POTENTIALS OF ALUMINUM AS FORMING MATERIAL IN MODERN AUTOMOTIVE PRODUCTION

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Fraunhofer IWU

Outline

1. **Short Introduction Fraunhofer IWU**
2. **Trends in car manufacturing**
   - Industrie 4.0 (smart, flexible, interconnected)
   - Lightweight design (car body, powertrain)
3. **Aluminium as lightweight material in car manufacturing**

   Innovations from research at IWU
   - Sheet metal Forming
   - Joining/Car body
   - Forming/Powertrain

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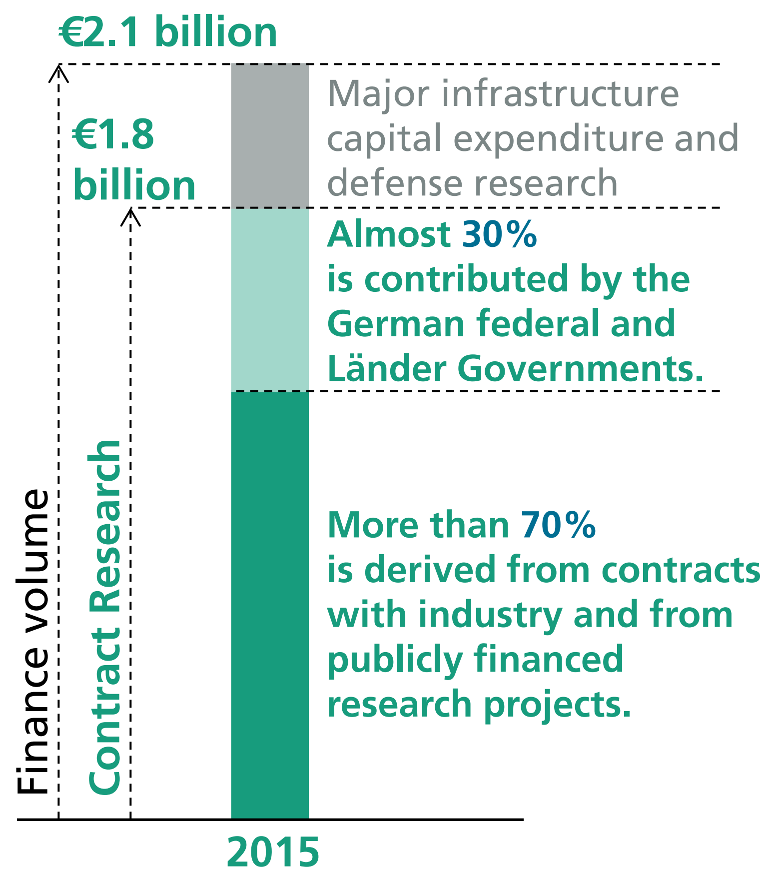
Introduction

Fraunhofer IWU – An institute of the Fraunhofer-Gesellschaft

Applied research for immediate utility of economy and benefit of society

24,000 staff

67 institutes and research units



Keynote Prof. Landgrebe AutoMetForm 2016

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Introduction

Fraunhofer IWU – An institute of the Fraunhofer-Gesellschaft

- Founded in 1991
- ~ 630 employees
- ~ 9 500 m² test facilities
- Locations: **Chemnitz**, **Dresden**,
  Zittau, Wolfsburg, Leipzig

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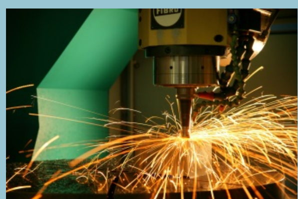
Introduction

Taking into account the whole process chain

Machining



Forming

Bulk Metal Forming

Sheet Metal Forming

Joining

Assembly

Machine Tools and Automation

Mechatronics and Lightweight Structures

Production Management

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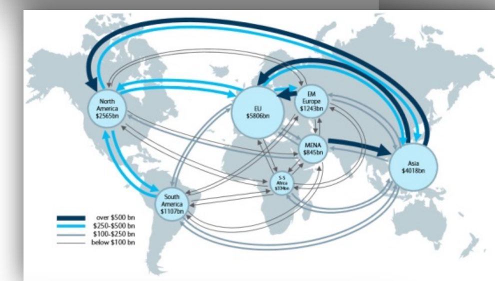
Global drivers and trends

Demographic Change

Scarcity of natural resources

Globalization and future markets



Dynamic Technology and Innovation
→ Digitalization
→ New Competition

Industry 4.0?

Source: Roland Berger Holding GmbH - Trend Compendium 2030
Picture sources: www.zerohedge.com, MEV Verlag, IWU

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Global drivers and trends

„Mass Customization“ and „Flexibility“

Fact:

- production lines shows an increasing demand on flexibility due to increasing product individualization

Porsche Leipzig GmbH:
3 different Types: Macan, Cayenne and Panamera in on final assambling linie
only 3 hours pre-definition time for the final production sequence
(Bülow, S., Porsche Leipzig GmbH „Porsche Leipzig – Erfolg durch Flexibiliät); CBC 2104; Chemnitz)

Volkswagen-Konzern (2013):
39.350 Units per Day / 310 Models worldwide
(Reiche, S., Volkswagen AG „Flexibilisierung als Herausforderung im Automobilbau; CBC 2104; Chemnitz)

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Global drivers and trends

„Mass Customization“ and „Flexibility“

Intelligent production

→ Interconnected, flexible maschines, systems und production equipment

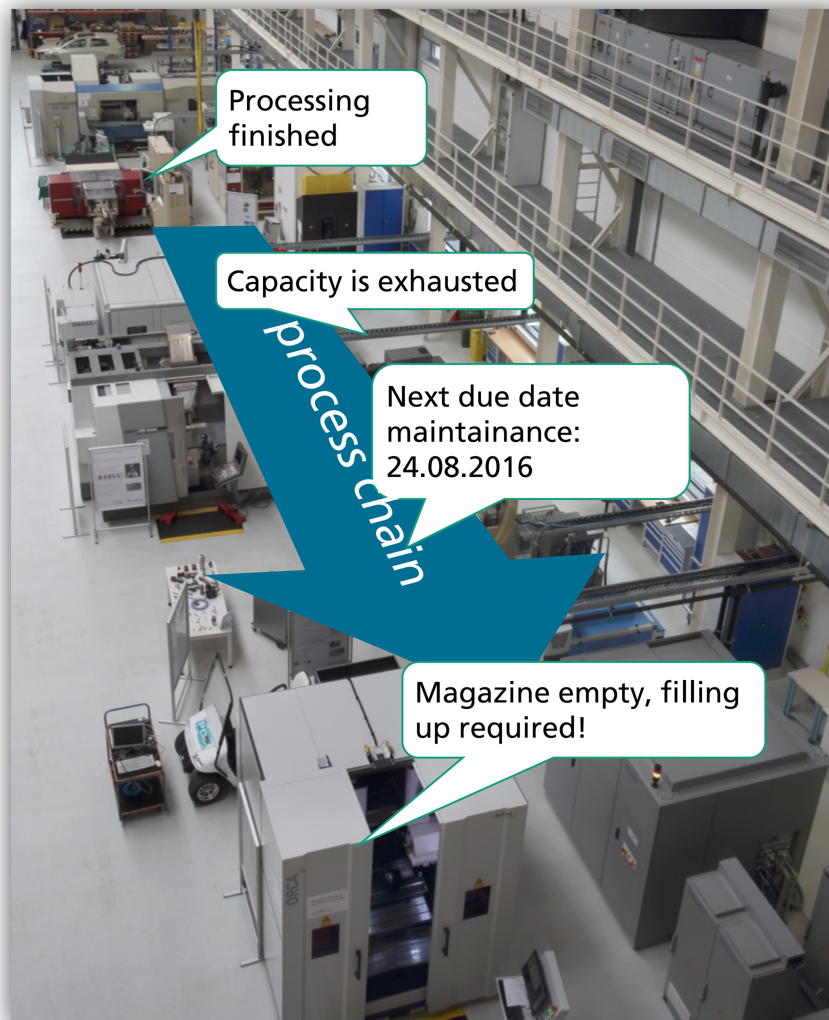
- Autonomous exchange of informationen
- Autonomous production control

Intelligent products

- Clearly identifiable
- Always locatable
- Know their history, current state status, condition, …) and alternative process routes

Focus: Human being and resources

- Energy- and resource efficiency
- Intelligent assisting systems
- Flexible work organization
- Demographic-sensible work



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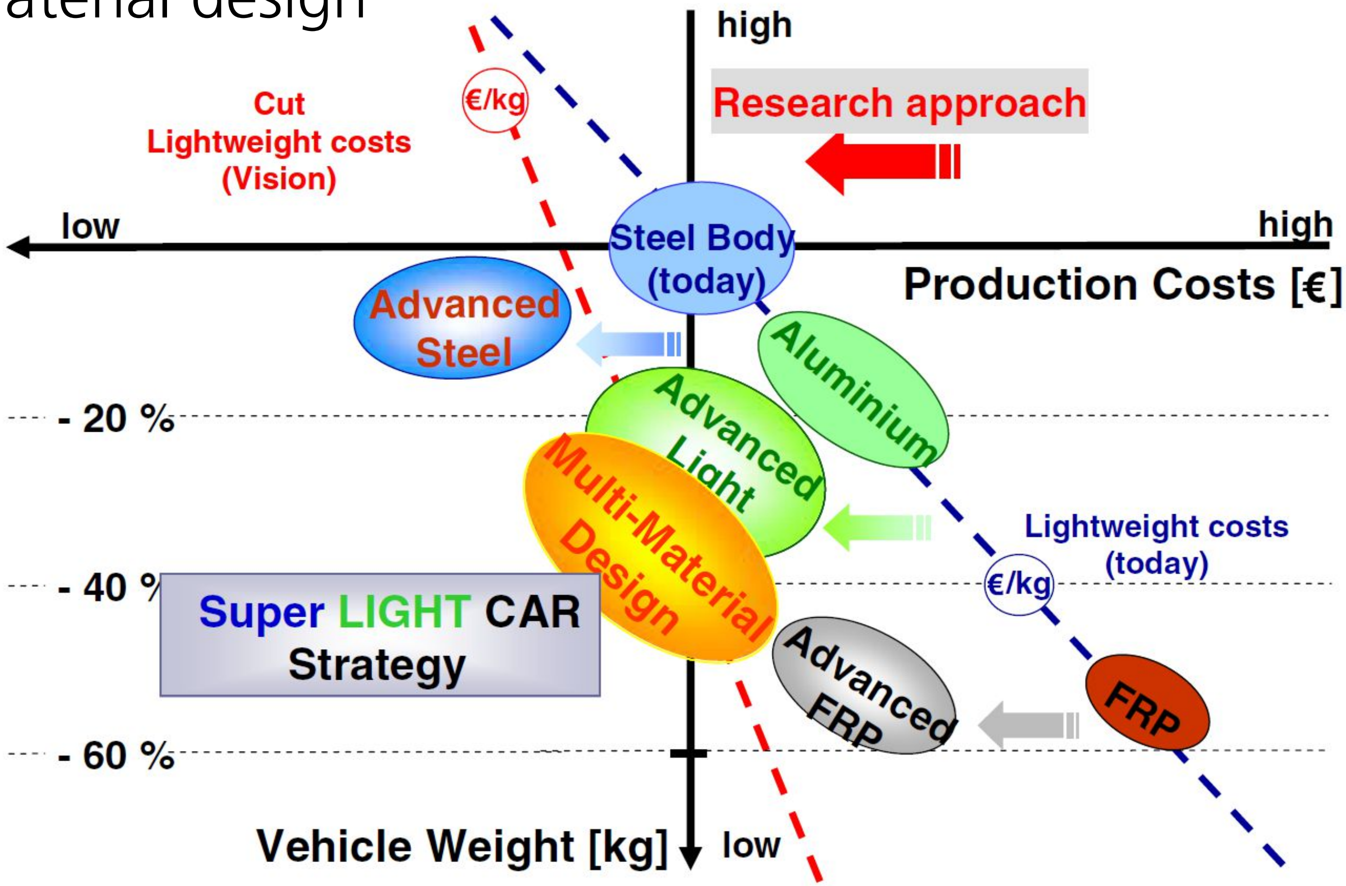
Lightweight design with aluminum in car body manufacturing

Multimaterial design



Quelle: Goede, M.; a.u.: Super Light Car-lightweight construction thanks to a multi-material design and function integration. Eur. Transp. Res. Rev. (2009)

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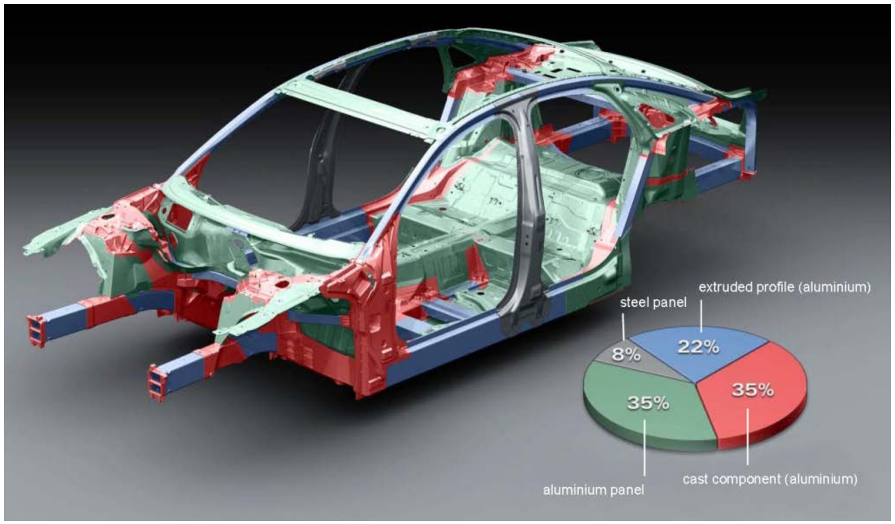
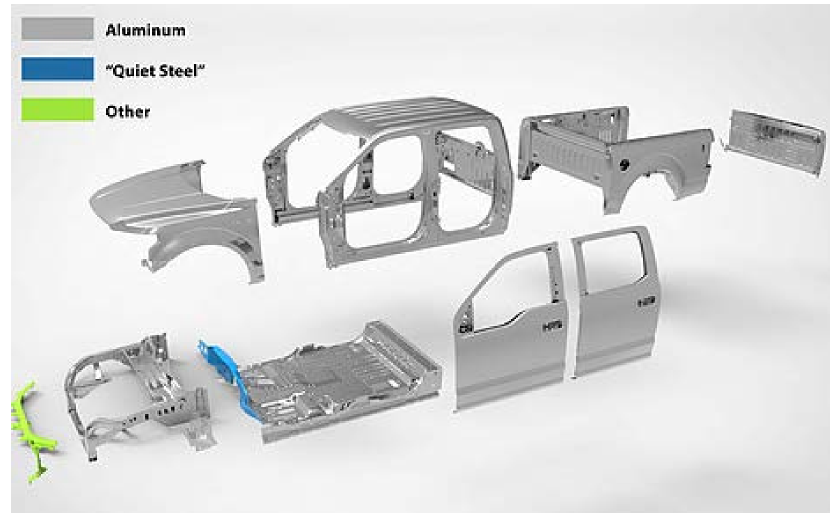
Lightweight design with aluminum in car body manufacturing



Audi Space Frame car body of the current Audi A8 [Audi AG]



Car body of the current Ford F-150 [Ford Corp.]

- Increasing proportion of aluminum to reduce the car body's weight

→ Growing demands for forming and joining technology

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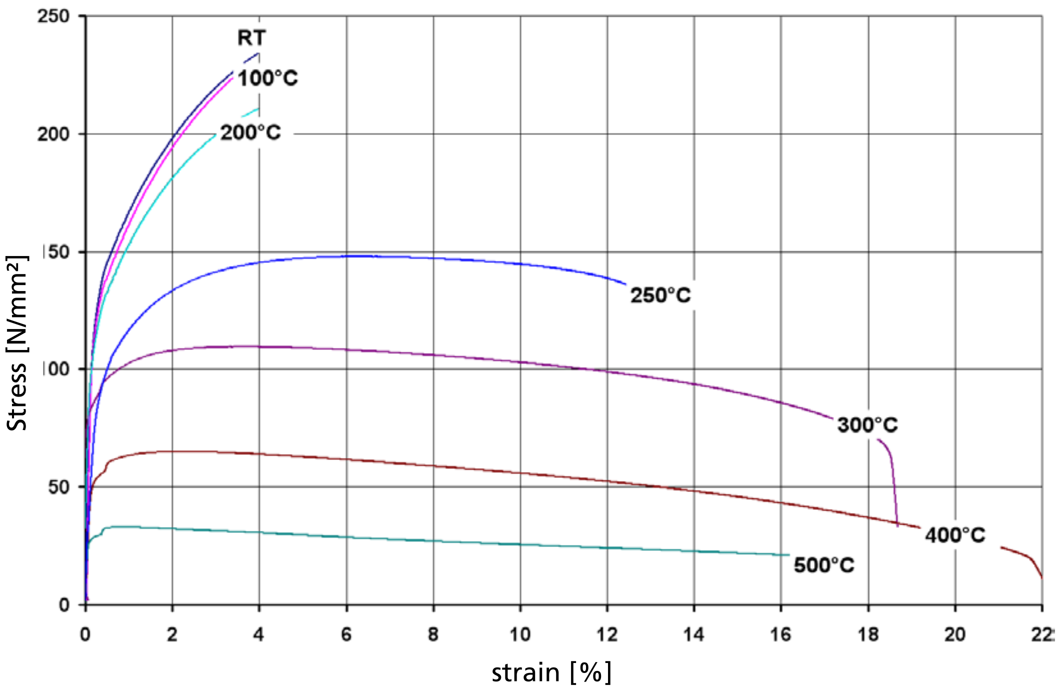
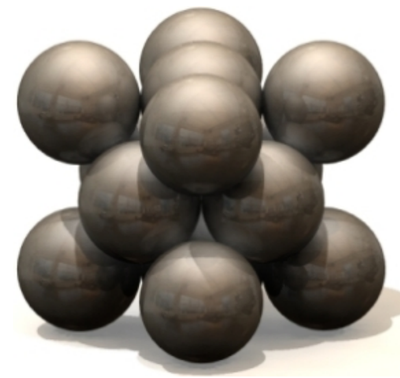
Temperature related forming behavior of Aluminum

Temperature supported tensile test
A6061; s_0 = 1,3 mm;

uniaxial tensile test according DIN EN 10002-5



face-centered cubic lattice of Aluminum



Thermal related effects

⇨ dissolution processes

⇨ recrystallization

⇨ diffusion processes

⇨ reduction of inner tensions

advantages forming properties by thermal support

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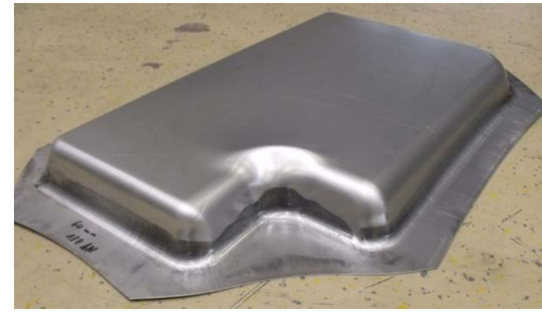
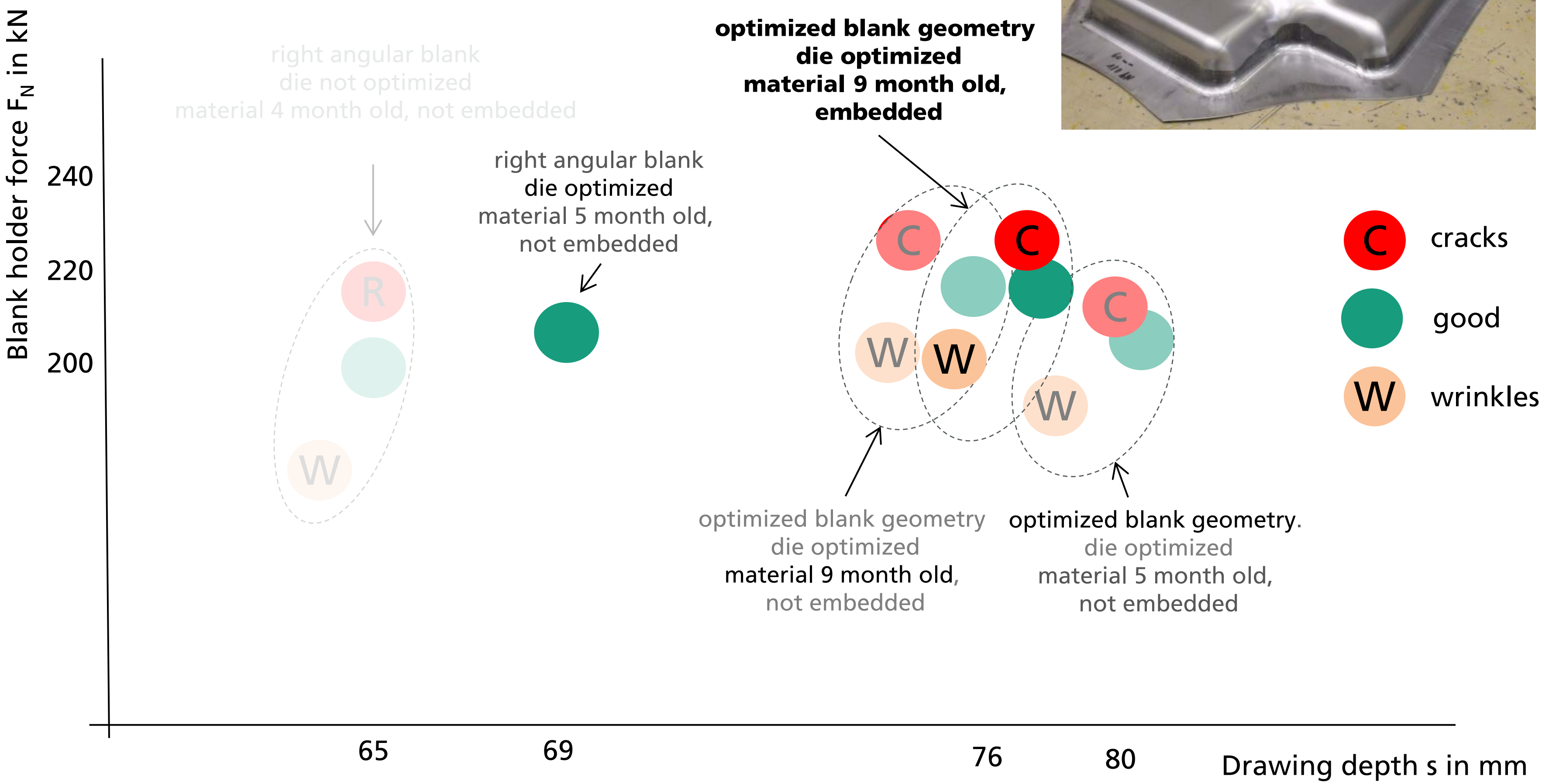
Aging related forming behavior of Aluminum

Test material A6014

related process window





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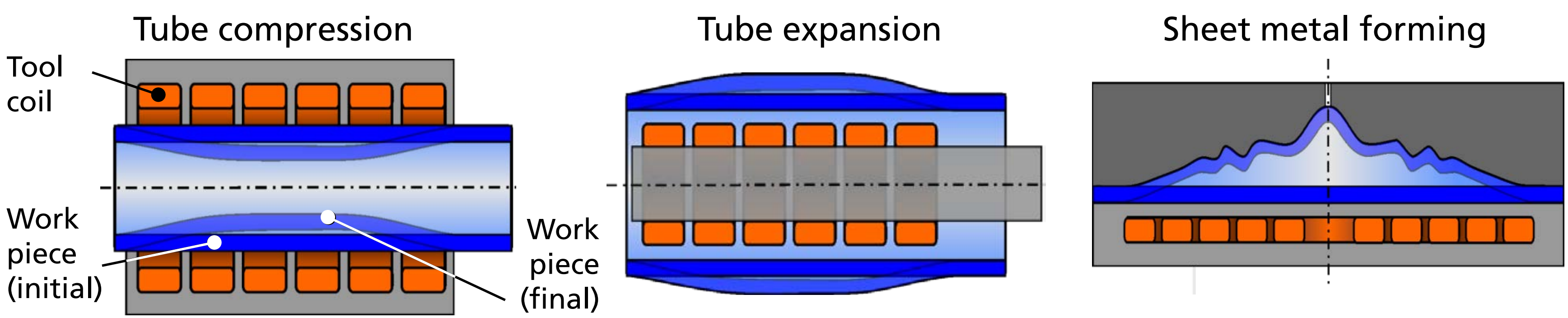
Electromagnetic forming (EMF)

Principle and important characteristics

- Capacitor discharge via tool coil causes damped sinusoidal coil current.
- Coil current induces magnetic field and countercurrent in the workpiece.
- Resulting Lorentz forces cause the workpiece deformation.

Velocity: up to 400 m/s   Strain rate: up to 10^4/s   Process duration: 20-200 µs

Variants



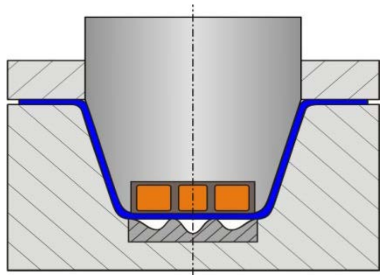
Major advantages

- **Contact-free** force application. => No surface disturbance, no lubrication required.
- High strain rates. => **Higher formability** for many materials.
- **Flexible applicability** of one tool coil for different manufacturing tasks.

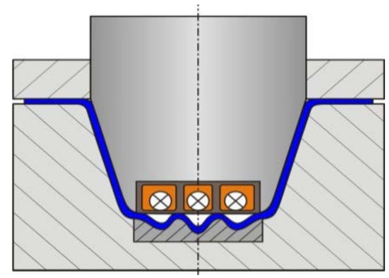
Deep drawing with integrated EMF of sheet metal

Principle

Step 1: Deep drawing



Step 2: Integrated EMF



Application examples

EM-formed structure

WESTFALIA Presstechnik

SAB Sächsische AufbauBank

EM-formed door handle

EM-formed design features

Major Advantages

Increased material formability and reduced wrinkling
➔ calibration of details impossible via conventional methods.

Integration of structures increases stiffness
➔ up to 30% weight saving due to reduced thickness.

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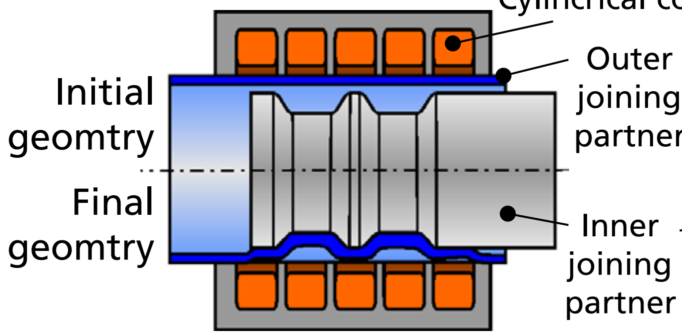
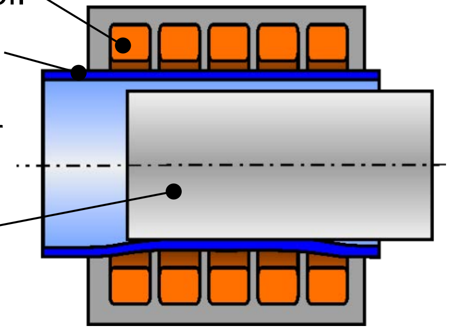
Joining by EMF

Principle

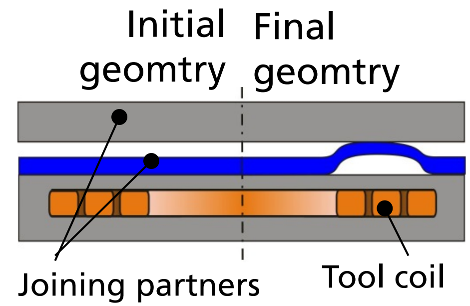
Tubular crimp joint



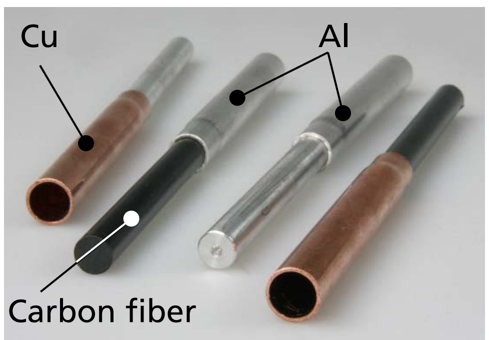
Tubular welded joint

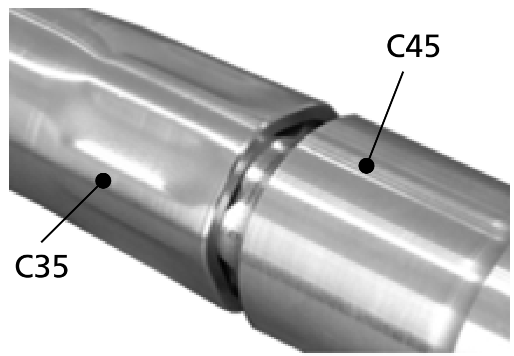


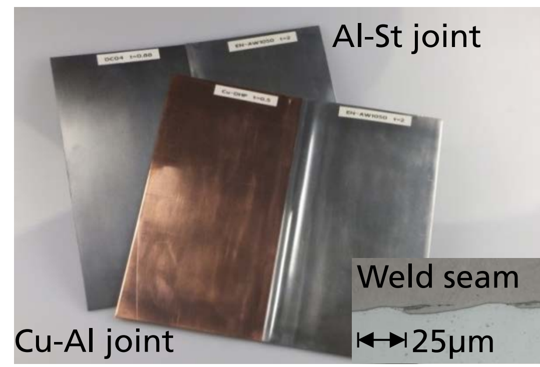
Sheet metal welded joint



Application examples







Major Advantages

(Nearly) no intermetallic phases ➔ high joint quality and strength.

No additives and fluxes required ➔ enviromentally friendly.

High conductivity of the joint ➔ suitable for electrical and heat conduction applications. ➔ electromobility

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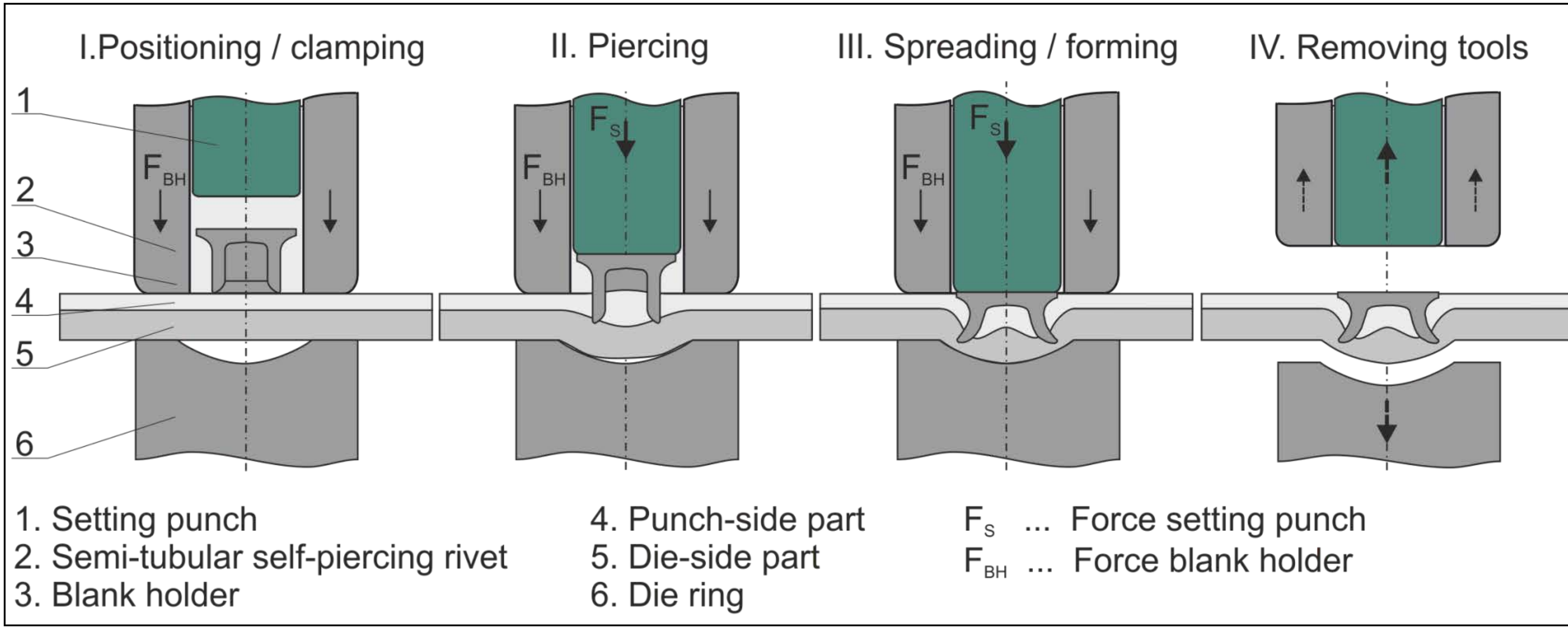
Self-pierce riveting with semi-tubular rivet – SPR-ST

Process steps



Process steps of self-pierce riveting with semi-tubular rivet (SPR-ST)

- Most important mechanical joining technology in automotive
- Self-pierce riveting process for joining **mixed compounds** (e.g. steel in aluminum, aluminum panel in cast aluminum)
- Good **compatibility with adhesive** bonding

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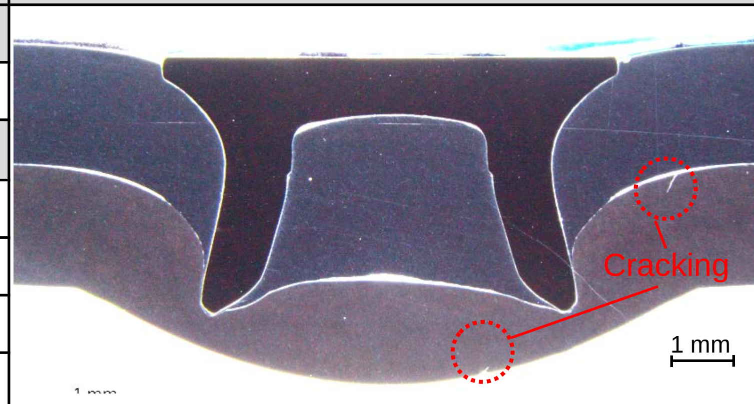
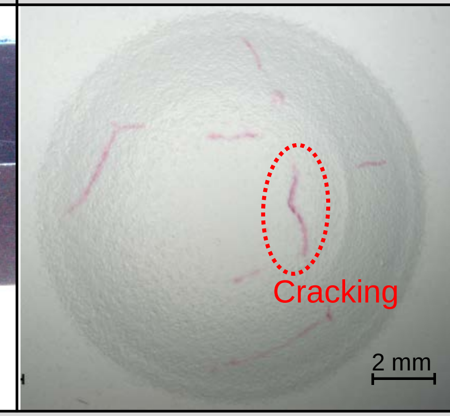
SPR-ST of cast aluminum

Problems during conventional process

<table>
<tr><th colspan="2">Process parameters</th><th colspan="2">Cross section</th><th>Closing head (CPT)</th></tr>
<tr><td>Punch-side part:</td><td>Thickness:</td><td colspan="2" rowspan="7">
</td><td rowspan="7">
</td></tr>
<tr><td>EN AW-6016-T4</td><td>2.0 mm</td></tr>
<tr><td>Die-side part:</td><td>Thickness:</td></tr>
<tr><td>AlSi9Mn F</td><td>2.0 mm</td></tr>
<tr><td>Rivet:</td><td>C 5.3 x 5.0 H4</td></tr>
<tr><td>Die:</td><td>M Ø10 x 1.3</td></tr>
<tr><td>System:</td><td>Promess 300</td></tr>
<tr><td>Joining force:</td><td>68 kN</td><td colspan="3">Evaluation criteria joint formation</td></tr>
<tr><td>Adhesive:</td><td>Betamate 1480</td><td>Undercut $u_{1,2}$:</td><td>Material thickness t_r:</td><td>Rivet foot diameter d_f:</td></tr>
<tr><td></td><td></td><td>0.05 mm</td><td>0.57 mm</td><td>6.37 mm</td></tr>
</table>

Process parameters, cross section and closing head after color penetration test (CPT) of conventional self-pierce riveting EN AW-6016 T4 (t = 2.0 mm) in AlSi9Mn F (t = 2.0 mm)

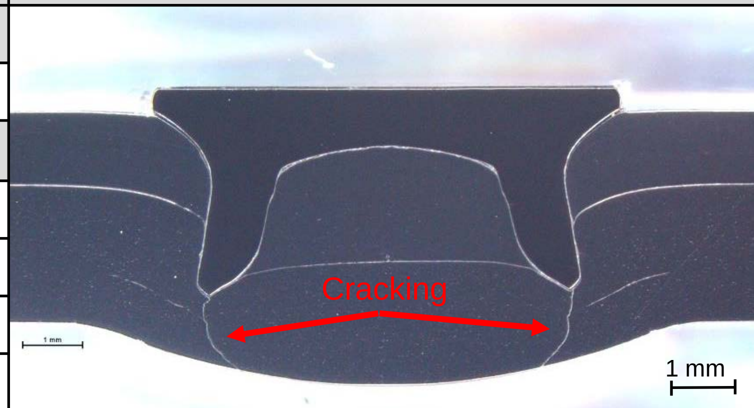
- **Competing targets**: Low interlock (higher die depth necessary) and cracking in the cast aluminum (lower die depth necessary)
- **Unsatisfying result** with conventional self-pierce riveting

SPR-ST of ultra high-strength aluminum panel

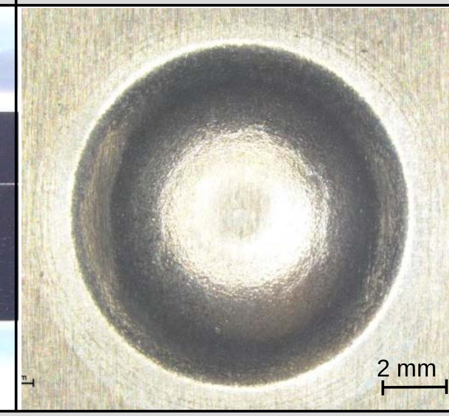
Problems during conventional process

Process parameters	
Punch-side part:	Thickness:
EN AW-6016 T4	1.2 mm
Die-side part:	Thickness:
EN AW-7075 T6	2.3 mm
Rivet:	C 5.3 x 4.0 H4
Die:	M Ø10 x 1.0
System:	Eckold
Joining force:	70 kN

Cross section



Closing head



Evaluation criteria joint formation		
Undercut $u_{1,2}$:	Material thickness t_r:	Rivet foot diameter d_f:
0.13 mm	1.12 mm	6.35 mm

Process parameters, cross section and closing head for SPR of EN AW-6016 T4 (t = 1.2 mm) in EN AW-7075 T6 (t = 2.3 mm)

- Very **high joining force** necessary
- **Cracking** in the ultra high-strength aluminum panel EN AW-7075 T6

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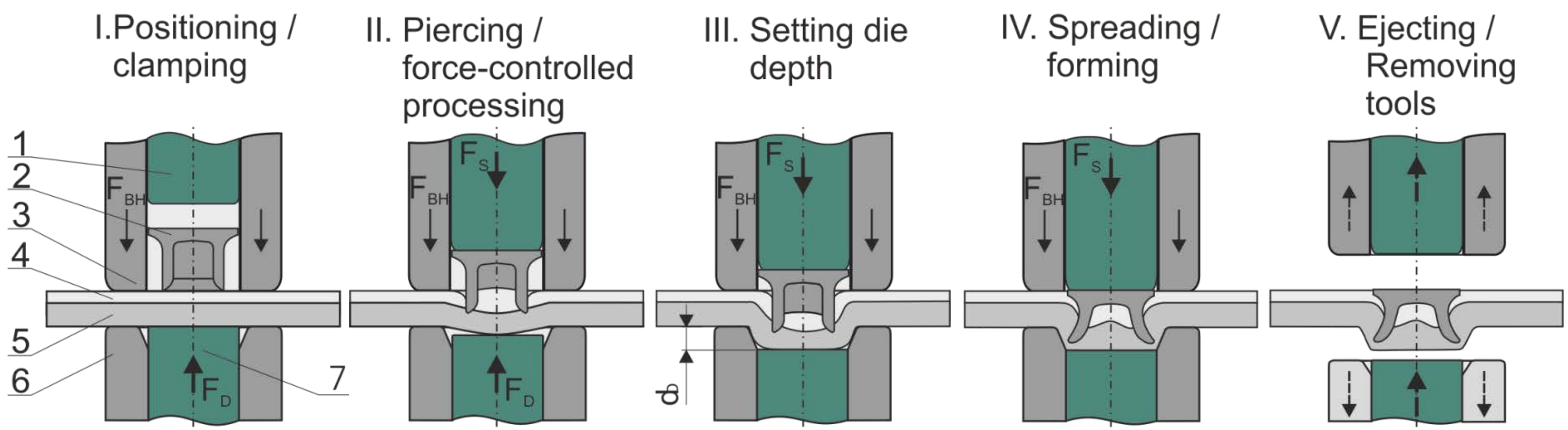
Self-pierce riveting with moveable die element – SPR-MD

Process steps



1. Punch
2. Semi-tubular self-piercing rivet
3. Blank holder
4. Punch-side part
5. Die-side part
6. Die ring
7. Moveable die element

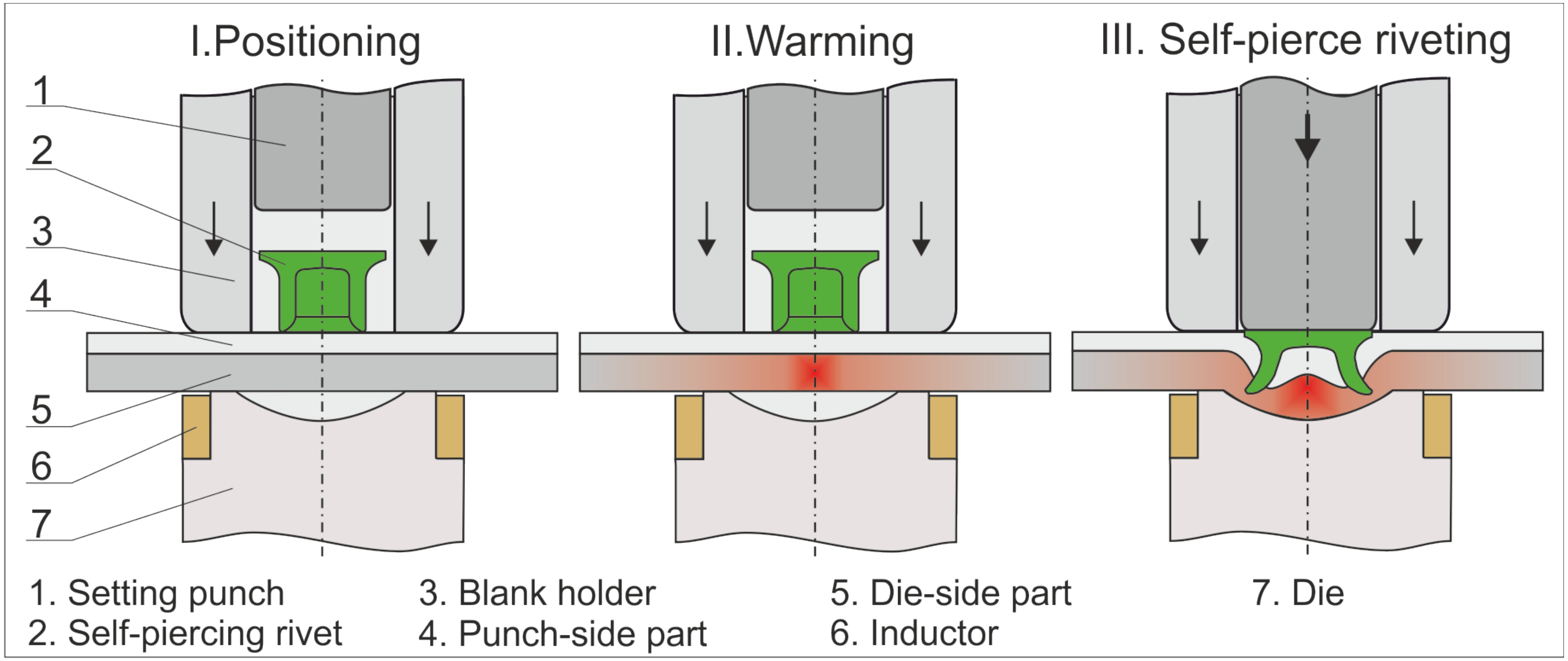
F_S ... Setting force
F_{BH} ... blank holder force
d_D ... Depth of die
F_D ... Counter force

Process steps of self-pierce riveting with moveable die element (SPR-MD)

- Die is **divided into two parts**, an outer die ring and an inner moveable die element
- Forming zone can be superimposed with **compressive stresses**

Thermal supported self-pierce riveting – SPR-TS

Process steps



Process steps of self-pierce riveting (SPR-TS)

- Improvement of formability by **joining process at elevated temperature**

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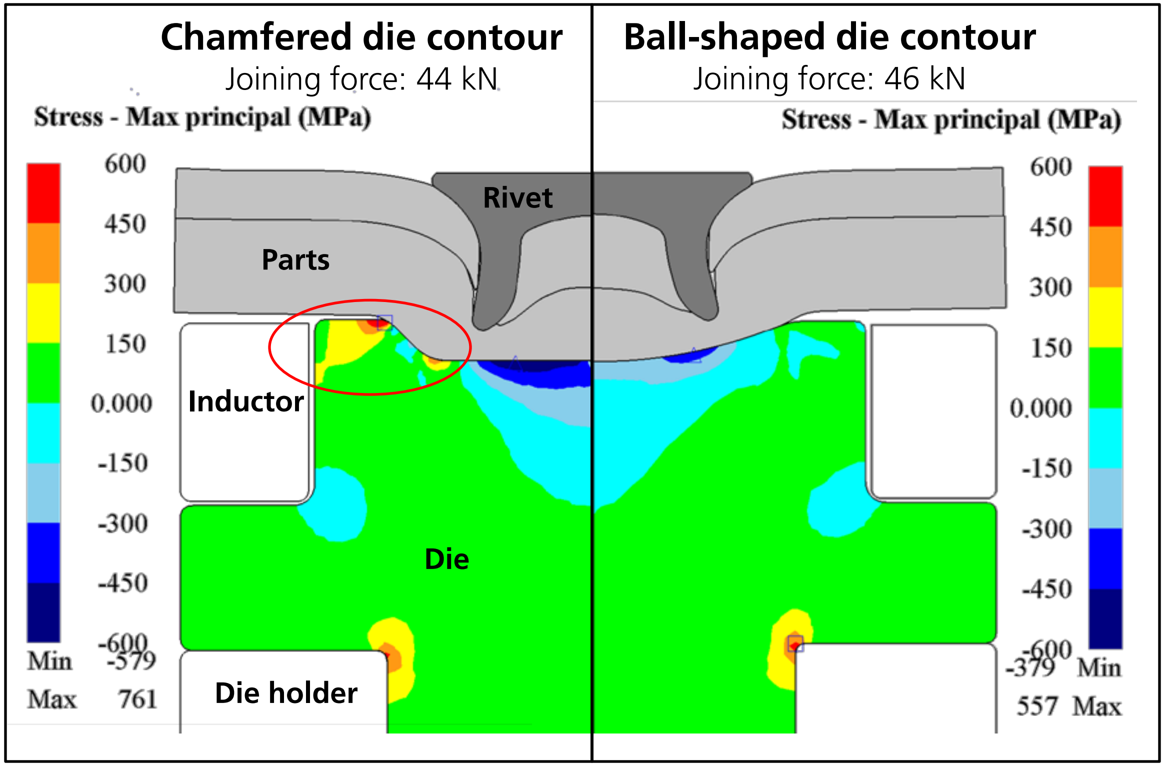
Joining tools for SPR-TS

Numerical development of geometry for ceramic die

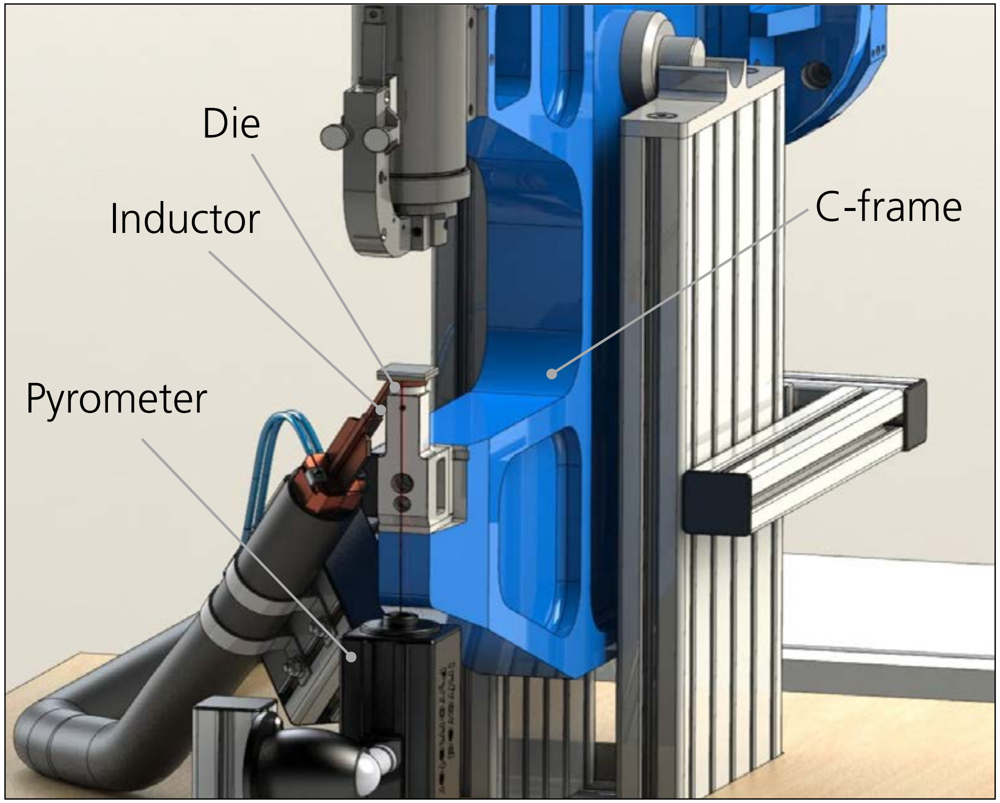


Calculated stress max. principal in the die at max. joining force

- **Reduction of tensile stresses** in the die by using a ball-shaped die contour

Test setup for SPR-TS

C-Frame with integrated inductive heating



Test setup for SPR-TS

Ceramic die with integrated inductor

- **Temperature control** using a inductor combined with a pyrometer
- **Ceramic die** to **reduce warming** of the joining tools

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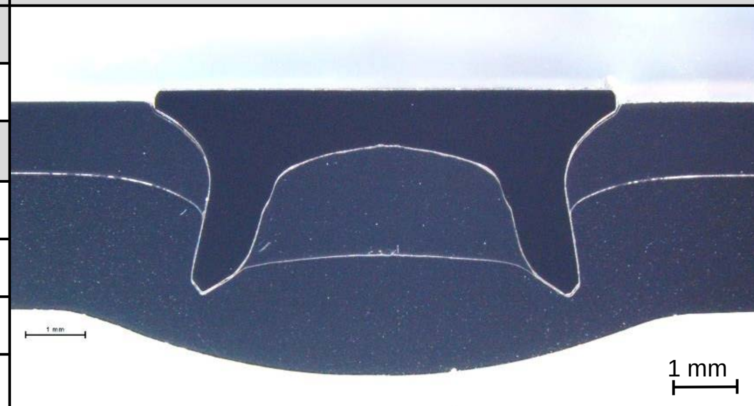
SPR-TS of ultra high-strength aluminum panel

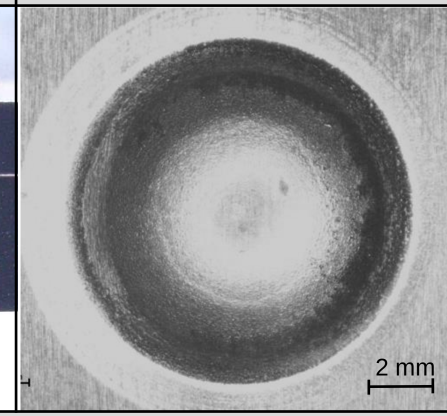
Process parameters and joint formation

Process parameters	
Punch-side part:	Thickness:
EN AW-6016-T4	1.2 mm
Die-side part:	Thickness:
EN AW-7075-T6	2.3 mm
Rivet:	C 5.3 x 4.0 H4
Die:	KM Ø10 x 1.0
System:	Eckold
Joining force:	65 kN
Temperature:	200 °C
Process time:	3.5 s

Cross section



Closing head



Evaluation criteria joint formation		
Undercut $u_{1,2}$:	Material thickness t_r:	Rivet foot diameter d_f:
0.20 mm	0.85 mm	6.48 mm

Process parameters, cross section and closing head of thermal supported self-pierce riveting of EN AW-6016 T4 (t = 1.2 mm) in EN AW-7075 T6 (t = 2.3 mm)

- Good joint formation
- **Avoidance of cracking** in the ultra high-strength aluminum panel EN AW-7075 T6

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Cross-Wedge Rolling of Lightweight Materials
Aluminium

Potentials of Appropriate Pre-Forming Technology for Subsequent Forging Processes

- Increase of manufacturing **efficiency**
  ➔ reduction of material use
  ➔ reduction of forming forces, tool loading and wear
- Increase of part **quality**
  ➔ guarantee of complete cavity filling
  ➔ avoidance of forging effects

realization of optimized pre-form

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Cross-Wedge Rolling of Lightweight Materials

Aluminium

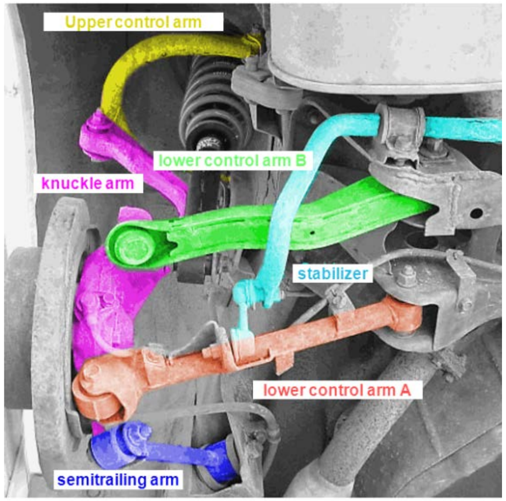
Motivation ➢ **weight reduction** of chassis components (control / suspension arms)

Approach ➢ use of aluminum alloys

Challenge

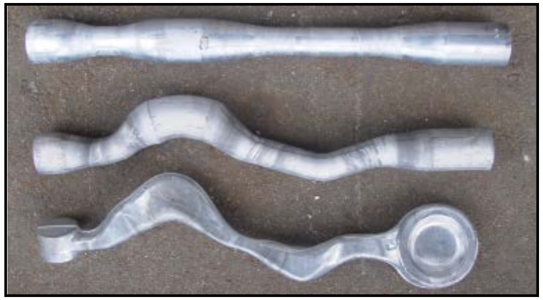
- ➢ **efficient** manufacturing **processes**
- ➢ **maximum material utilization** (minimization of scrap)

➔ **cross wedge rolling** for efficient realization of pre-forms



aluminum use for chassis parts

pre-form variants for subsequent forging processes



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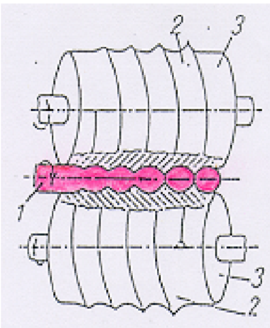
Cross-Wedge Rolling of Lightweight Materials

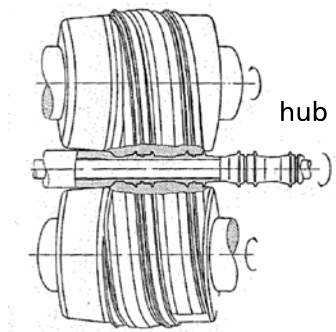
Aluminium

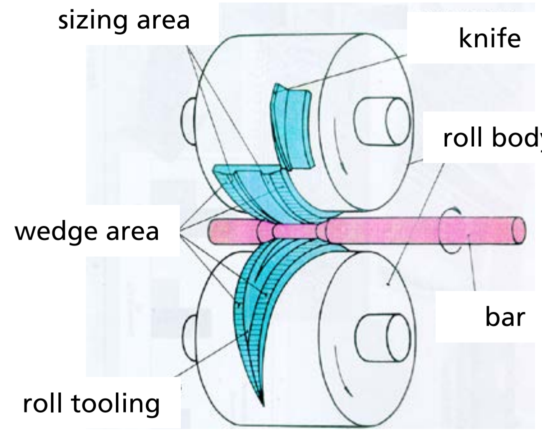
Process Variants

continuous operation - **through-feed method**



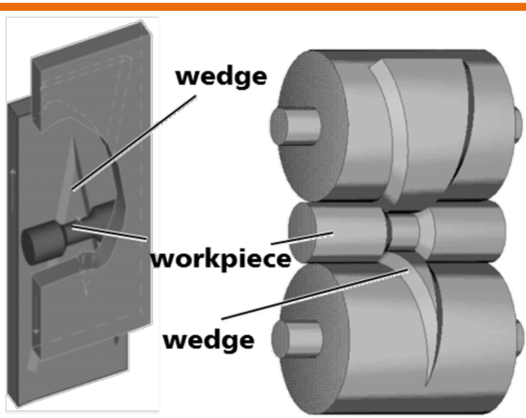
(1) work piece
(2) roll wedge
(3) roll body
(4) flat tool
(5) segment tool



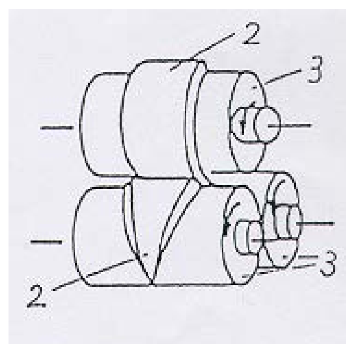


mill from a bar

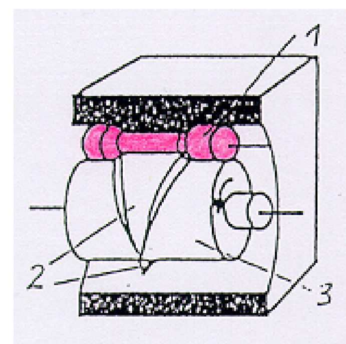
discontinuous operation - **plunge mode**



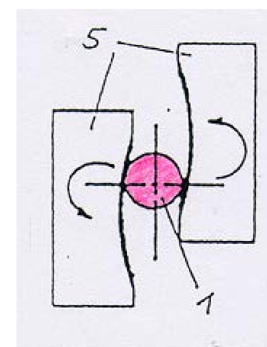
flat tools **round tools** (2 rollers)



3-roller



circular



segment

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Cross-Wedge Rolling of Lightweight Materials

Aluminium

Principle

realization of rotation-symmetric part geometries by acting tool wedges

→ optimized pre-forms / material distribution
for subsequent processes (e. g. forging)

Technology Variants

Flat Tools	Round Tools
➔ **opposite tool movement** with **clamped part** - simple **tool design*** - small manufacturing **effort*** - - - - - - - - - - - - - reduced **productivity*** (non-productive return stroke) - large **machine dimensions***	➔ **synchronous tool rotation** and **opposite workpiece rotation** - high **productivity*** → no idle stroke → semi-finished product: bar - small **machine size*** - - - - - - - - - - - - - complicated **tool design*** - high **demands** on tool manufacturing*

* in comparison to alternative variant
■ advantage ■ disadvantage

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Conclusion

- A solution for a improved light weight design can be found in mixed material design

- In this context Aluminum will be an appropriate material for different application – as well for car body parts as for powertrain components
- The thermal treatment and the age of the material plays a significant role
- An improvement of productivity and a decrease of production cost can be found in suitable improved or new processes like electromagnetic forming
- Solutions can be found by interdisciplinary research

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Thank you for Your Attention!

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