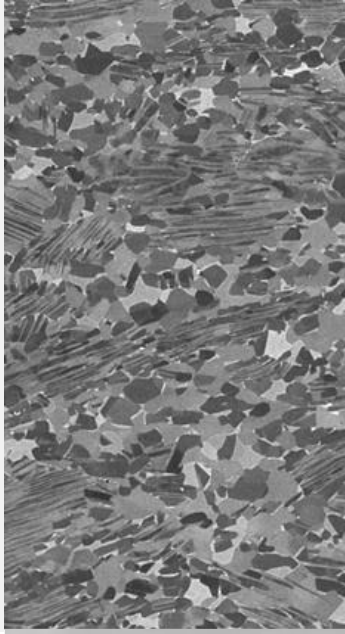
Brandenburgische Technische Universität Cottbus - Senftenberg

Lehrstuhl Konstruktion und Fertigung

# Flexible forming processes and process chains



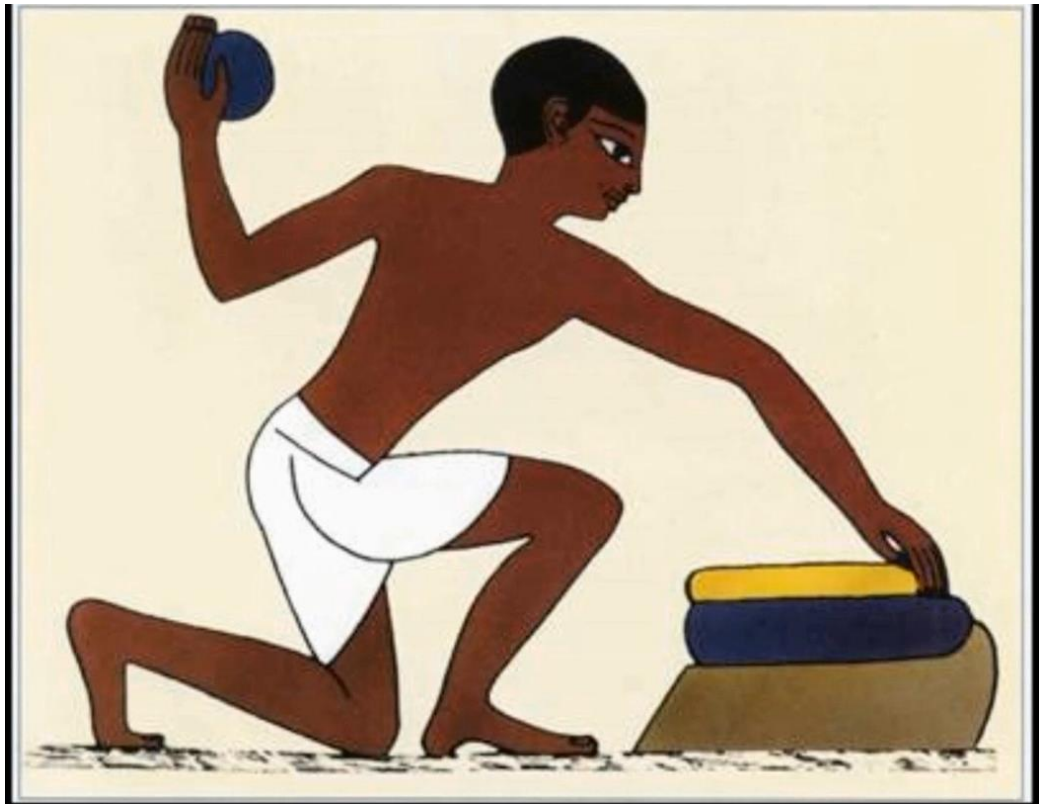
Prof. Dr.-Ing. habil. Markus Bambach

Chair for Mechanical Design and Manufacturing
BTU Cottbus-Senftenberg

Poznan, Poland, April 24, 2017

# Metal forming used to be a flexible technology

- **Metal Forming:**
  - deliberate change of **shape, surface and properties**
  - no change of **mass and connectivity**
- **Flexible forming:**
  - simple, generic tooling
  - **at least one controlled DOF**



Source: IMU / Paul Zimmermann

# Profile of the chair of Mechanical Design and Manufacturing

## Manufacturing

**Forging, Rolling**

**Stretch forming / Stamping**

**Flexible and hybrid Processes**

**Mechanical Joining**

## Materials

**Lightweight material**

**Steel and high temperature materials**

**Characterization/ Simulation/Development**

## Leightweight structures

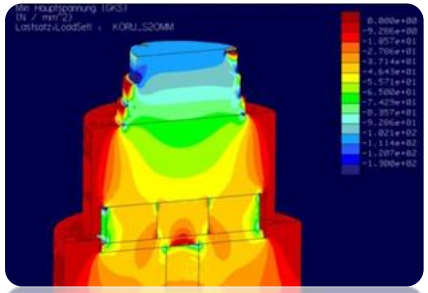
**Sandwich material**

**Composites**

**Aluminum foam**

**Tailored Blanks and Beams**

## Design



**CAD / Design**

**Optimzation**

**Part behavior**

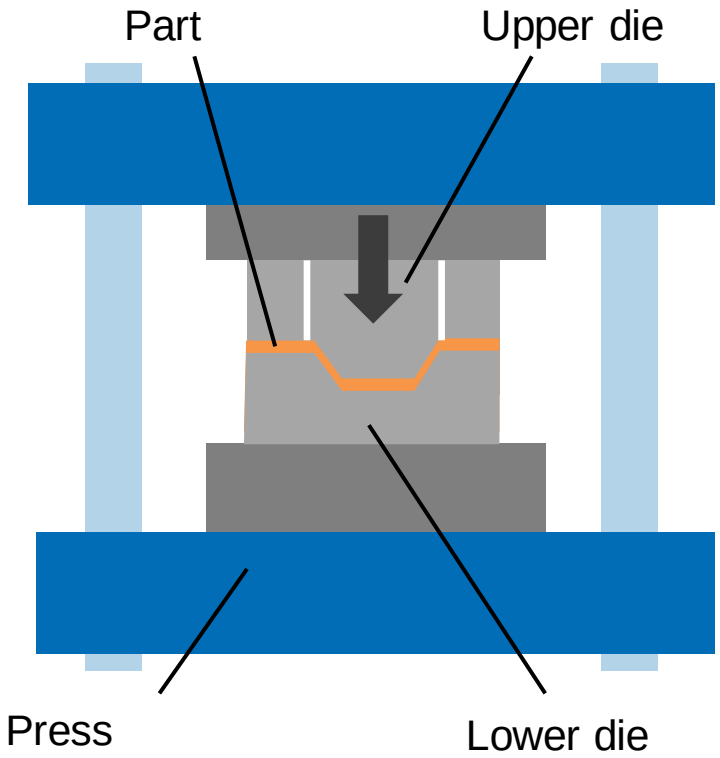
- Head: Prof. Dr.-Ing. habil. Markus Bambach
- Chief engineer: Dr.-Ing. Alexander Sviridov
- 17 scientific staff
- 7 employees in administration / technical support
- ~10 student assistants

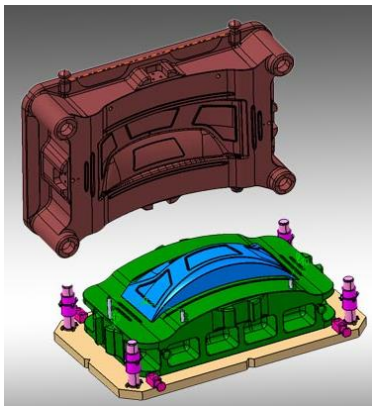
# Outline

# Incremental sheet metal forming

## conventional (stamping)

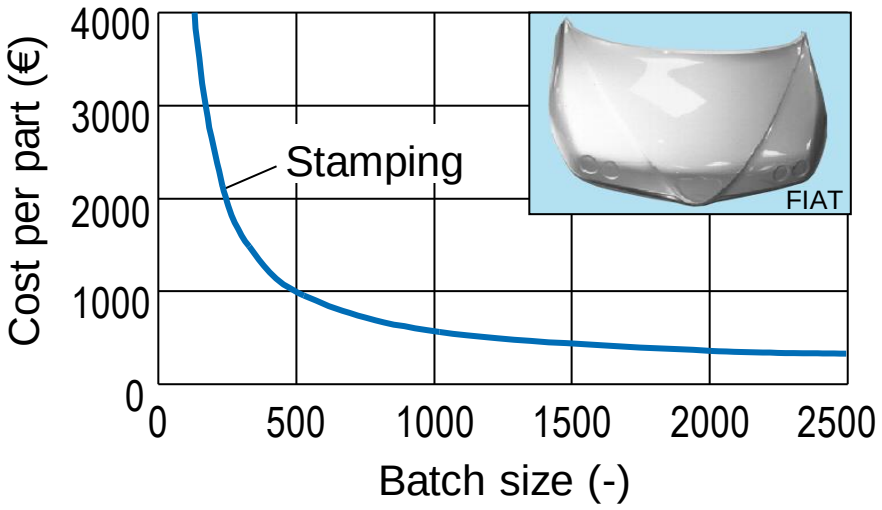
- Dedicated tooling
- High equipment costs
- Only economical in mass production



Source: Fritzmeier Technologie


Source: Schuler




Quelle: J. Ames, IBF / RWTH Aachen

# Incremental sheet metal forming

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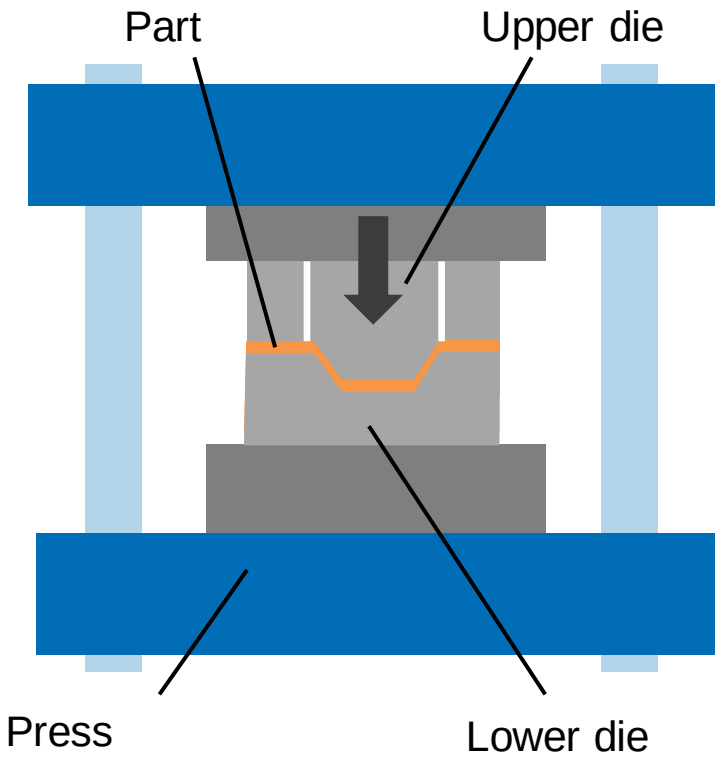
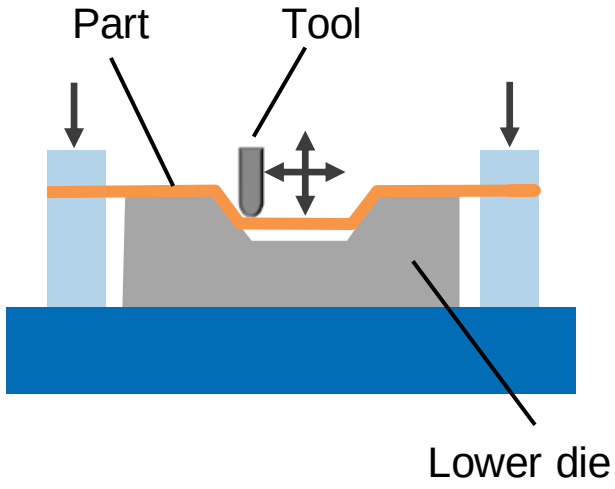


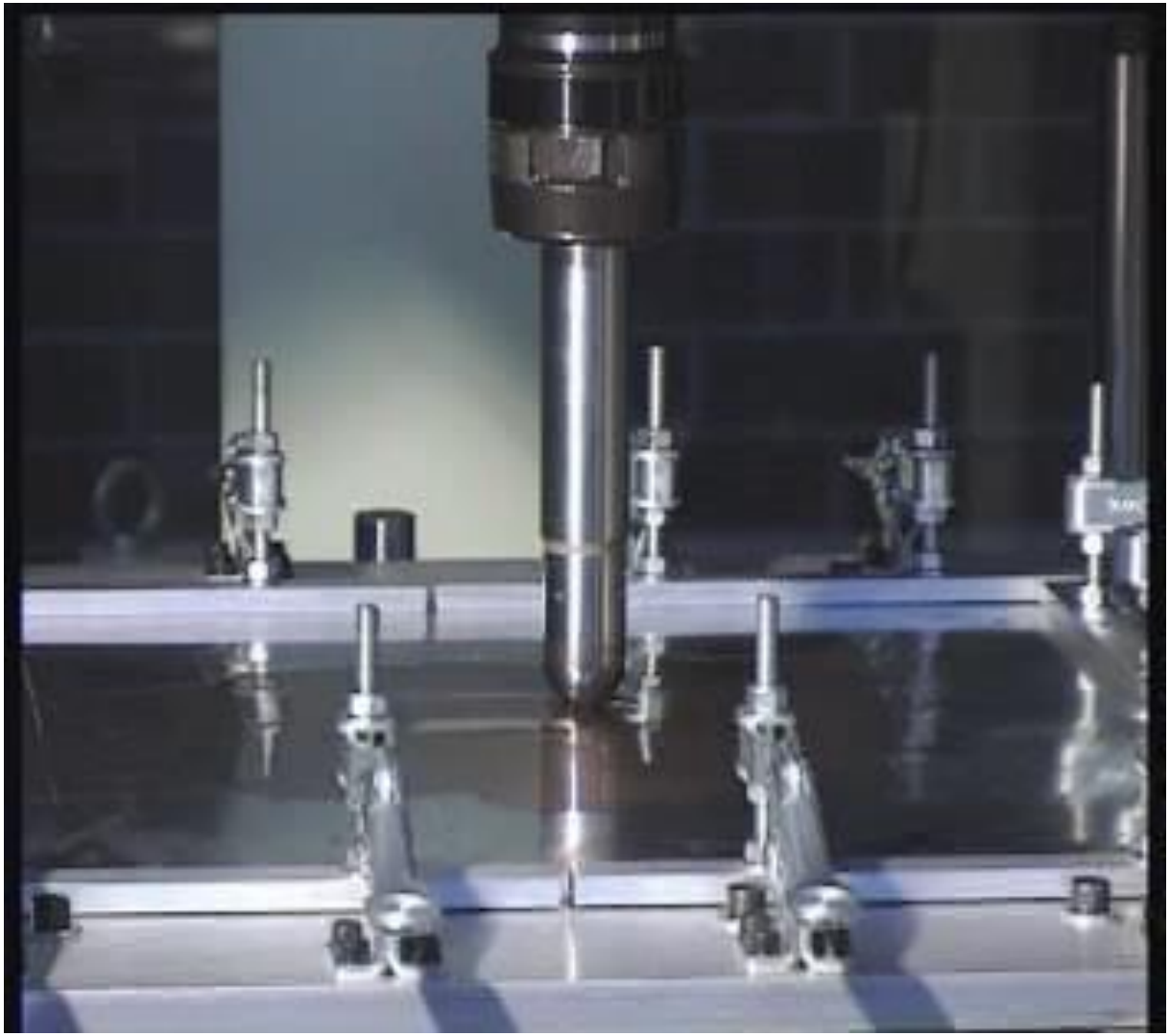

## Incremental sheet forming

- Replaces at least one die by generic tooling (CNC or robot controlled)

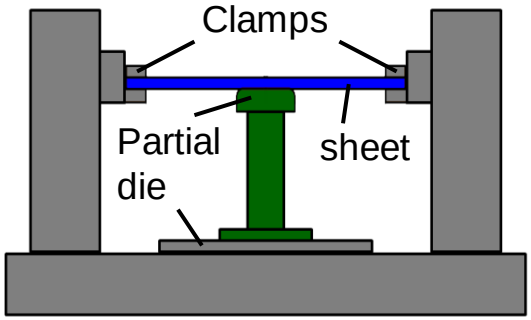



- Direct forming fFrom CAD model
- Low forming forces
- Large design freedom

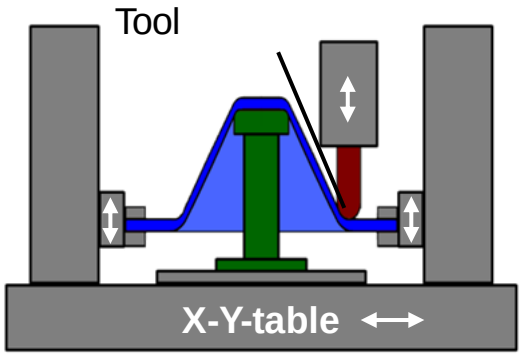
# Process principle



## Before forming




## During forming

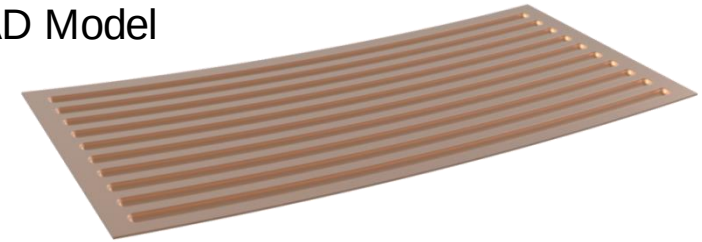


# Project example
# Forming of ICE train panels

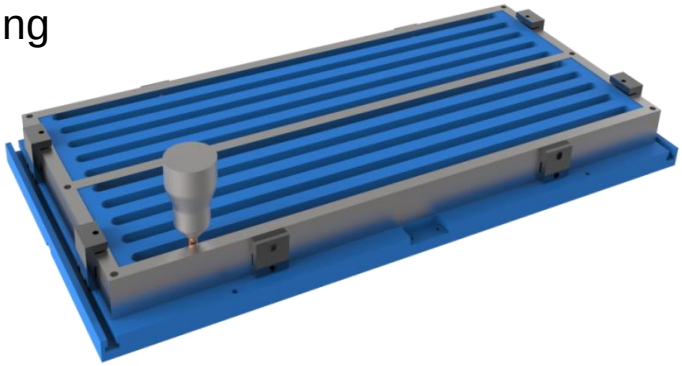
## ICE train AC panels


## Process chain

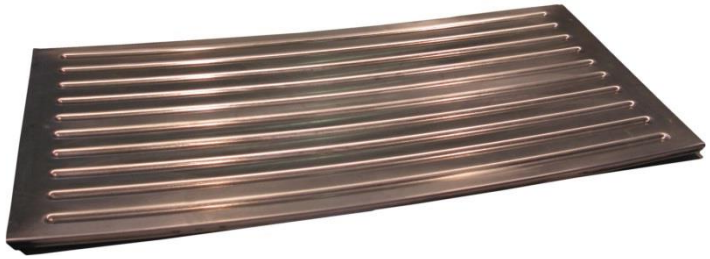
CAD Model



Forming



Part



► Technology transfer to industrial partner.

# Outline

1 Flexible sheet metal forming

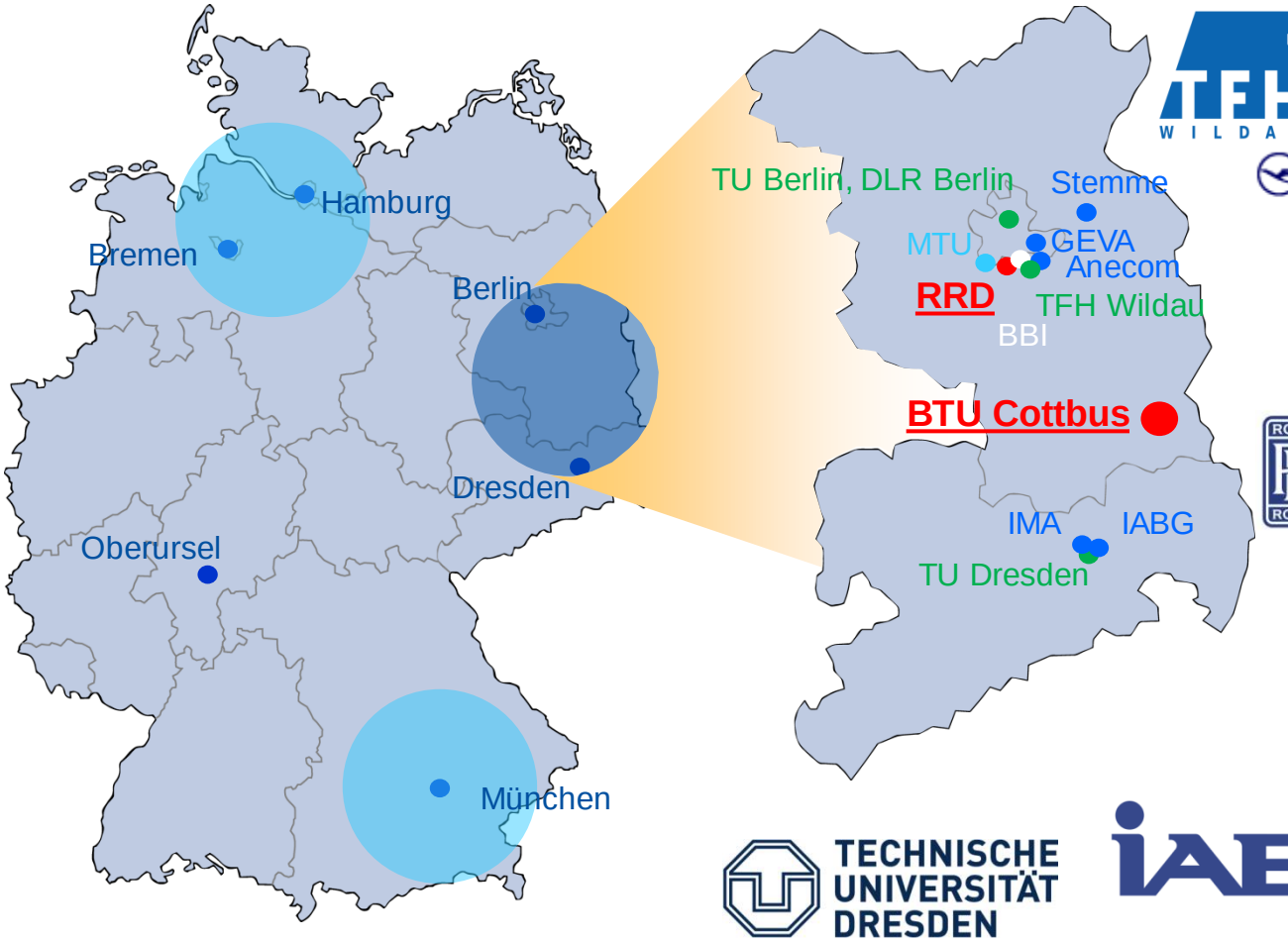
2 **Flexibility in Forging**

3 Combination of metal forming and additive manufacturing

4 Flexible stretch bending of profiles

5 Conclusion and Outlook

# „Aerospace Region 3“: Berlin/Brandenburg/Dresden




Quelle: Kühhorn

# Titanium Aluminide (TiAl) Intermetallics

**Aerospace, power generation, automotive**

Substitution of

- Nickel-base Superalloys and
- Titanium alloys (limited to ~ 500 °C)

Source: Leistritz Turbinentechnik GmbH

| | Nickel-base Superalloys | Titanium alloys | Titanium Aluminide alloys |
|---|---|---|---|
| Max. Temperature, °C | 1100 | 500 | 750 |
| Density, g/cm$^3$ | 8.0-8.6 | 4.5 | 3.9 |

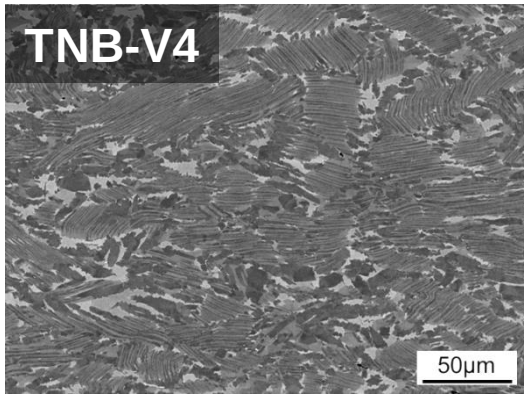
➡ an important task in processing of TiAl-based alloys consists in the investigation of the materials behavior, to overcome the problems associated with the limited workability of these alloys

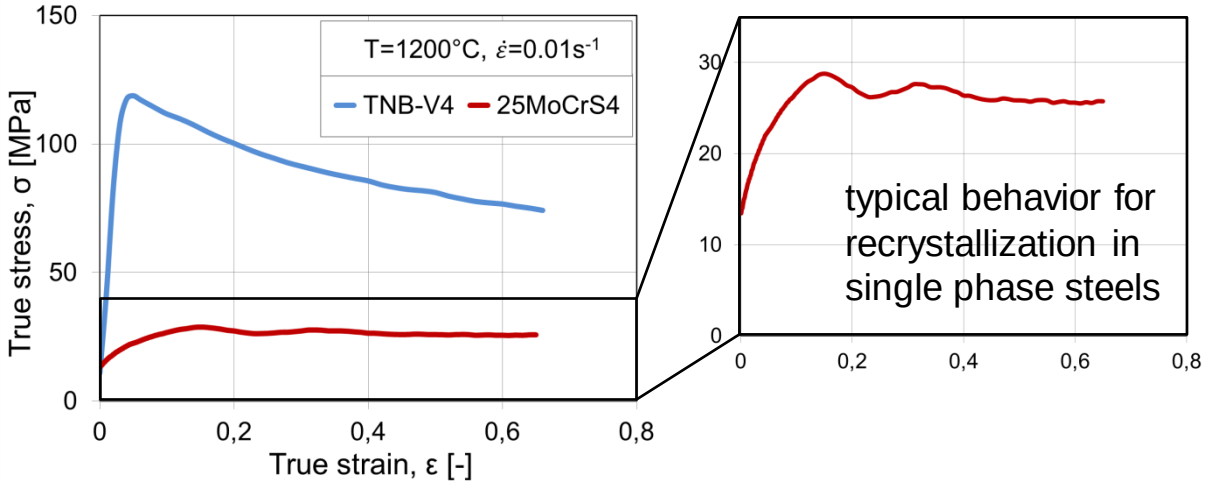
# Problem statement

## Current state: Process chain

| Metallurgical Processing | Extrusion | Isothermal Forging | Part (Blade) | Coating |
|---|---|---|---|---|
| microstructure is coarse and inhomogeneous | microstructure can recrystallize to smaller grains | high temperatures and extremely low strain rates | good fatigue strength and good heat resistance | to improve environmental resistance |

## Differences in microstructure and flow stress behavior of TiAl



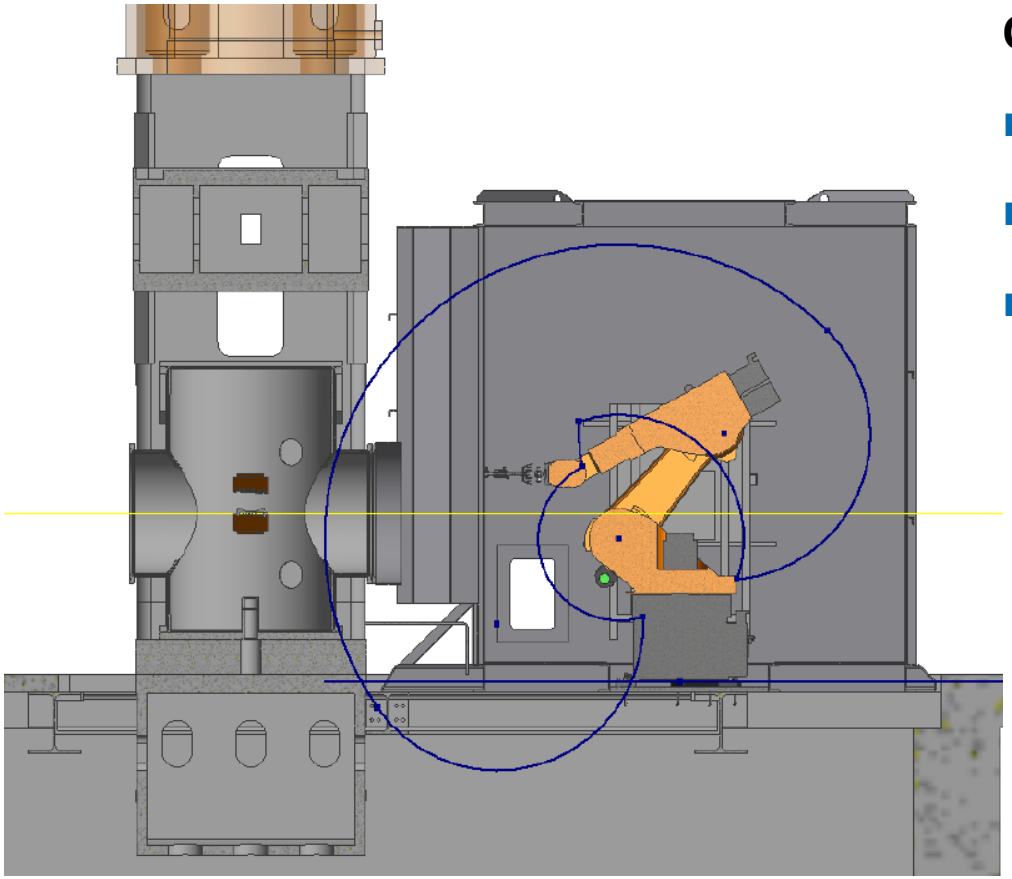



# Forging Center

**Technical features:**

- Forging Temperatures up to 1400 °C
- Force: 1700t
- Vacuum or protective atmosphere
- Fast feed: up to 200mm/s
  Slow feed: down to 0,05mm/s
- Processes
  - Closed-die forging
  - Hot-Die-forging
  - Isothermal and superplastic forging
- Forging with stationary dies
- Batch processing

# Current work
## Automation of the forging center



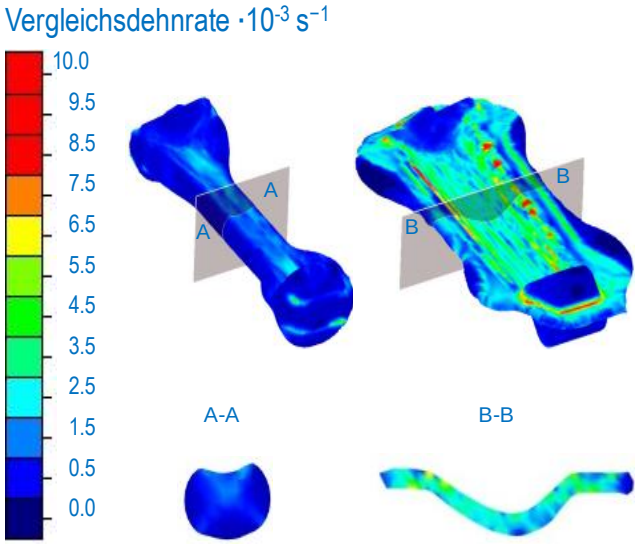
**Goals:**

- Integration of handling robot
- Coupling of robot and press control
- reproducible processes

Investition in **Ihre** Zukunft!
EUROPÄISCHE UNION
Europäischer Fonds für Regionale Entwicklung
www.efre.brandenburg.de

# Forging with stationary dies

## FEM-Simulation




## Forging

Schaufel-Rohling im Gesenk

unmittelbar nach der Schmiedung

## Blade

geschmiedete Schaufel im Gesenk

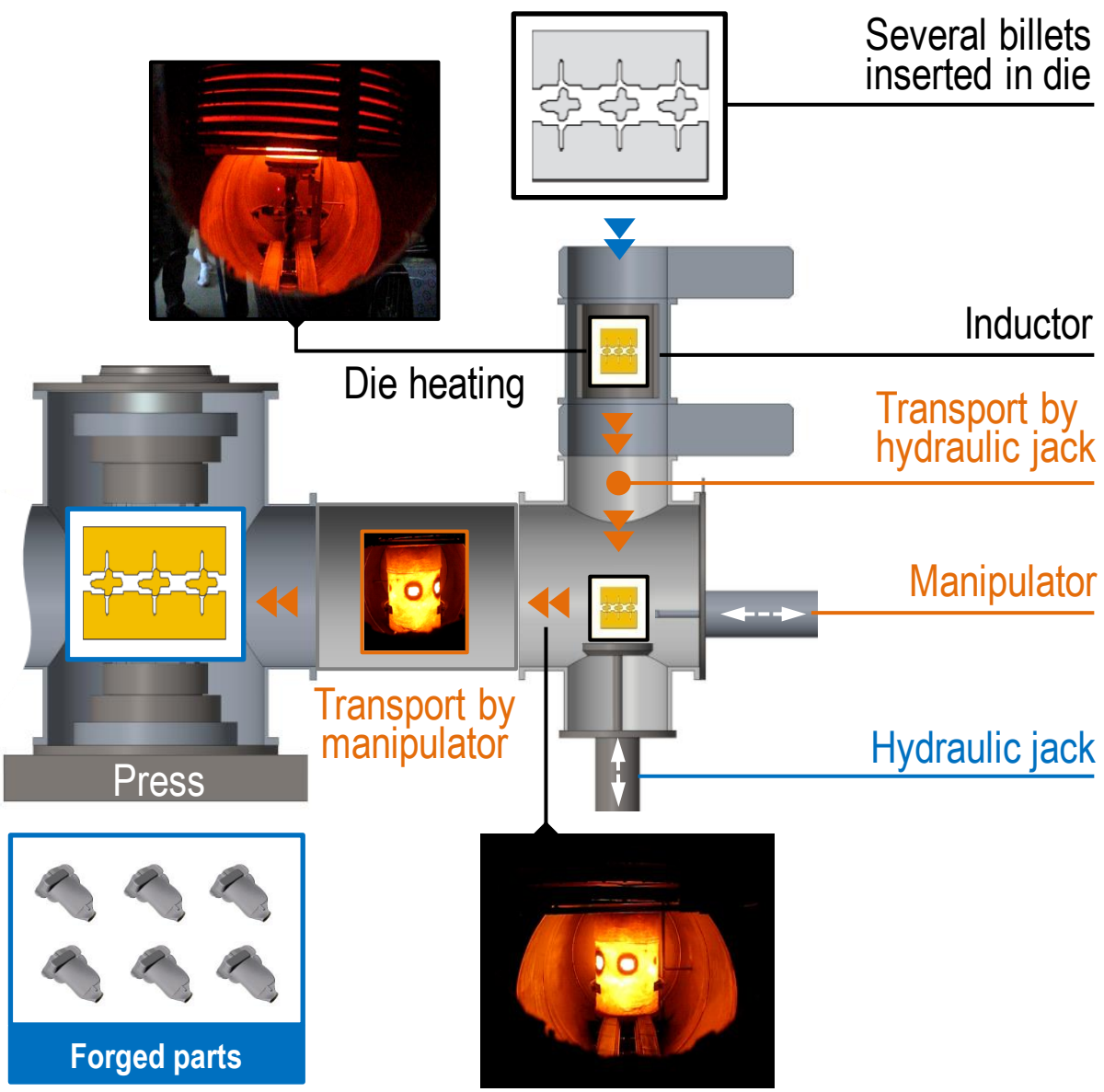
Forging with stationary die set does not allow for production of different parts or variants.

→ Flexibilization of set-up needed!

# Flexible Isothermal forging by batch processing

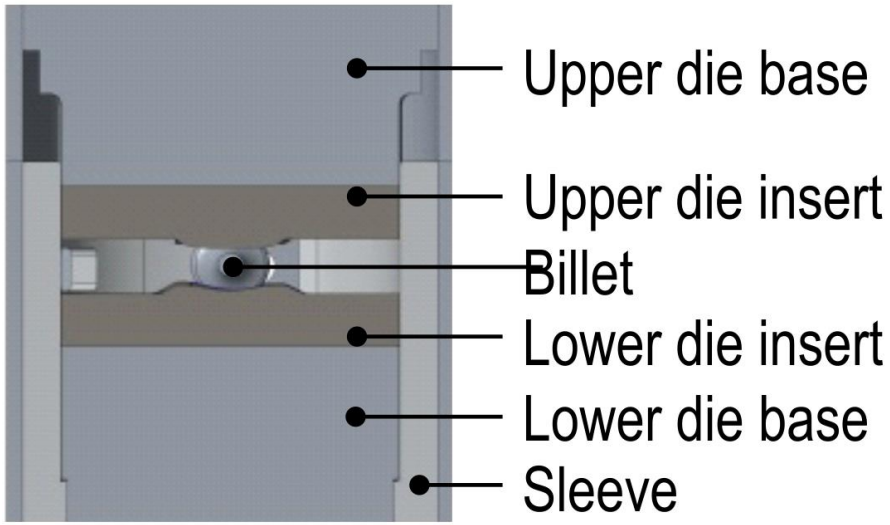
**Forging press**

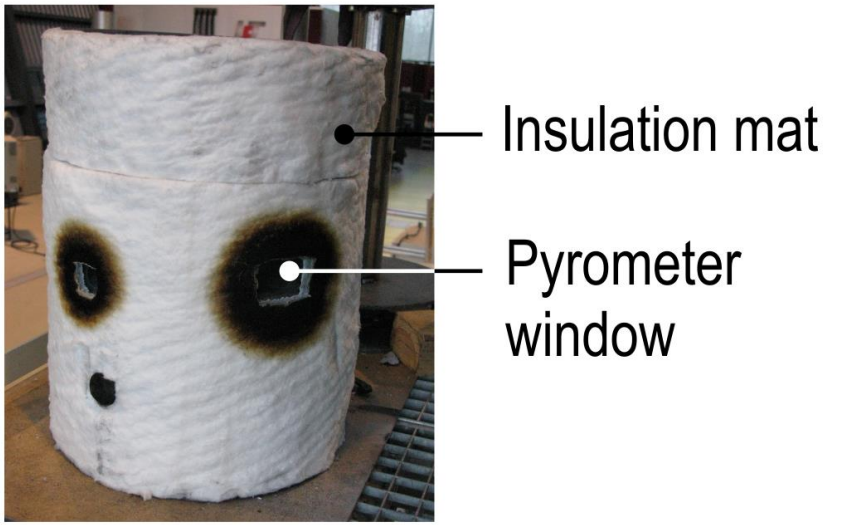
**Lock system**



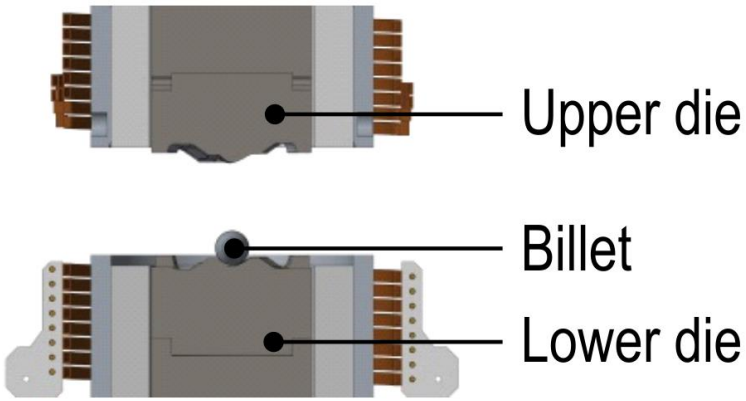
# Die design

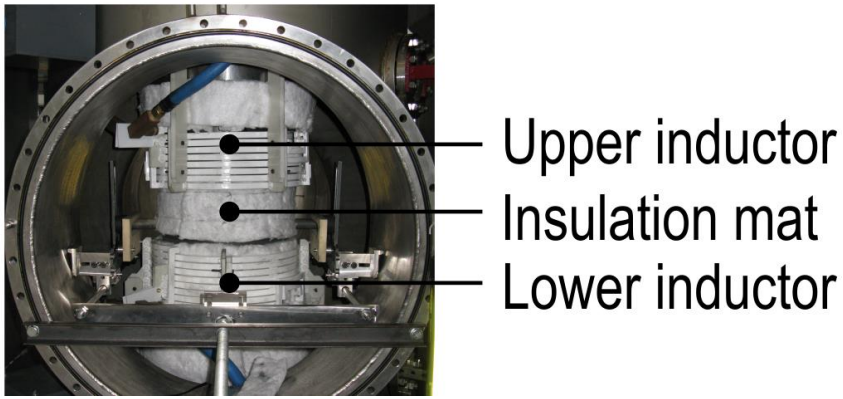
## Die for batch processing




## Stationary die



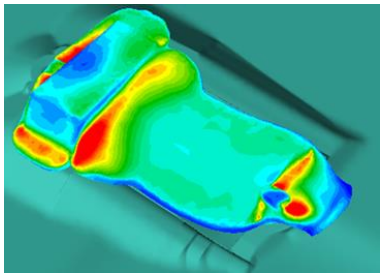
# Systematic Development of Isothermal Forging Process

**1. Material testing under variation of**

- strain, strain rate
- Temperature

**2. Microstructure modelling and FE simulation**

- analyses with scanning electron microscopy
- finite element program Q-Form

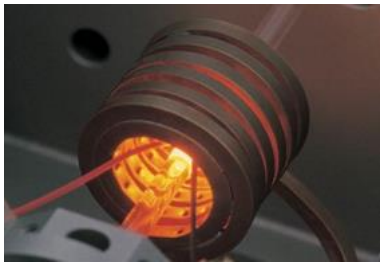


**3. Experimental forging trials using an isothermal forging press**

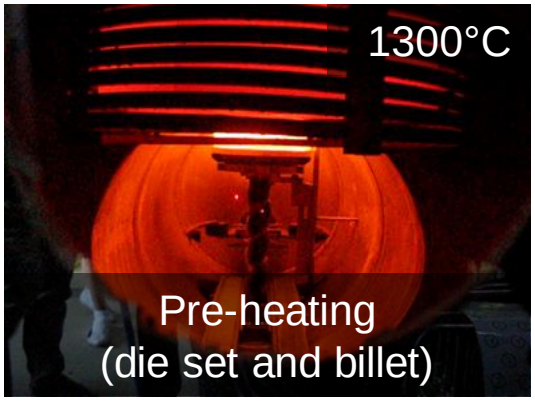
- forging temperature up to 1400 °C
- integrated furnace (vacuum/protective atmosphere)

**4. Model validation**

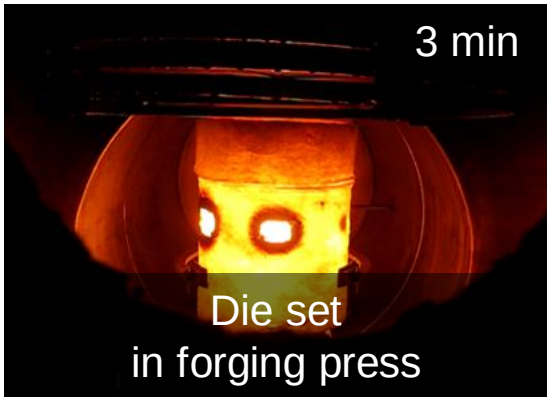
- deformation with various strain rates in agreement with data history from the simulation



# Isothermal forging process





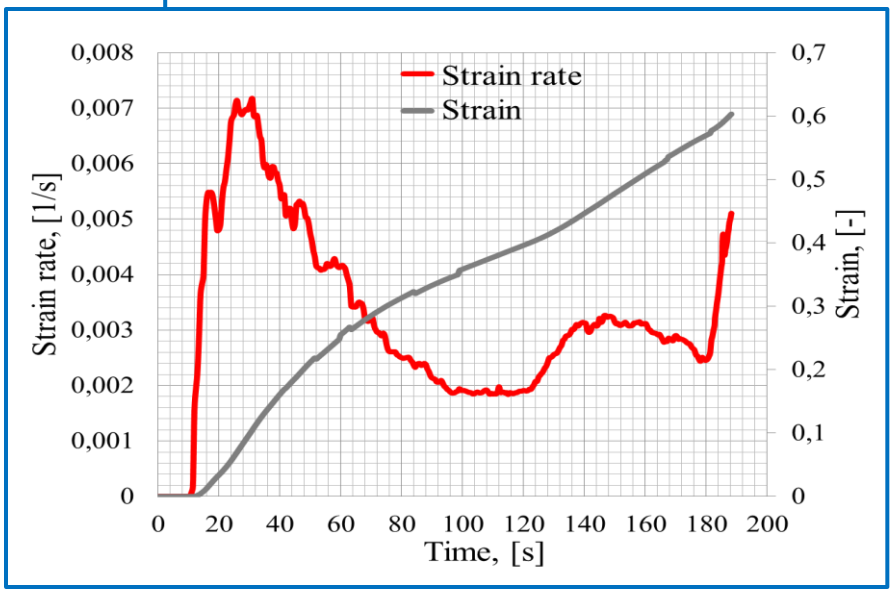




short carbon fiber reinforced
silicon carbide (C/SiC)

- forging time: ≈ 3 min
- velocity: ≈ 0.17 mm/s
- lubricate: boron nitrite
- temperature control during forging process

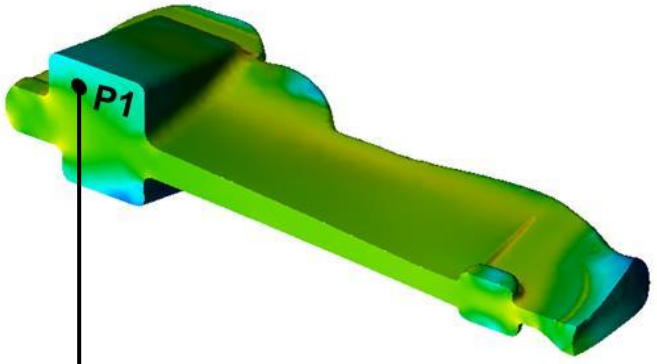
# Comparison of predicted grain sizes with experimental results


- The testing conditions included deformation in agreement with data history obtained from the simulation process
- strain up to 0,6
- strain rates range ≈ 0.001 … 0.007 $s^{-1}$

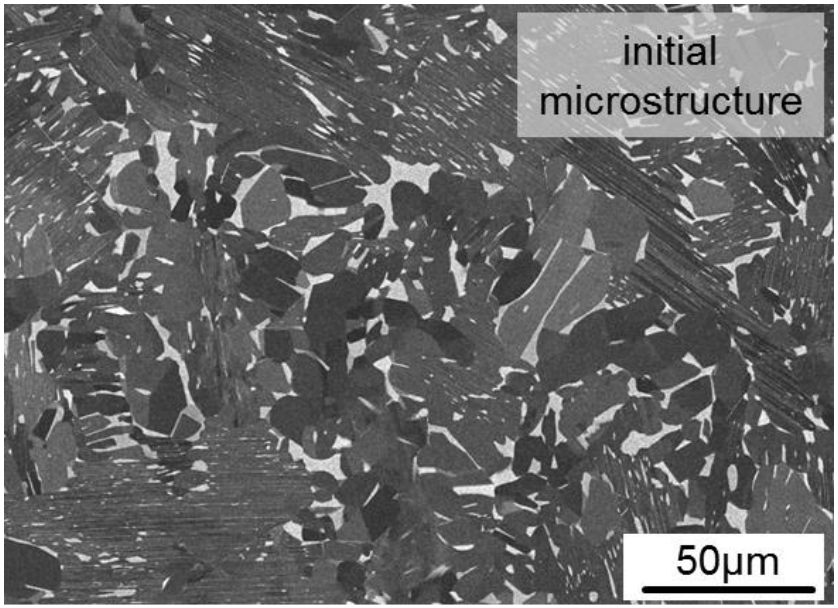
# Comparison of predicted grain sizes with experimental results

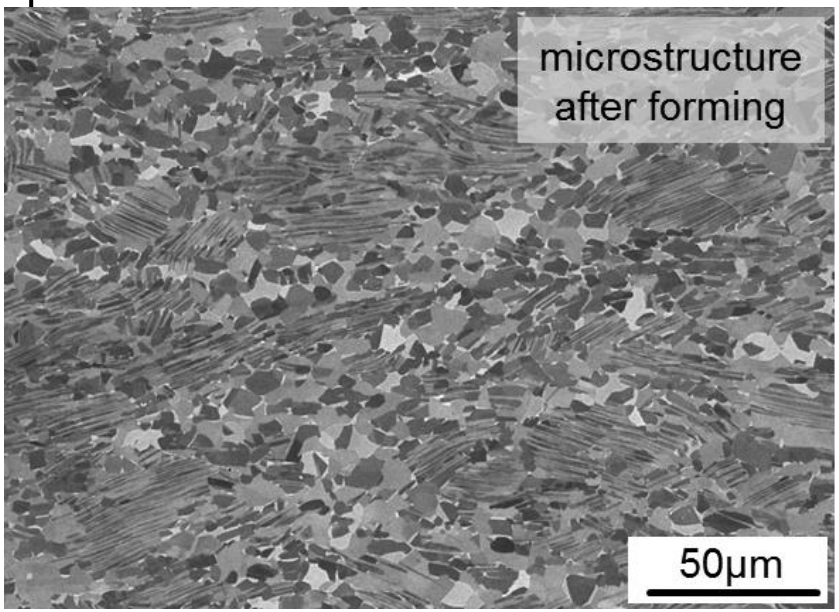
| Point P1 | Calculated grain size, µm | Measured grain size, µm |
|---|---|---|
| γ-phase | 12.71 | 10.37 |
| $\beta/\beta_o$-phase | 12.86 | 10.24 |




β-grain size, µm

16
15
14
13
12
11

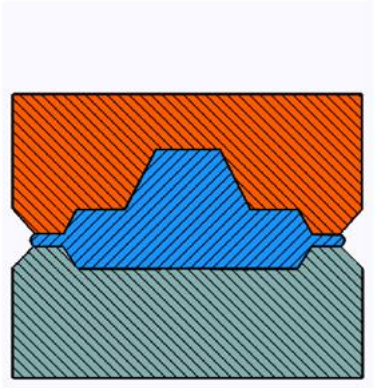


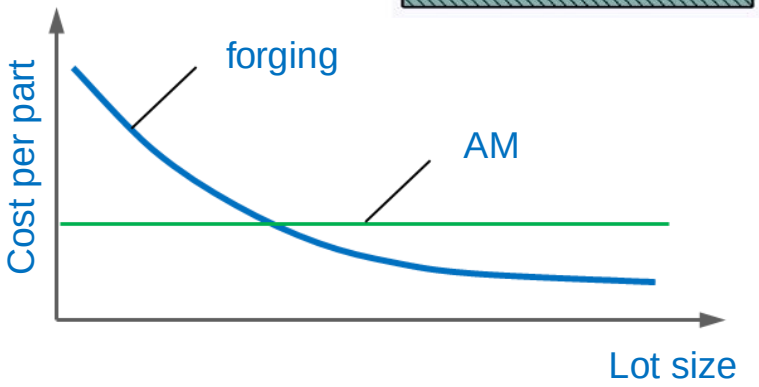



# Outline

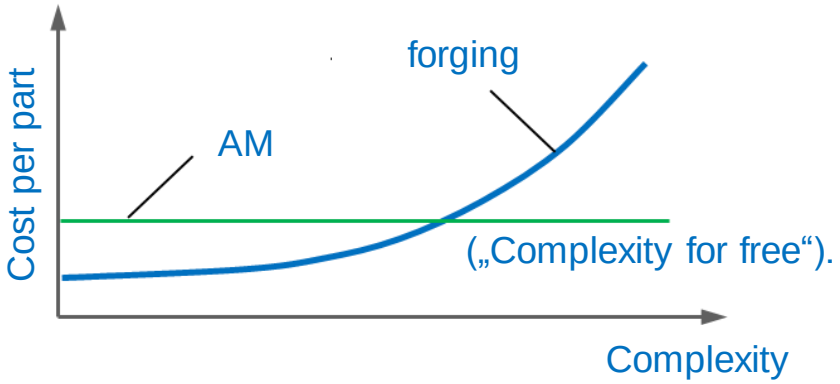
# Forging vs. Additive Manufacturing (AM)

## Forging



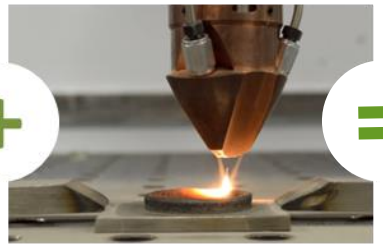



## Additive Manufacturing




Forming

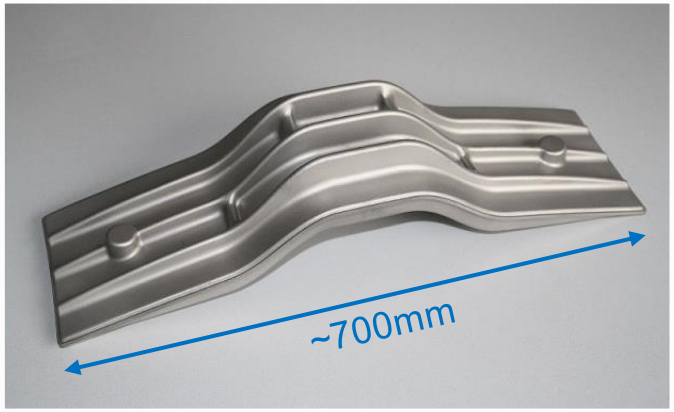
AM



Cost- and material efficient production independent of lot size and part complexity?

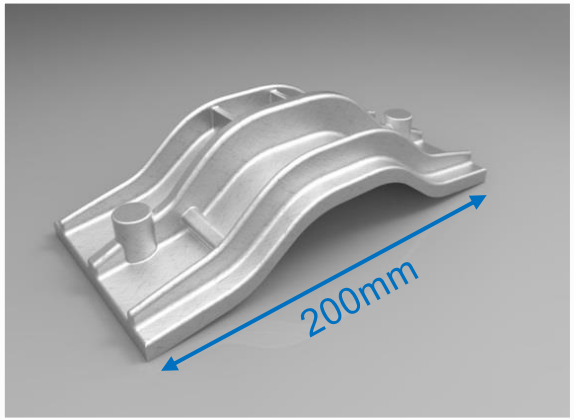
# Demonstrator 1
## Automotive crash barrier

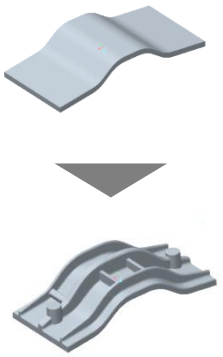
### Forged Part




*Source: www.umformtechnik.net, B&W Fahrzeugentwicklung*

### Demonstrator



**Manufacturing by Forging**

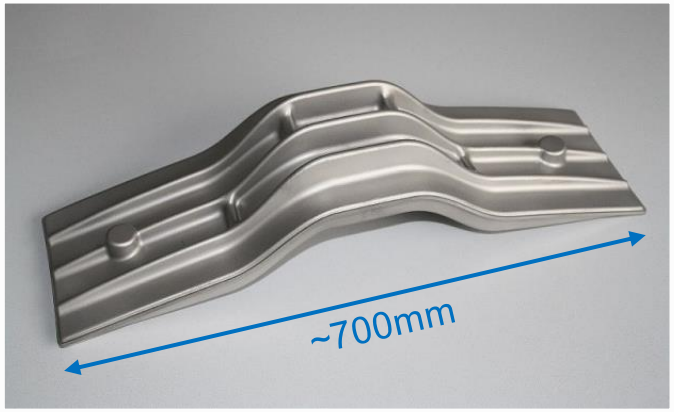
- Complexity due to ribs
- Complex process design
- Cost-intensive tooling

**Manufacturing by Bending + Additive Manufacturing**

- Simple bending process
- Design freedom by additive manufacturing
- For prototypes and small series

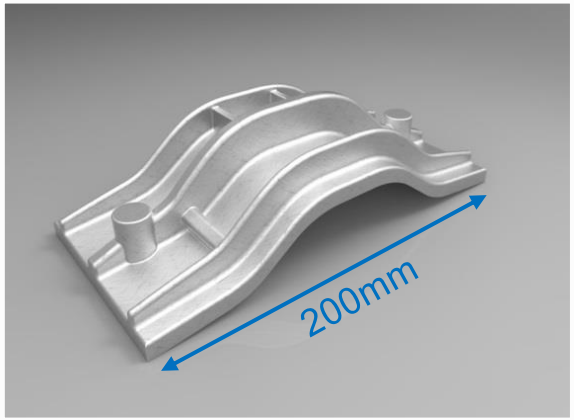
# Demonstrator and process design

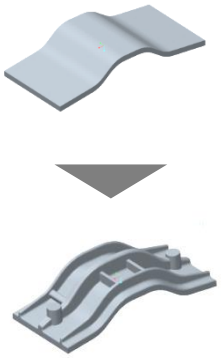
## Forged Part



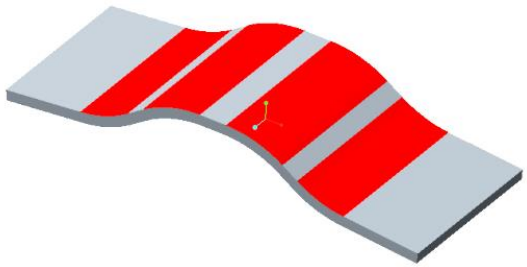

*Source: www.umformtechnik.net, B&W Fahrzeugentwicklung*

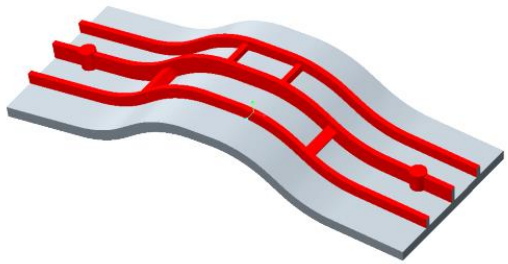
## Demonstrator

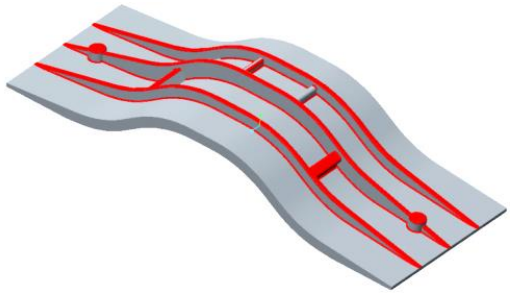


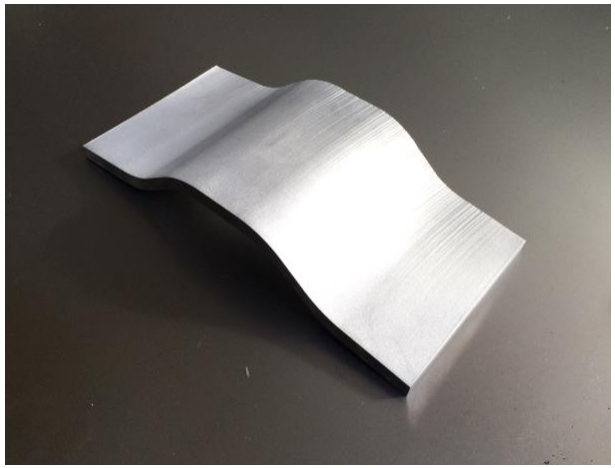
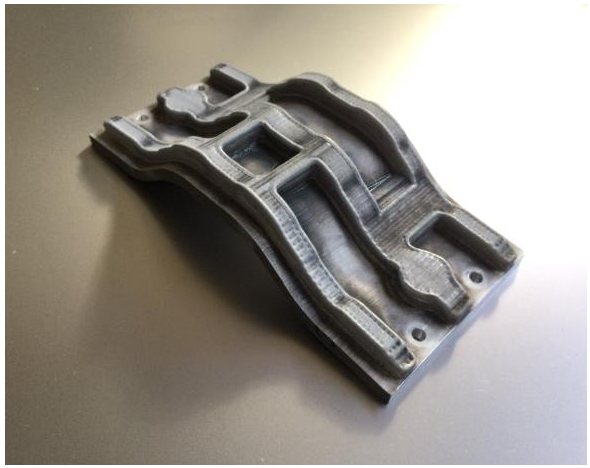
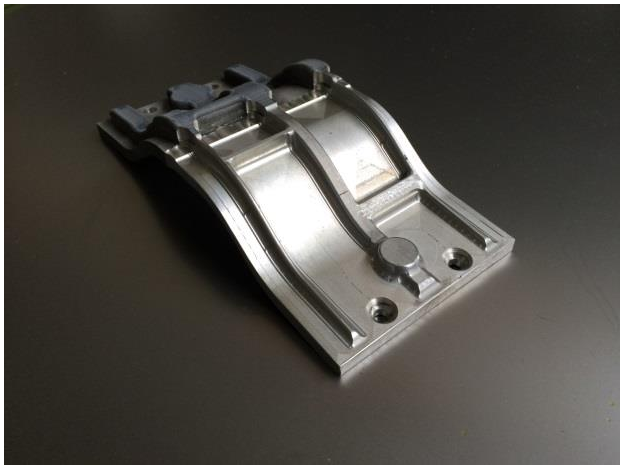
| **Pre-form** *Process: Bending* | **Stringers / ribs** *Process: Additive Manufacturing* | **Finishing** *Process: Milling* |
|---|---|---|







# Demonstrator 1
## First results (material: AA6082 + AlSi7)

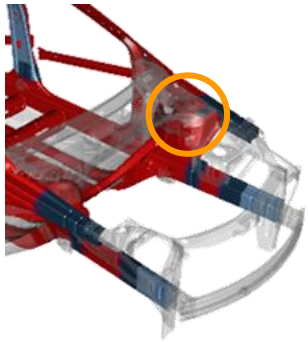
| Preform | Additive Manufacturing | Milling |
|---|---|---|
|  |  |  |

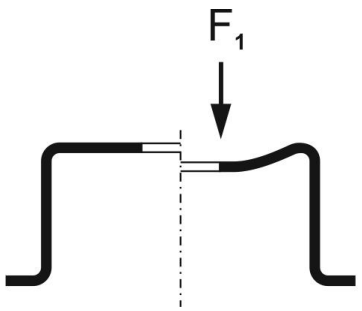
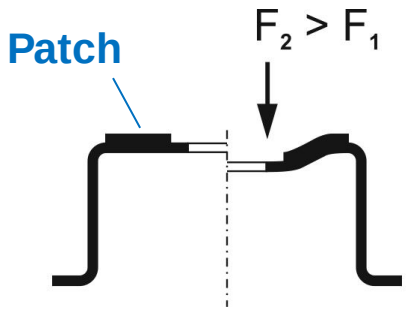
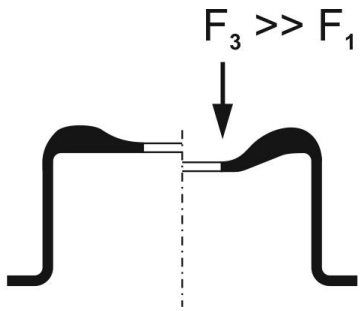
**Current state**

- Feasibility has been shown
- Better control of AM process (microstructure, distortion) needed
- Additive Manufacturing (AM) still time intensive (4.5 h) **but SLM takes ~ 2 days !**

→ **Reduction of volume created by AM ?**

# Demonstrator 2
## Flexible local reinforcements

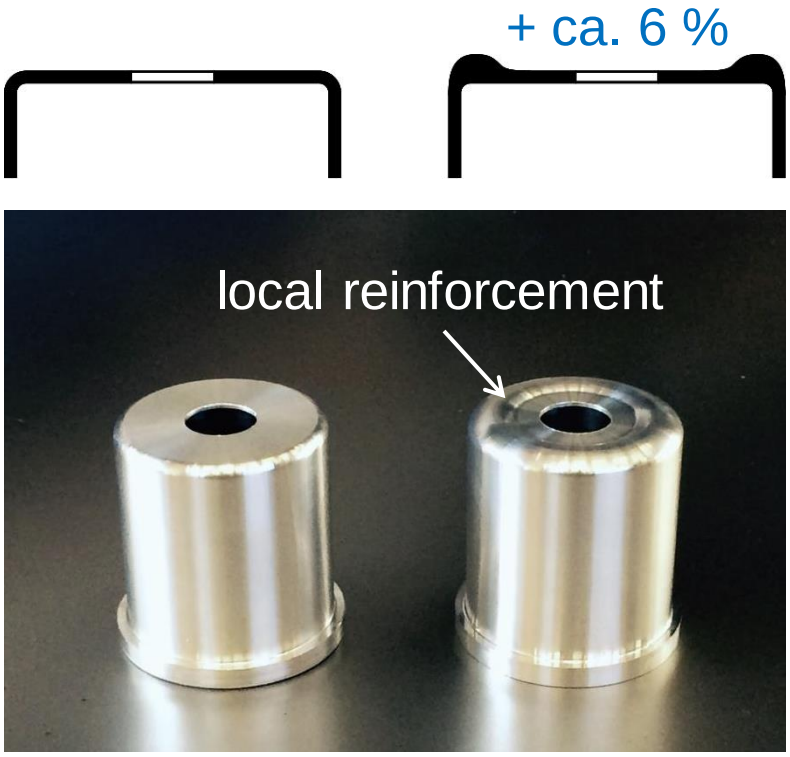


| | Standard Part | Patchwork Reinforcement | Additive Reinforcement |
|---|---|---|---|
| |   |   |   |
| Δthickness | no | constant | non-linear |
| Δstiffness/ Δmass | ➡ | ⬆ | ⬆⬆ |

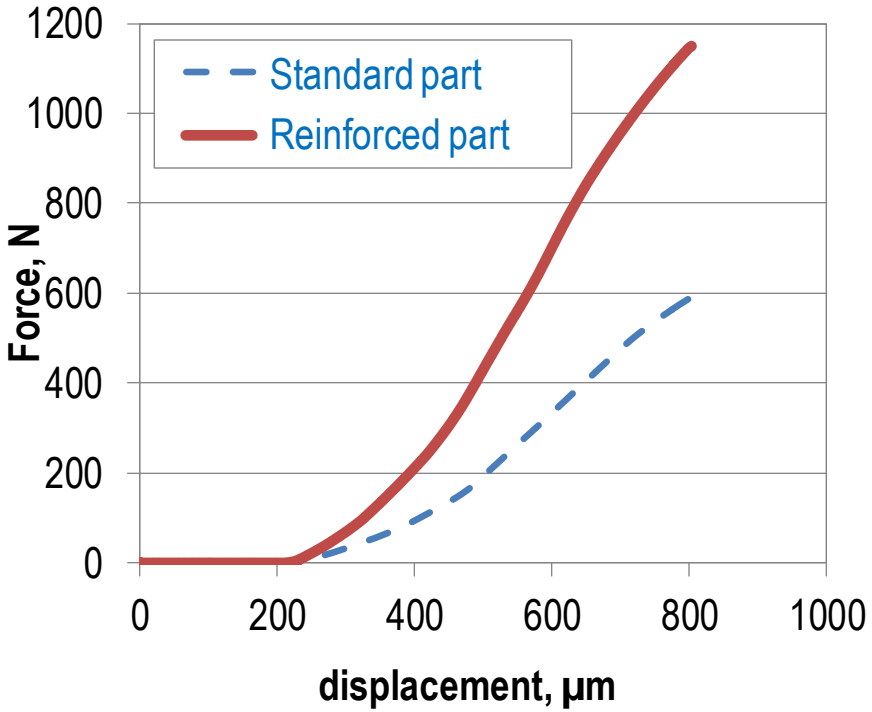
For some applications (e.g. the production of variants),
a flexible reinforcement technology (additive manufacturing) could be beneficial.

# Demonstrator 2
## Stiffness increase by addition of reinforcement

### Manufactured demonstrator

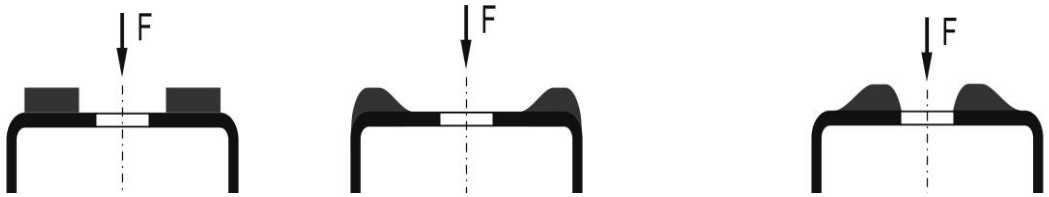



### Stiffness increase




Large stiffness increase with little added mass possible.

# Demonstrator 2
## Optimal location of added material?




| | Basic sheet | Patchwork Blank | Reinforcement (at radius) | Reinforcement (at hole, sizing optimization) |
|---|---|---|---|---|
| Weight | 100 % | + 6 % | + 6 % | + 4,7 % |
| Stiffness | 100 % | + 75 % ↑ | + 95 % ↑↑ | + 163 % ↑↑↑ |

state of the art

best compromise **stiffness / distortion**

best stiffness increase

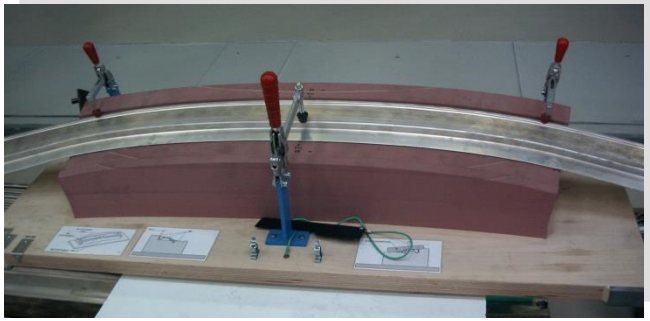
**Current research:**

- Optimization of location and shape of additively manufactured features
- Integration into process chain

# Outline

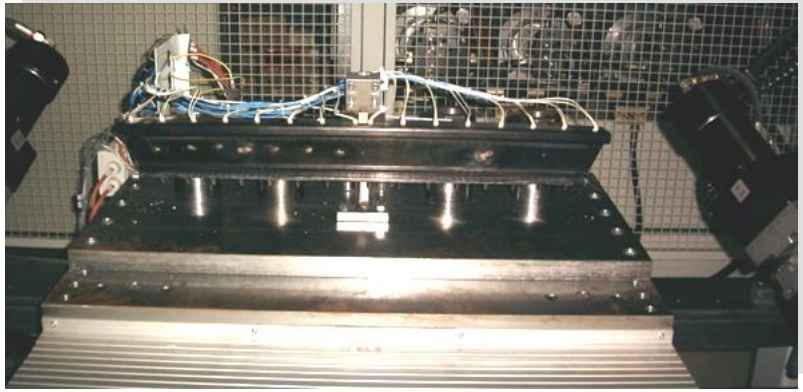
# CNC bending of profiles

*Strech bending machine at KuF*



*Formed part*

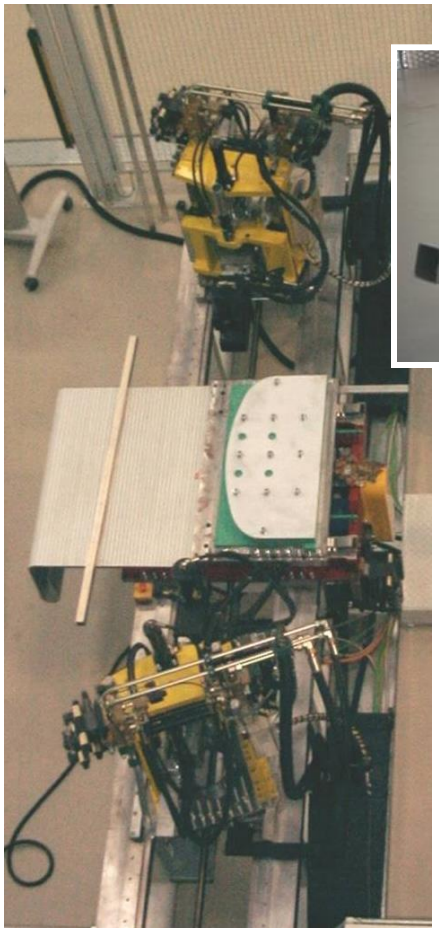
- Force max. 60kN
- Positioning accuracy: 0.05mm
- CNC- and Teach-In-Programming



*Heatable die for magnesium profiles*

# Project examples

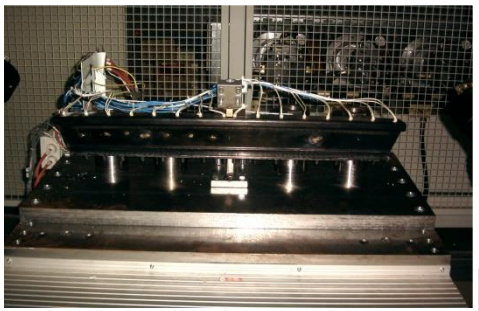
## Square Al-profiles



Fertigteil

Betrachtungen und Messungen am Fertigteil

## Magnesium Profiles



Tooling für isothermal strecht-bending of Magnsium profiles

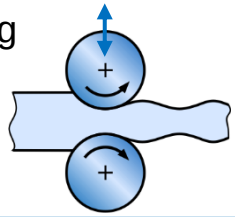
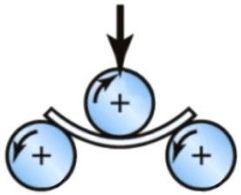
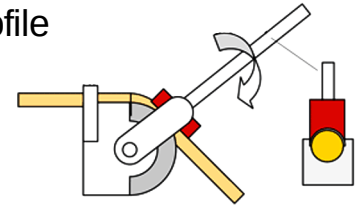
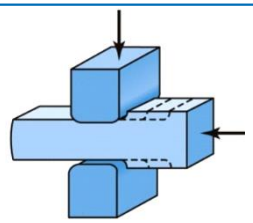
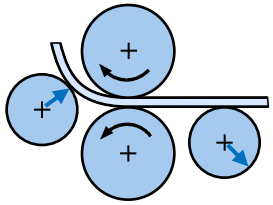
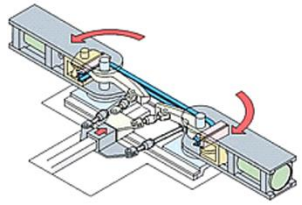
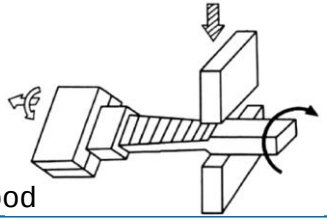
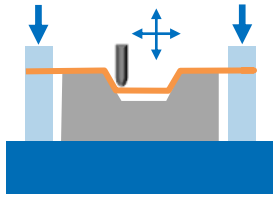
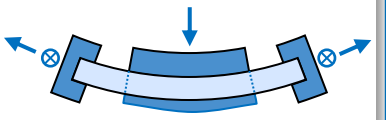
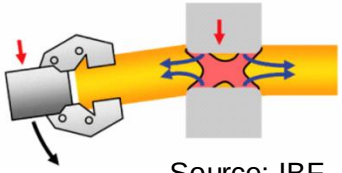
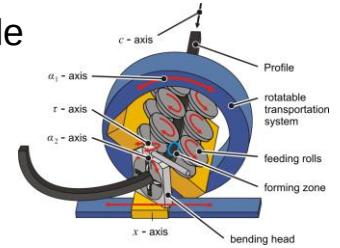
AZ31 Mercedes roof frame part

Upper part: no failure

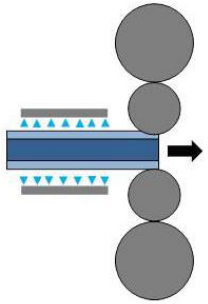
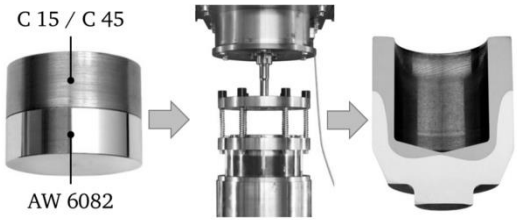
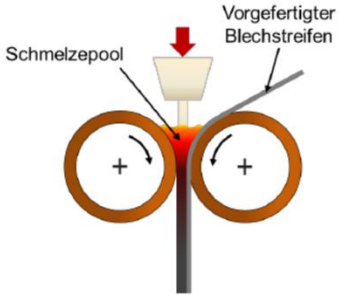
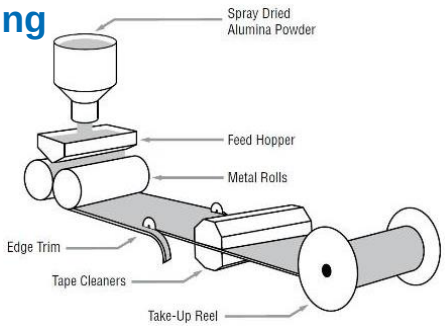
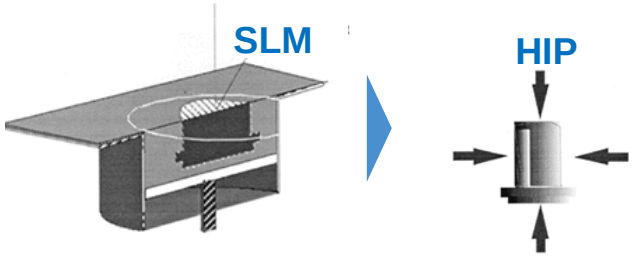
Lower part: Wrinkles due to low streching

# Outline

# “Ordinary flexible forming” → no change of mass

| DoF | Bulk | Sheet | Tube/Profile |
|---|---|---|---|
| 1 | ▪ Flexible rolling and extrusion  | ▪ 3-roll bending  | ▪ Tube/profile bending  |
| 2 | ▪ Open die forging  | ▪ 4-roll bending  | ▪ Stretch bending  |
| 3 | ▪ Open die forging + twisting  Source: Allwood | ▪ Incremental sheet forming  | ▪ 3D Stretch bending  |
| >3 | ▪ Open die forging + bending  Source: IBF | ▪ Robot based driving  Source: UTG | ▪ Tube/profile forming   Source: IUL |

# “Extended flexible forming” → adding or substituting material

| | Sheet | Bulk |
|---|---|---|
| solid | **Roll Cladding (IBF/RWTH Aachen)**<br>**Partial Cladding**<br>  | **Combined Cold Extrusion (PtU/Prof. Groche)**<br>  |
| liquid | **Cladding by strip casting (IBF/RWTH Aachen)**<br>  | **Thixojoining (IBF/RWTH Aachen)**<br>  |
| powder | **Spray compacting (azam.com)**<br>  | **SLM + HIP (Das et al., 1998)**<br>  |

# Thank you for your attention!

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