 4000 W/(m²*K)
(ceramic contact plate)

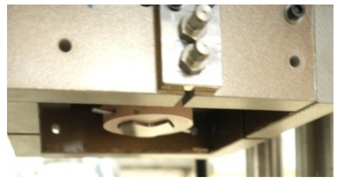


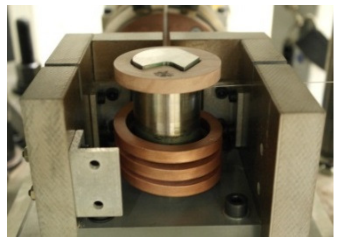
test tool



blank





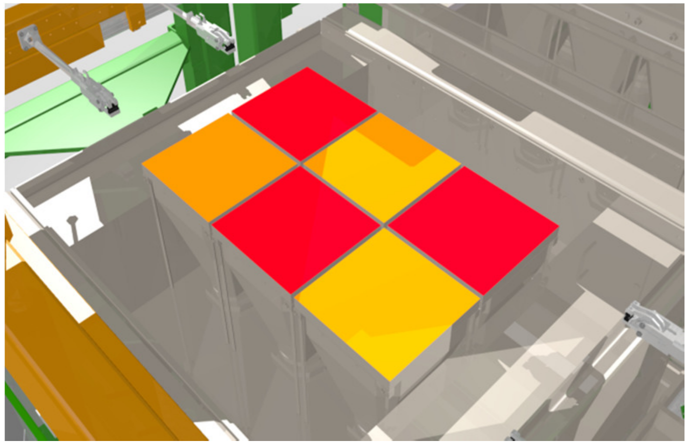


thermal camera image - 5 s after part remove from tool

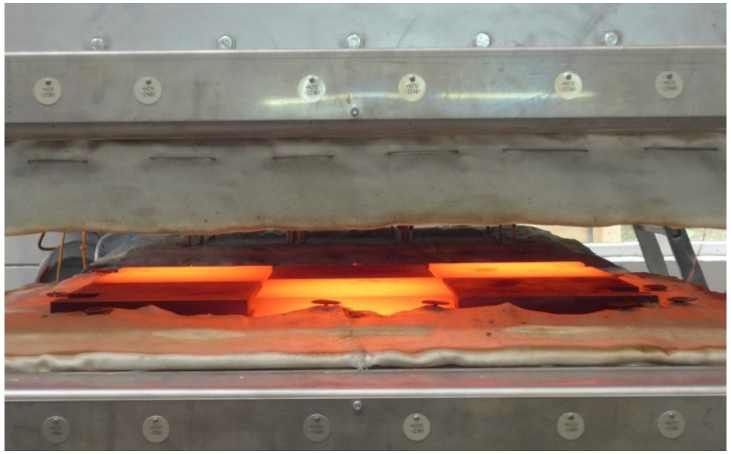
2. Pre-Processing

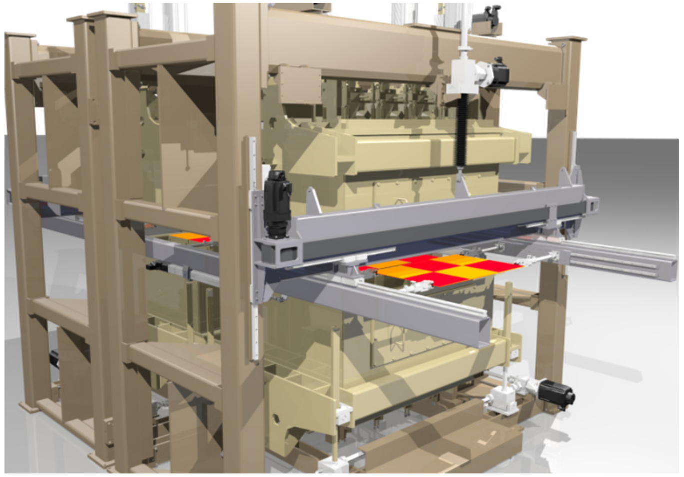
Contact Heating – Fast and Efficient

Testing device at Fraunhofer IWU

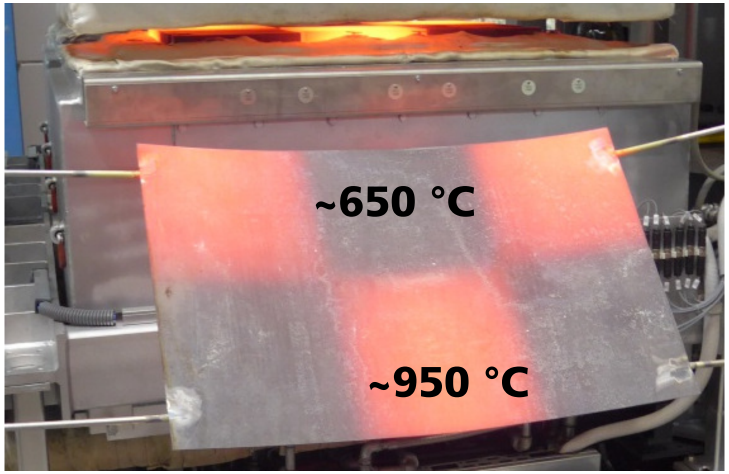


contact plates





blank, adaptive heated



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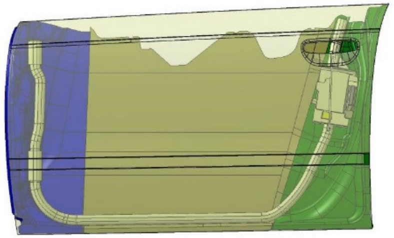
Magnesium Forming

Deep Drawing & Stretch forming

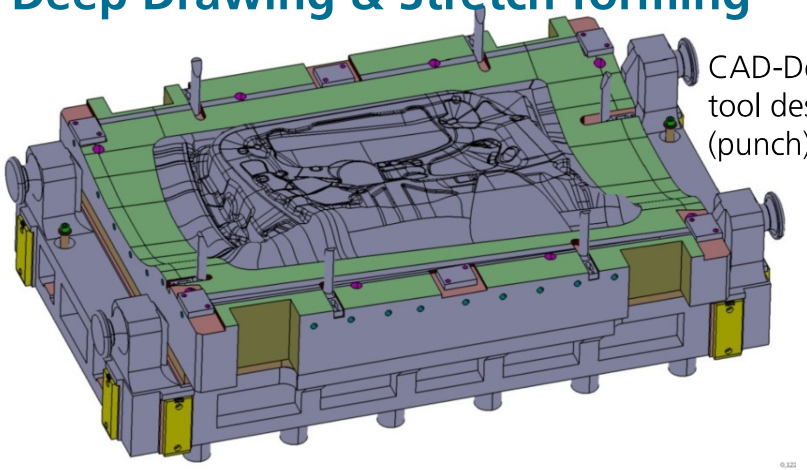


tool heating strategy

tool: → die, blankholder – electrical cartridges

→ punch – fluid (thermal oil)

blank: → furnace (outside of press)



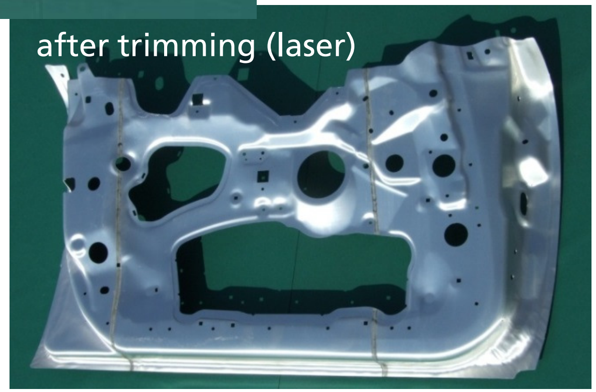
CAD-Design
tool design
(punch)

testing tool in 16,000 kN tryout press

after deep drawing

"Door Inner Panel"

triple tailored blank
2,0mm/1,2mm/2,0mm



after trimming (laser)

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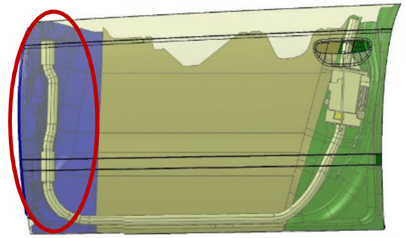
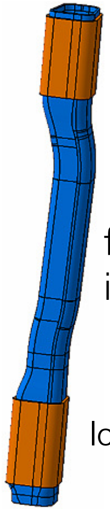
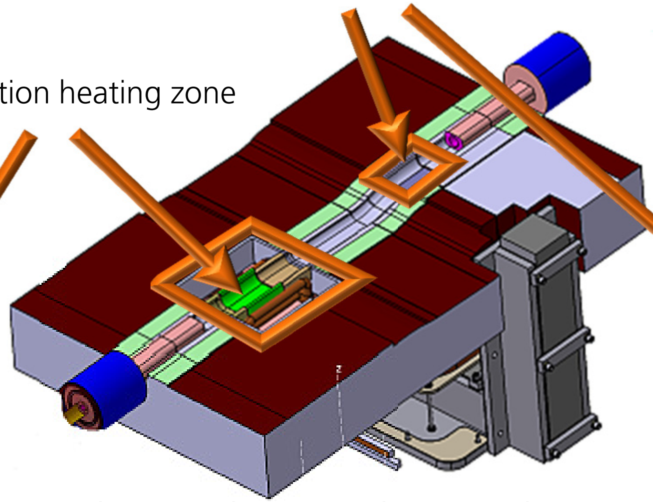
Magnesium Forming

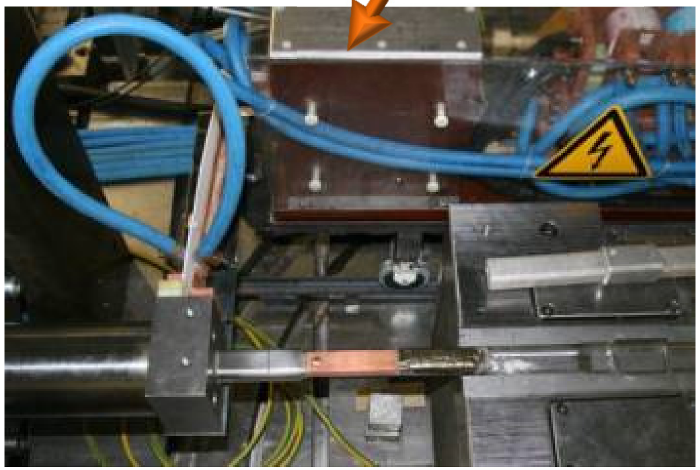
Hot Gas Forming







lower die including local heating devices



realized induction heating

Lower gas forming tool

realized magnetic heating

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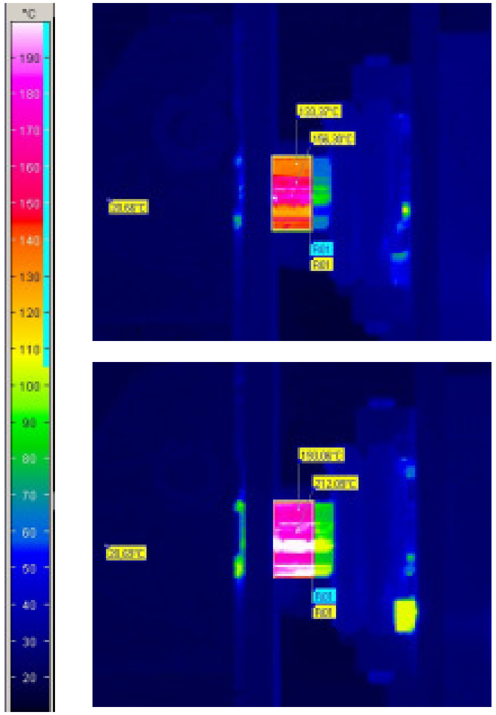
Magnesium Forming

Free shape bending



adjusting of power level for induction heating

frame bending at parallel kinematic bending machine "HexaBend"

comparison of bended parts incl. and without induction heating

matching – frame in door inner panel

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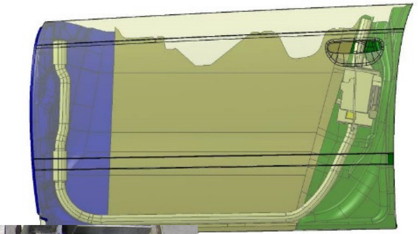
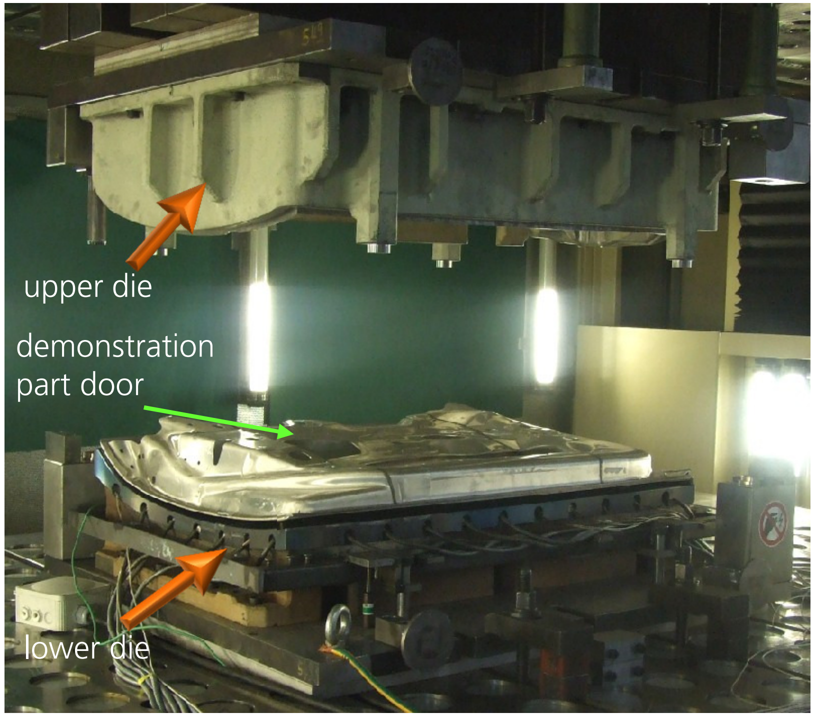
Magnesium Forming

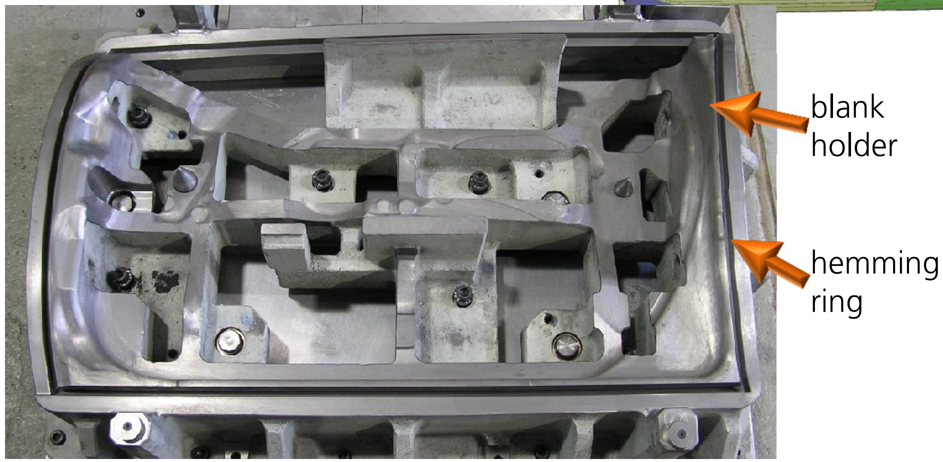
Hemming



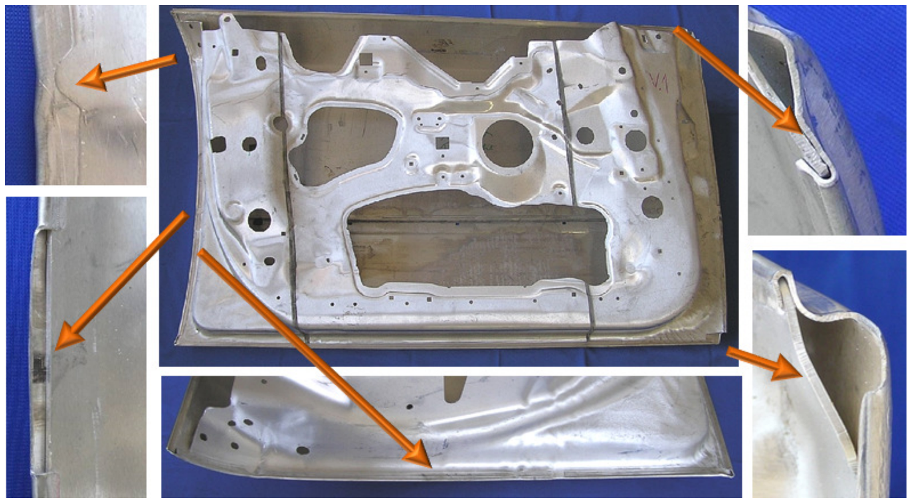


hemming die in test press EHP1600 (IWU)
(lower die – heating by electric cartridges)

- **hemming of demonstration parts – door geometry incl. electrical heating**
- **tryout of induction heating**
  → existing potentials



hemming tool upper die upper



door assembly after hemming - results

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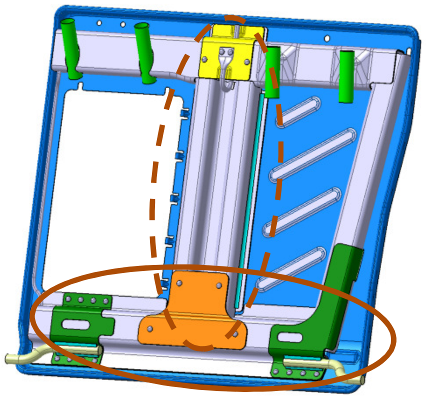
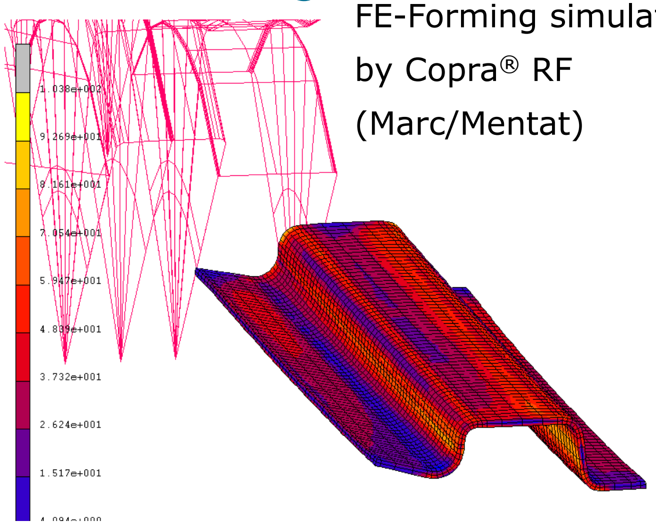
3. Forming Processes

Magnesium Forming

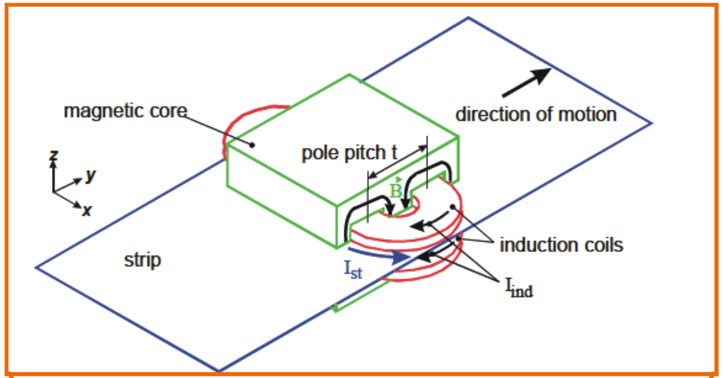
Roll Forming

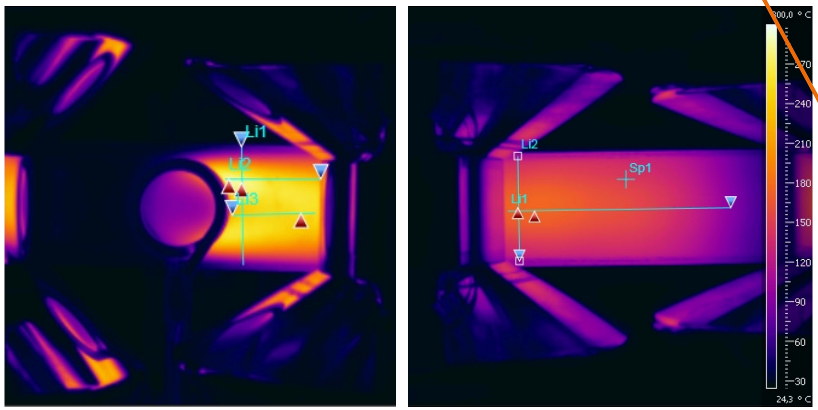




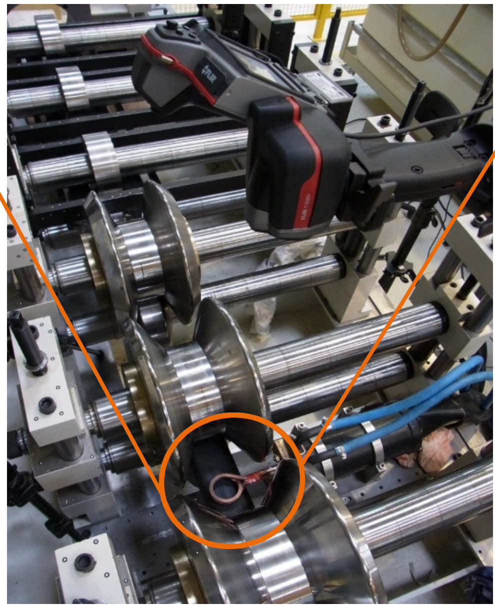
FE-Forming simulation by Copra® RF (Marc/Mentat)

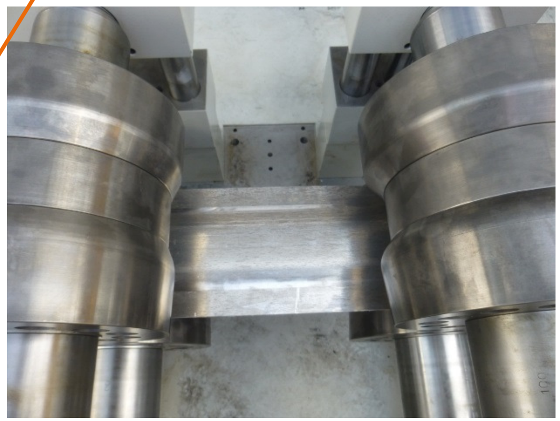
principle of induction heating





experimental determination of heat losses by radiation & roll contacts





realization of profiles

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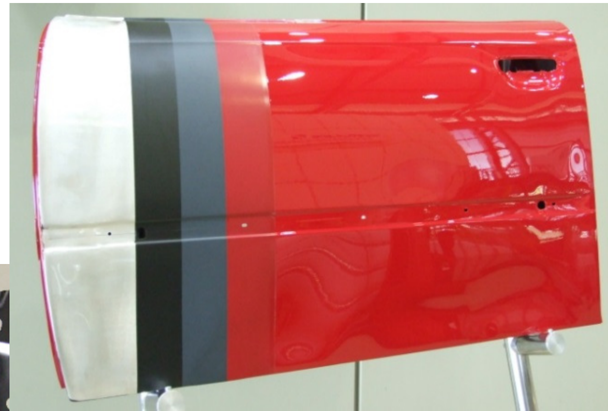
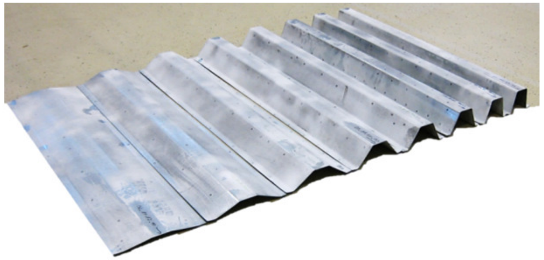
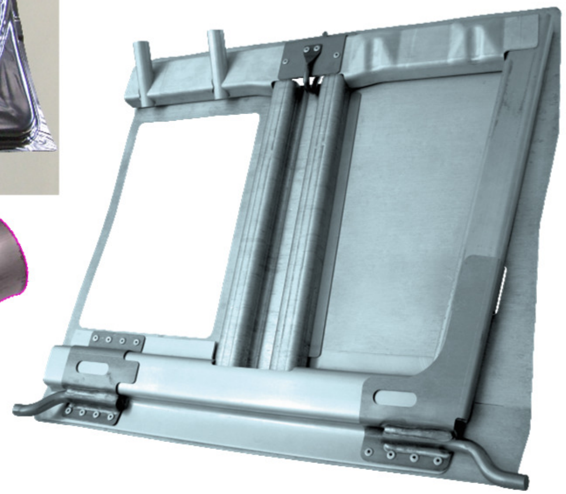
Magnesium Forming

Conclusion

- semi finished products (blanks, tubes and profiles) **available**
- established forming technologies **ready for application**
- temperature support (~200 °C) **must be**
- lubricant for serial production is **not available**
- corrosion protection is **critical**







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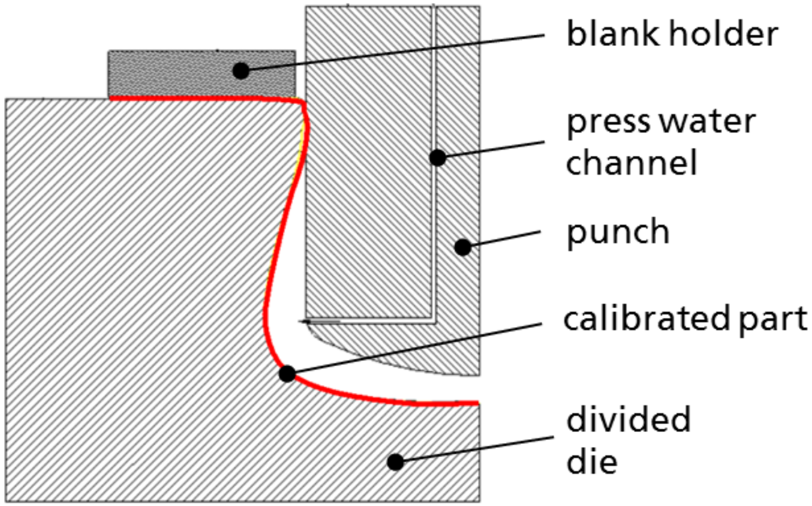
Hybrid Technologies

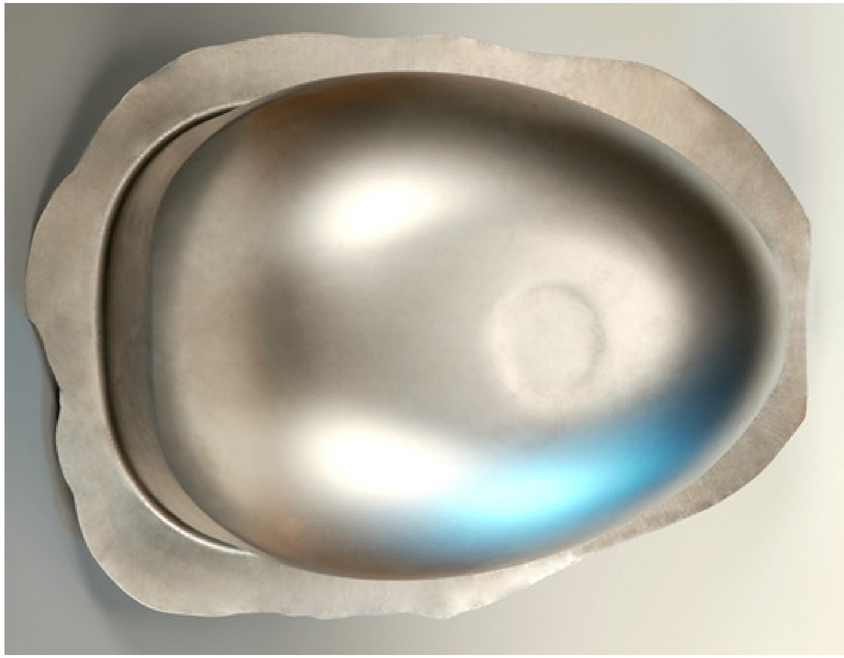
An old idea… 10 years ago

process combination of deep drawing and hydroforming

tool principle



demonstration part motorcycle fuel tank



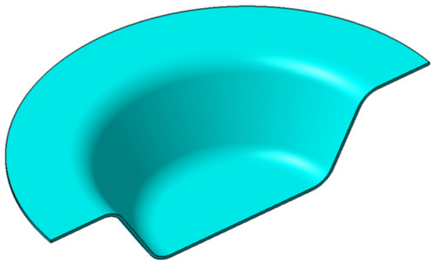
- ⇨ reduction of joining operations
- ⇨ increasing of forming limits, part quality as well as complexity (new design free space)
- ⇨ …
- ⇨ **new challenges in tool design and process control**

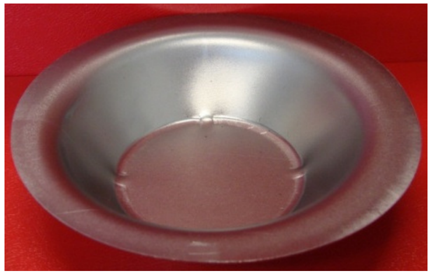
Hybrid Metal-Polymer Technologies

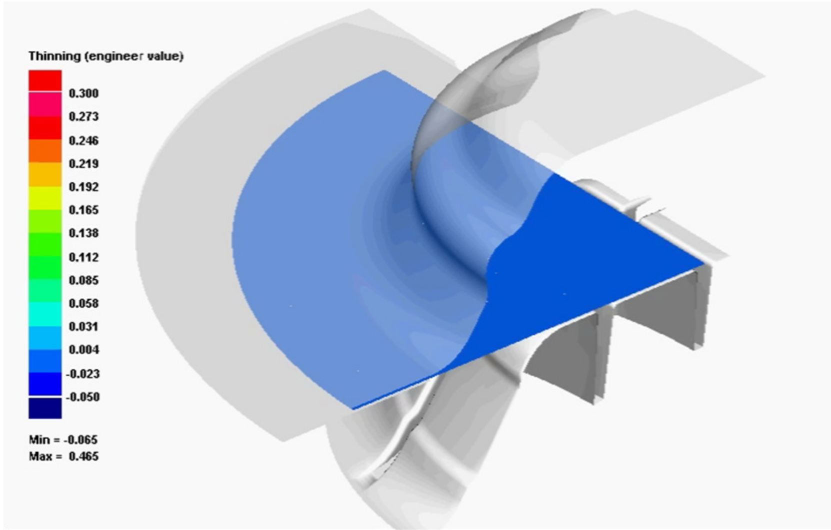
Process Combination Deep Drawing & Injection Molding

why not using heated fluid polymer as forming media?

1. Conventionally deep drawing of a cup geometry

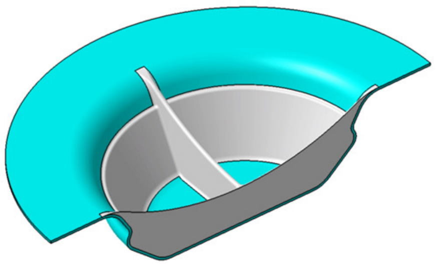


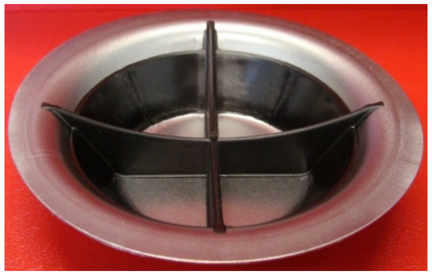




2. Injection molding for:

→ forming undercuts
→ inserting of reinforcement elements





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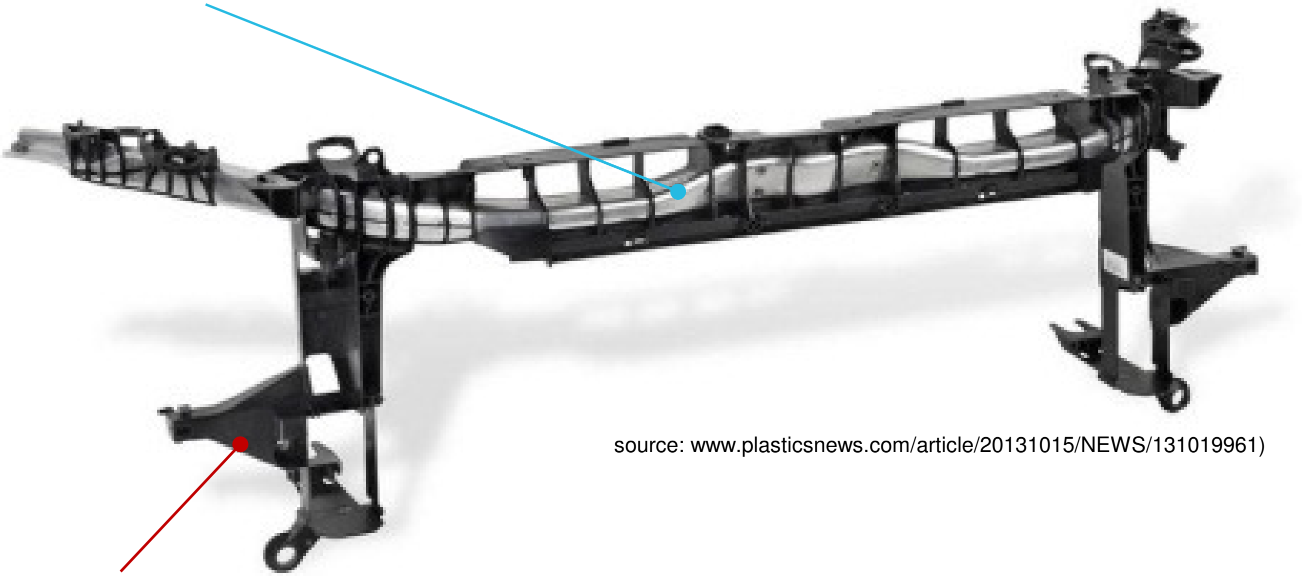
Hybrid Metal-Polymer Technologies

Process Combination Hydroforming & Injection Molding

1. Hydroforming of metal tube / realization of a counter pressure



source: www.plasticsnews.com/article/20131015/NEWS/131019961)

2. Injection molding of plastic functional sections

challenges:

- ➔ using of gas (nitrogen) as forming media
- ➔ substitution of bonding agents by surface structuring

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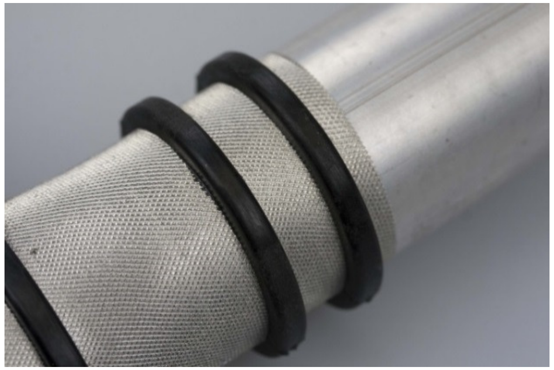
3. Forming Processes

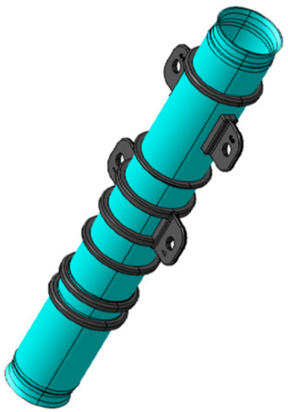
Hybrid Metal-Polymer Technologies

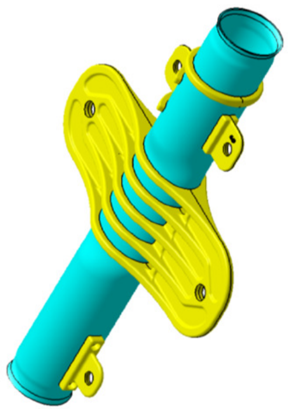
Challenges in different load directions

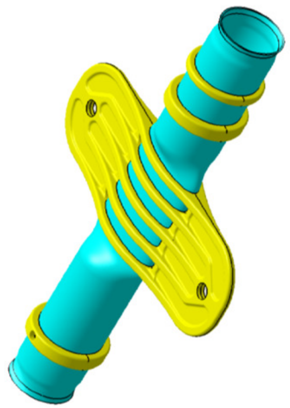
Connecting concepts for optimized load paths

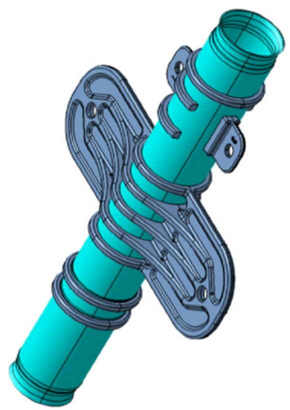
tensile strength	shearing strength	torsion strength











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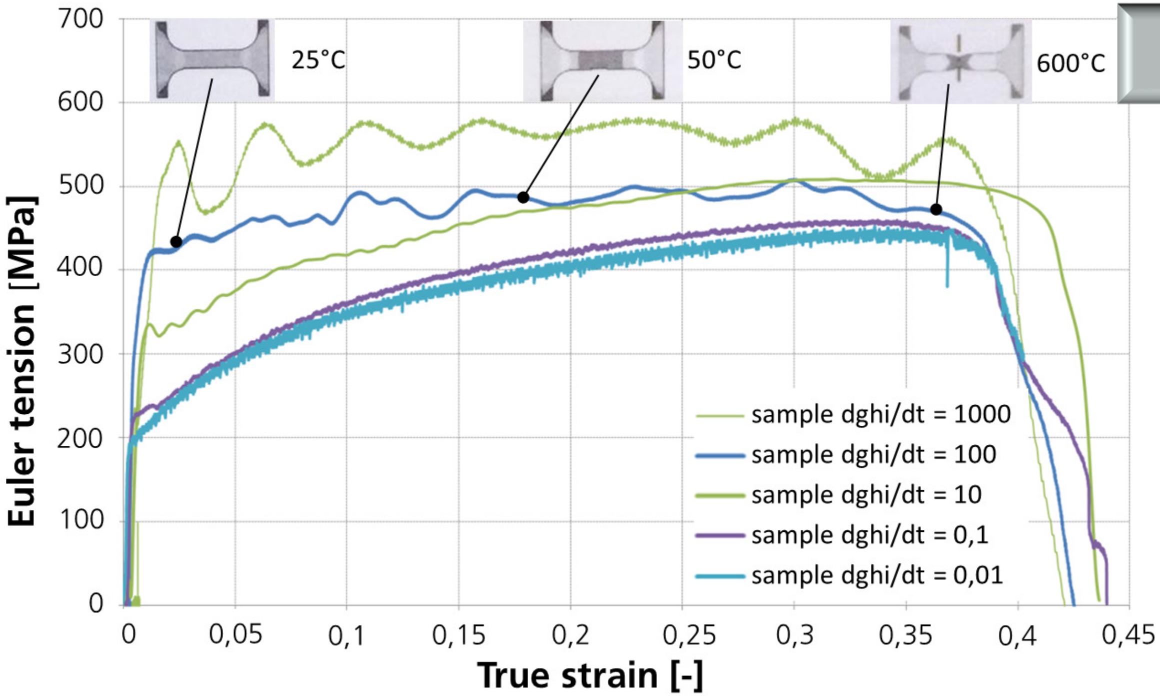
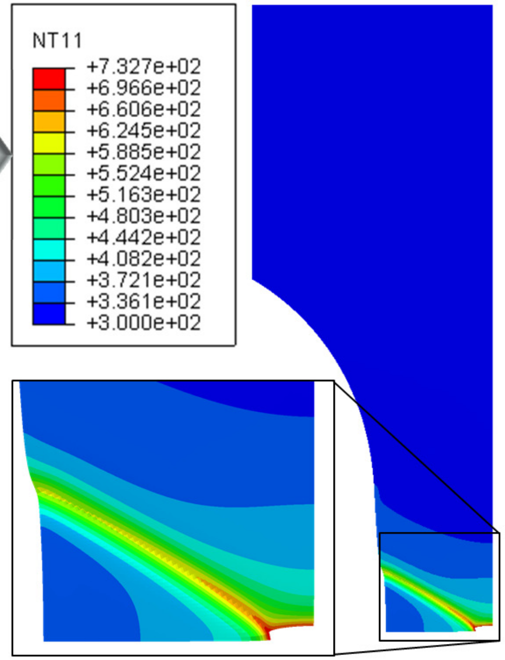
Velocity effects

Strain rate related tensile tests





- dissipation of plastic energy at ~90% to heat:
  - → increasing of temperature
  - → decreasing of yield stress
- Process period short:
  - → adiabatic heating in very limited zone
  - → further Temperature concentration (hot spot)

effects

- → **formability** ⇑
- → **forming forces** ⇓
- → **spring back** ⇓

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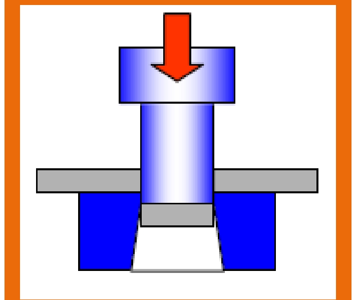
Part Trimming by High Speed Impact Cutting (HSIC)

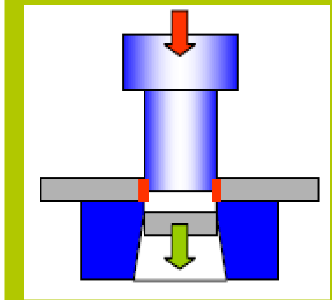
Function principle

Shear cutting

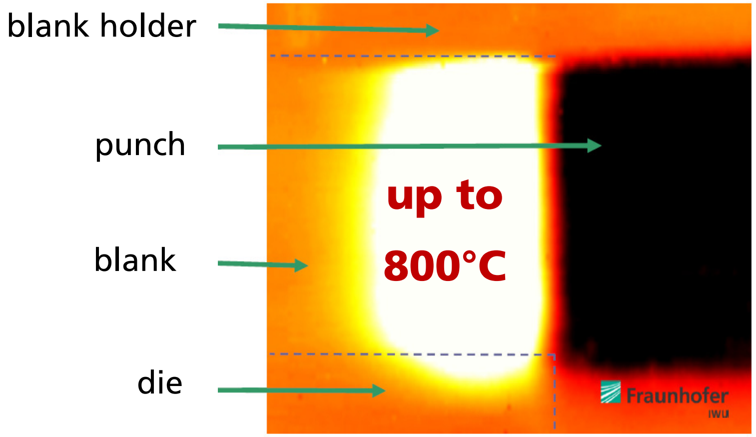


v_s ~ 0,1 m/s

HSCI



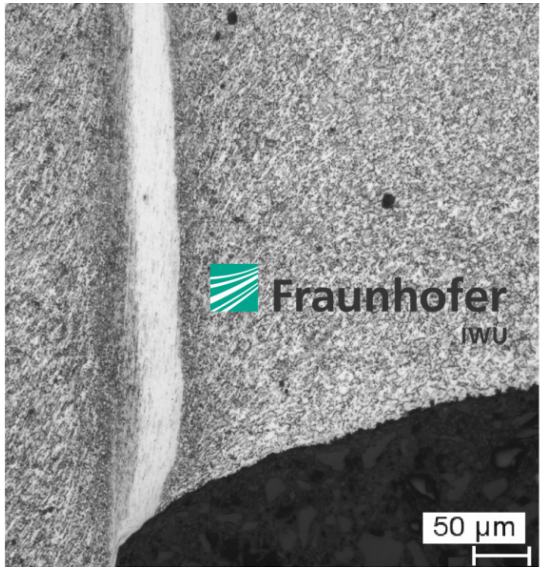
v_s = 10 m/s



shear band

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



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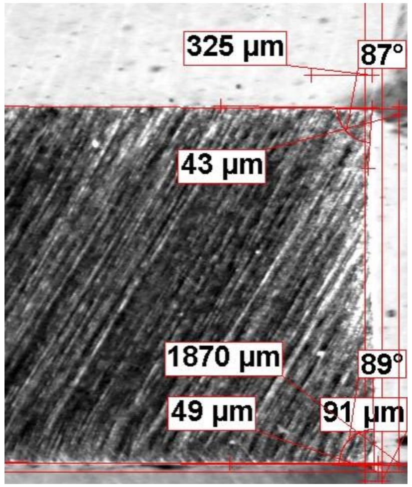
Part Trimming by High Speed Impact Cutting (HSIC)

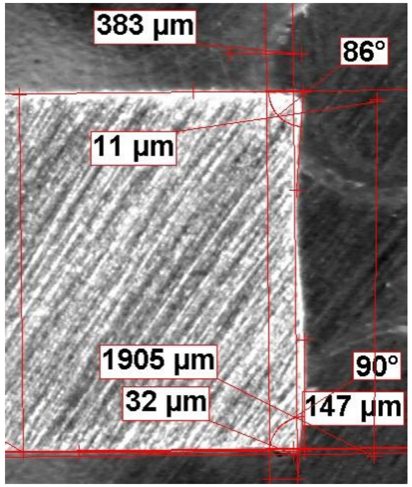
Effects regarding cutting quality – example press hardened steel

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

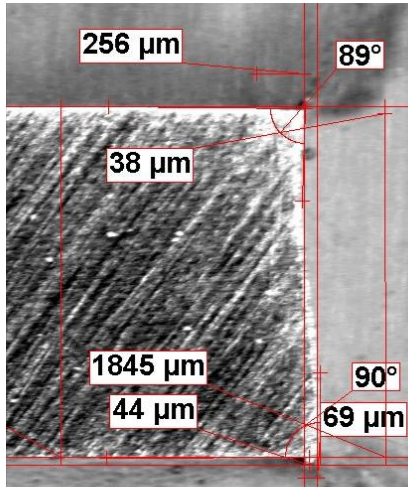
HSIC



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



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

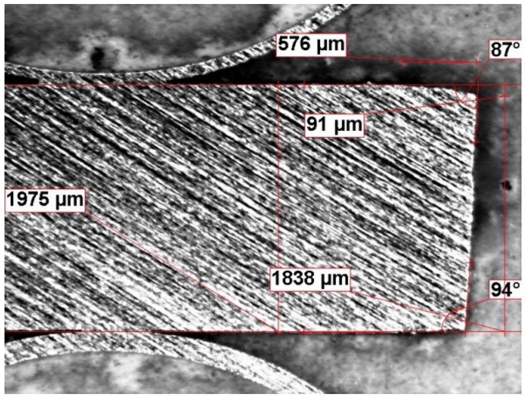


E = 7000 J (v = 9,6 m/s)

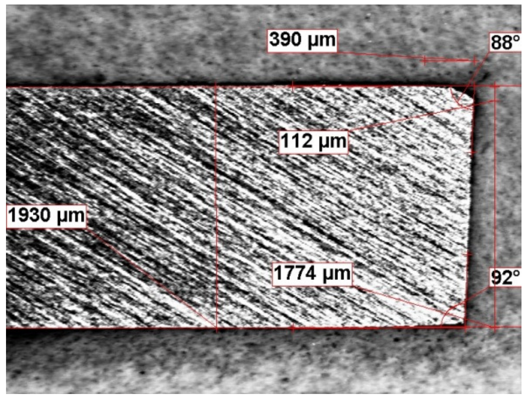
Shearing

(reference)

v_S = 25 mm/s



v_S = 100 mm/s



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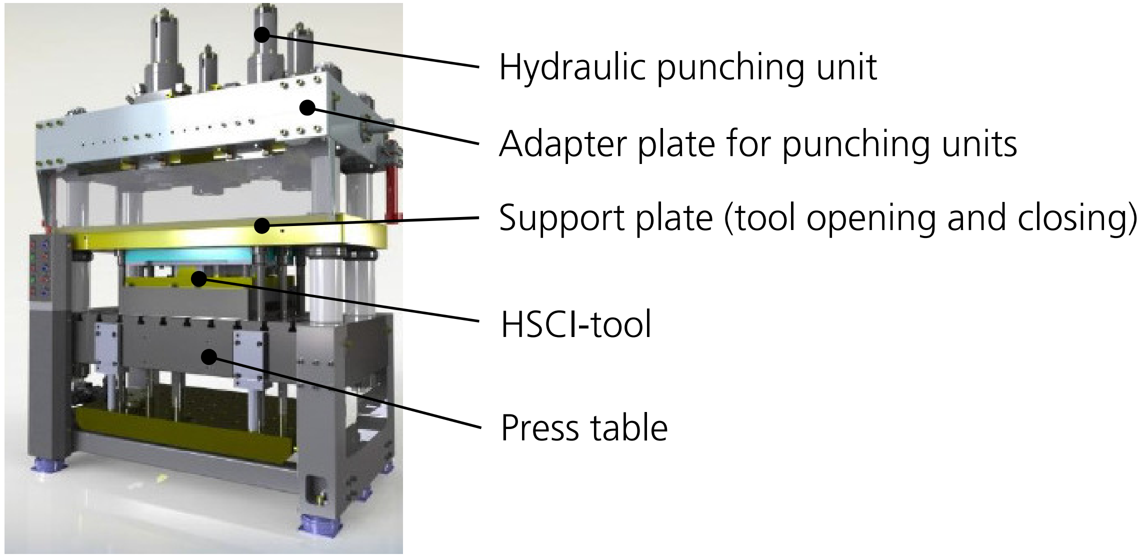
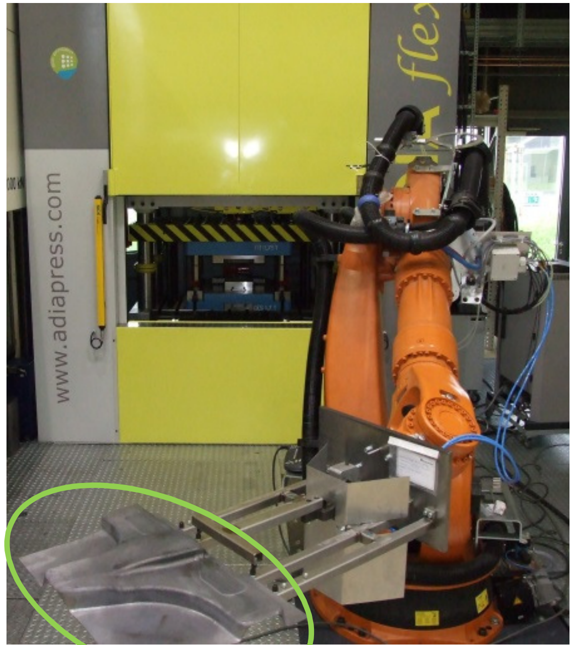
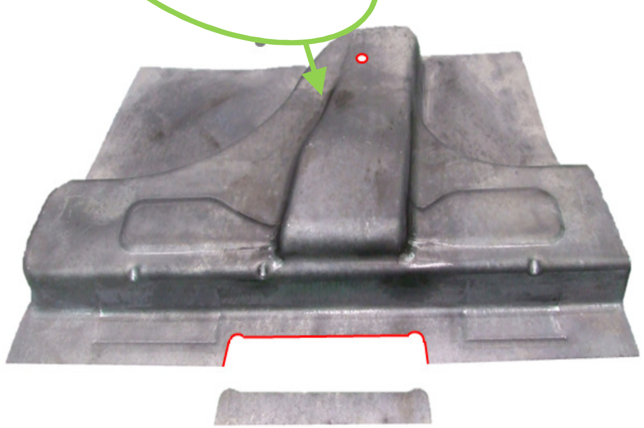
Part Trimming by High Speed Impact Cutting (HSIC)

Testing device at IWU







<u>Test equipment</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

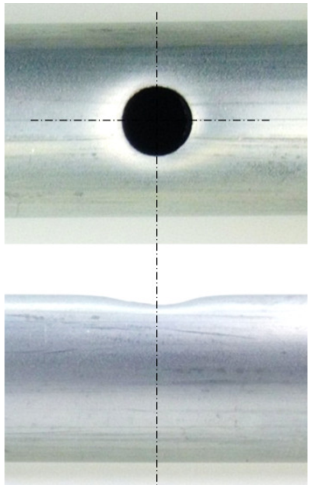
Part Trimming by High Speed Impact Cutting (HSIC)

Die less HSIC piercing of tubes

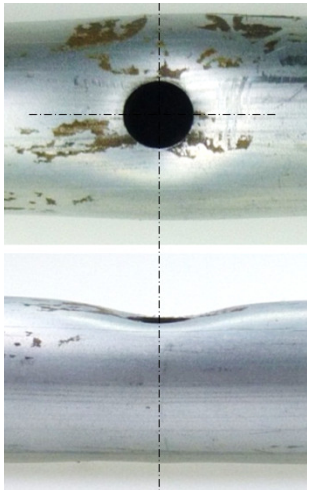
test device for die less piercing

<u>Test equipment</u>

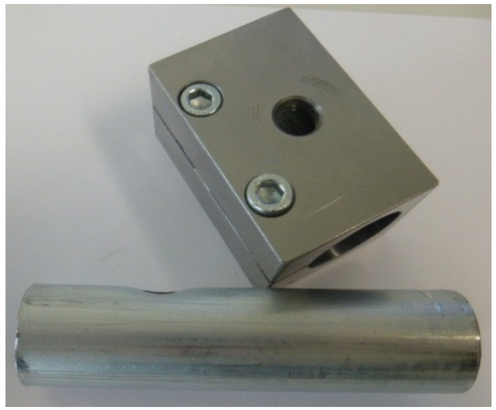
- captive-bolt pistol with piercing punch Ø 8,37 mm
- cutting speed: 50,2 – 70,2 m/s
- basic material - tubes
  - diameter Ø 25 – Ø 55 mm
  - wall thickness 2,0 – 3,0 mm
  - tube materials S355 (St 52), copper alloy, ferritic stainless steel (1.4509)



with outer tube clamping device



without outer tube clamping device



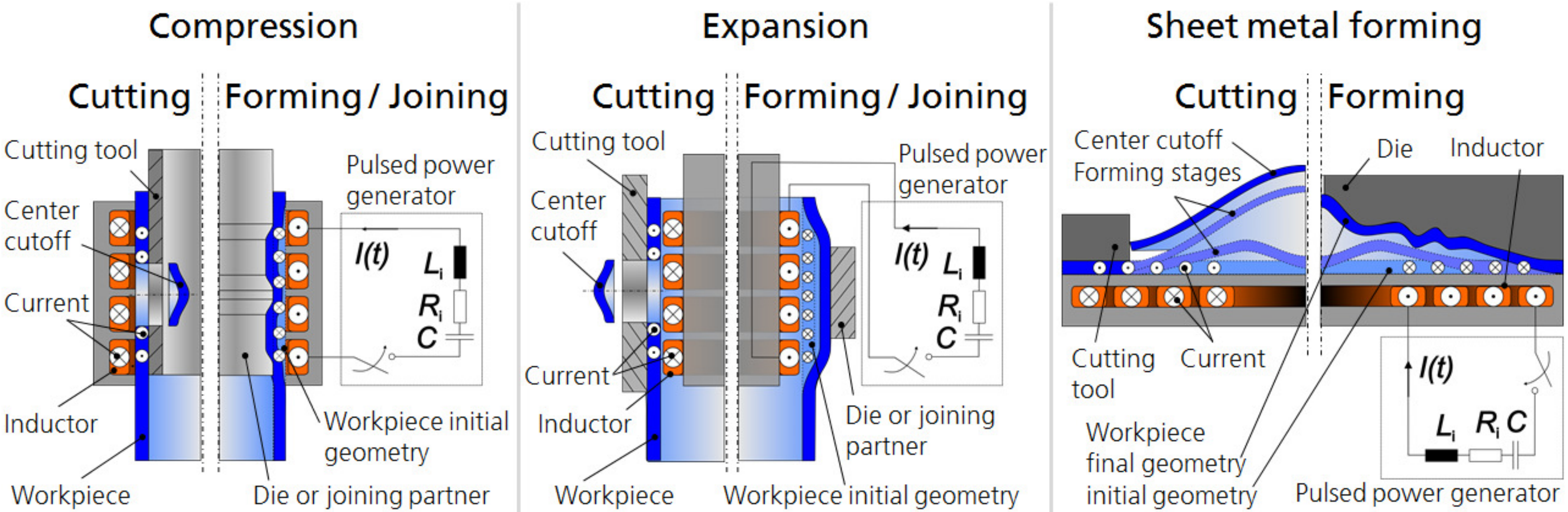
tube and clamping device

Electromagnetic forming - EMF

Process principle

- pulsed magnetic fields initiate repulsive Lorentz forces between inductor and electrically conductive work pieces
- compression / expansion of tubes and hollow profiles as well as forming on flat or preformed sheet metal materials is possible within microseconds

Technology variants

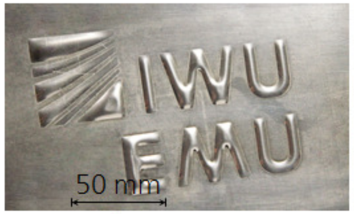


Electromagnetic forming - EMF

Fields of application

Forming

Door handle cavity
(AA6060; thickness 1.0 mm)



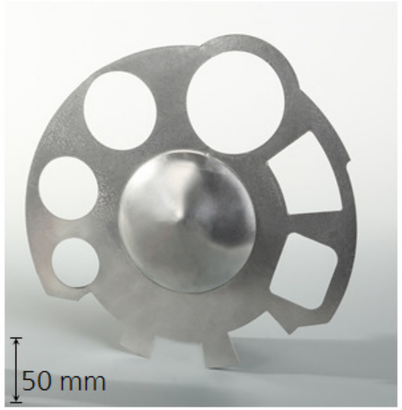
Design element
(AA3103; thickness 0.6 mm)

Joining

Multi material joints (Al, Cu, CFRP)

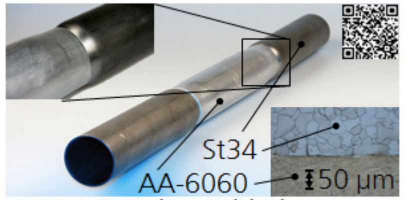
Torque shaft (outer joining partner: C35; Ø 42.4; thick-ness: 3.2 mm)

Cutting

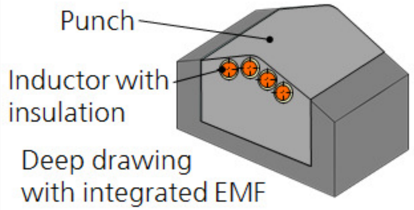


Multiple cutout demonstrator
(AA-6060; thickness 1.2 mm)

Combined processes



Magnetic pulse welded hybrid tube for hydroforming



Deep drawing with integrated EMF

Major advantages

- contactless force application to the workpiece
- in many materials high strain rates (10^4 s^{-1}) allow higher strains than in conventional forming
- integration of additional technologies i.e. cutting and joining is possible
- combined application with conventional technologies allows exploiting complementary advantages

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Innovative Forming Technologies for Efficient Light Weight Design in Car Body Structures

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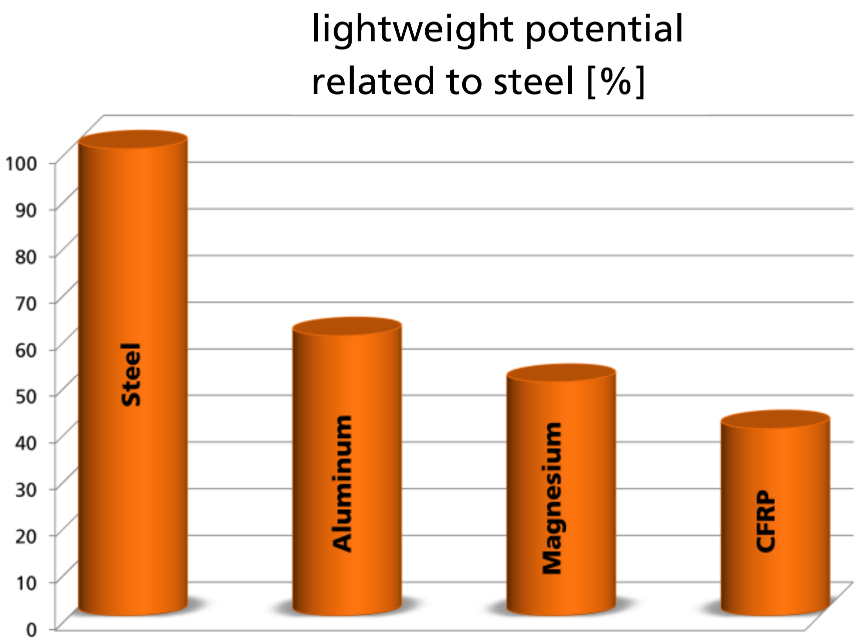
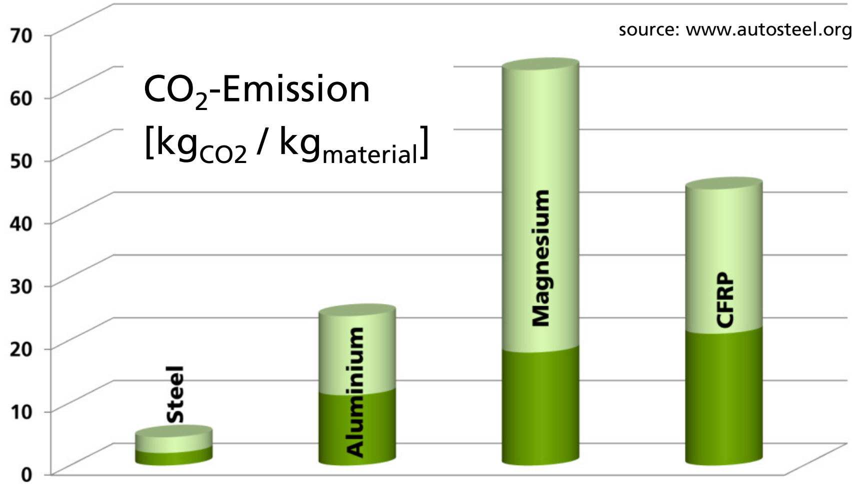
Lightweight Design and the Outcome

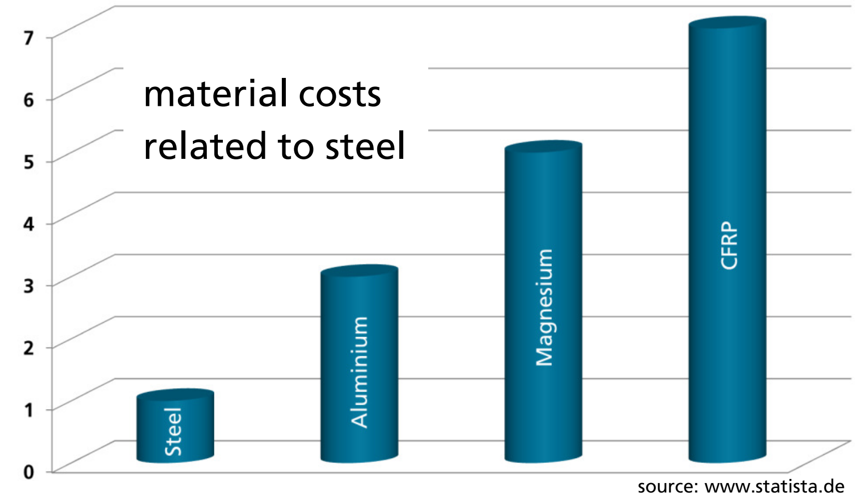
operation phase



	density		
7,85	2,7	1,8	1,5
Young's modulus [N/m²]			
210 000	70 000	45 000	50 000… 140 000

production phase





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Efficiency Potential of Optimized Process Chains

Light Weight Designed Components

Product optimization

efficient lightweight design:

- → right material for right application
- → functional integration (intelligent components)
- → multiple tailored component properties
- → increased component strength
- → optimized part dimensions

Process optimization

efficient production:

- → shorted process chains
- → minimized matching effort (forming &joining in one step)
- → reduced number of single components (reduce joining effort)
- → reduced logistic efforts
- → high resource and cost efficiency
- → increased product flexibility

Challenges in Future Production Scenarios

how to solve the resource problem?

1st approach:

more efficient use of existing resources

2nd approach:

exploitation of new resources

Change in the paradigm of entrepreneurship!

Today: success is maximum profit with minimum capital effort

Future: success is maximum profit with minimum effort on resources*

* Prof. Neugebauer, president of the Fraunhofer Society

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Thank you for your kind attention!