Institut für
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Experimental Investigations on Forming Limits for EN AW-5083 Sheet Metal at Quasi-Static and High Strain Rates

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Motivation

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Several materials show increased formability at high strain rates

…but…

- The cause for the increase in formability is still in discussion (inertia effects, strain rate sensitivity)
- Analysis of forming limits is only standardized at low strain rates
- Forming devices capable of high forming speeds / strain rates lack the possibility of defined strain paths and reproducibility:
  - electromagnetic punch stretch test (Chu et al. 2012)
  - detonation forming tests (Yasar et al. 2006)
  - …

➔ A device for high speed testing of forming limits in accordance to international standards is needed!

Chu, Y.Y., Lee, R.S., Psyk, V., Tekkaya, A.E., 2012. Determination of the flow curve at high strain rates using electromagnetic punch stretching. Journal of Materials Processing Technology 212, 1314–1323.

Yasar, M., Demirci, H.˙I., Kadi, I., 2006. Detonation forming of aluminium cylindrical cups experimental and theoretical modelling. Materials & Design 27, 397–404.

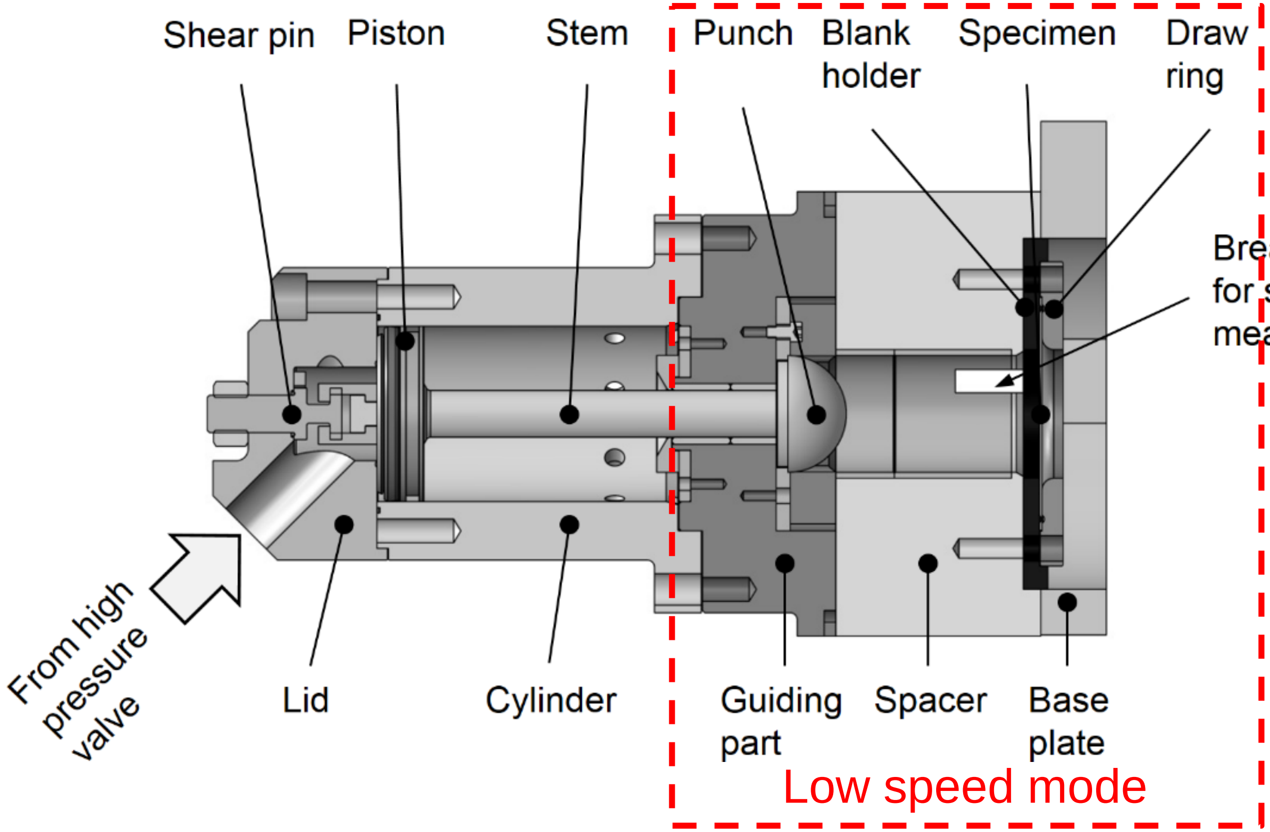
Outline

1. **Experimental setup and forming device**
2. **Experimental investigations**
   – Testing of forming limits of EN AW-5083 sheet metal
   – Results of quasi-static and high-speed testing
3. **Summary and outlook**

Experimental setup and forming device

Modular forming device

Two testing modes possible: High speed (pneumo-mechanical)
Low speed (mechanical)

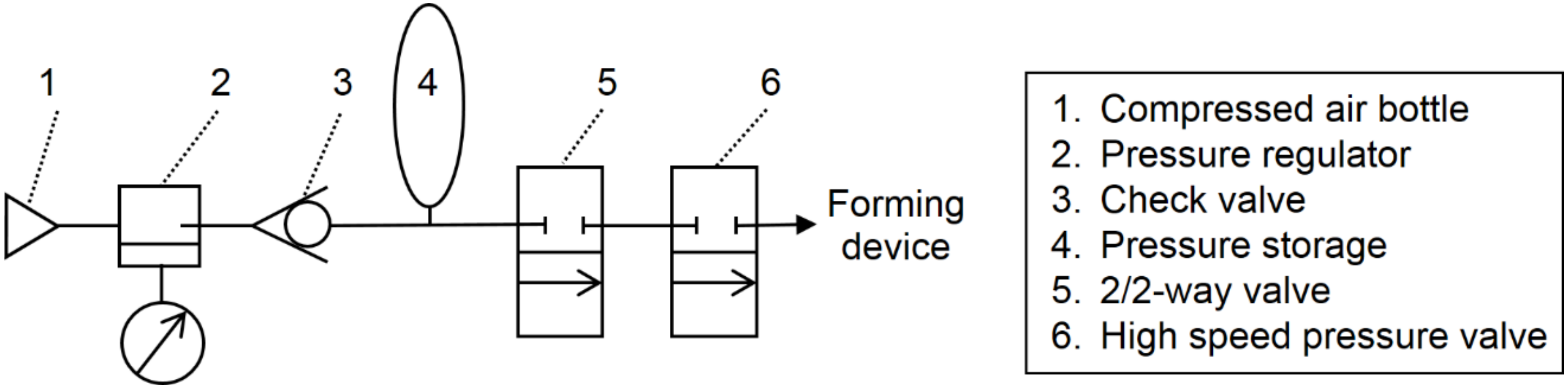


Engelhardt, M., Klose, C., 2014. Experimental investigations on forming limits for aluminium alloy sheet metal at various strain rates, in: Hoon, H., Tekkaya, A.E. (Eds.), High Speed Forming 2014, pp. 11–20.

Experimental setup and forming device

Pneumatic energy supply

- Maximum air pressure of 250 (300) bar
- ½” tubings for high air flow
- High speed pressure valve with minimal switching time of 30 ms



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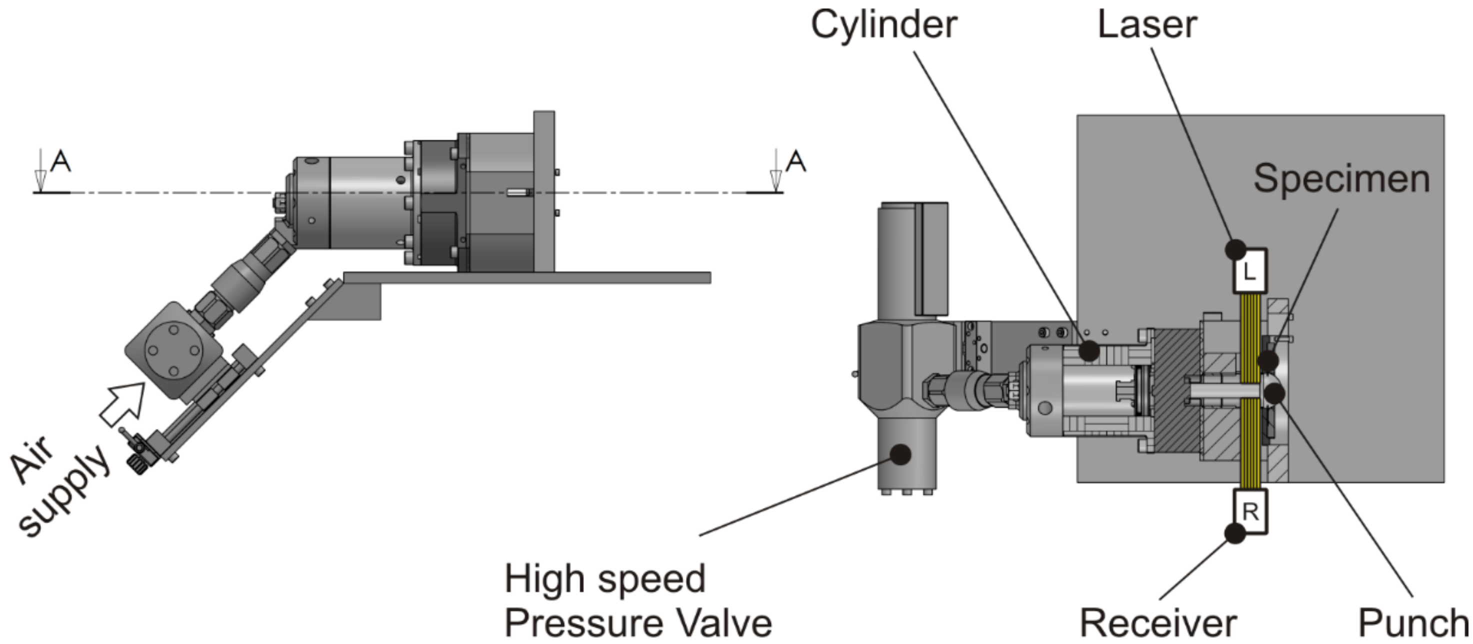

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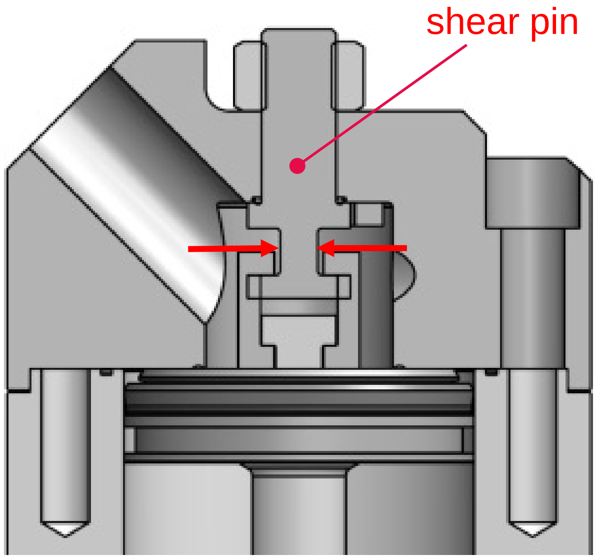
Experimental setup and forming device

Speed adjustment in high speed mode

- Air Pressure adjustable between 50 bar and 250 bar

Shear pin

- Prevents release due to pneumatic shock waves before full pressure is available
- Locks cylinder in place
- Various diameters or no shear pin possible



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Experimental setup and forming device

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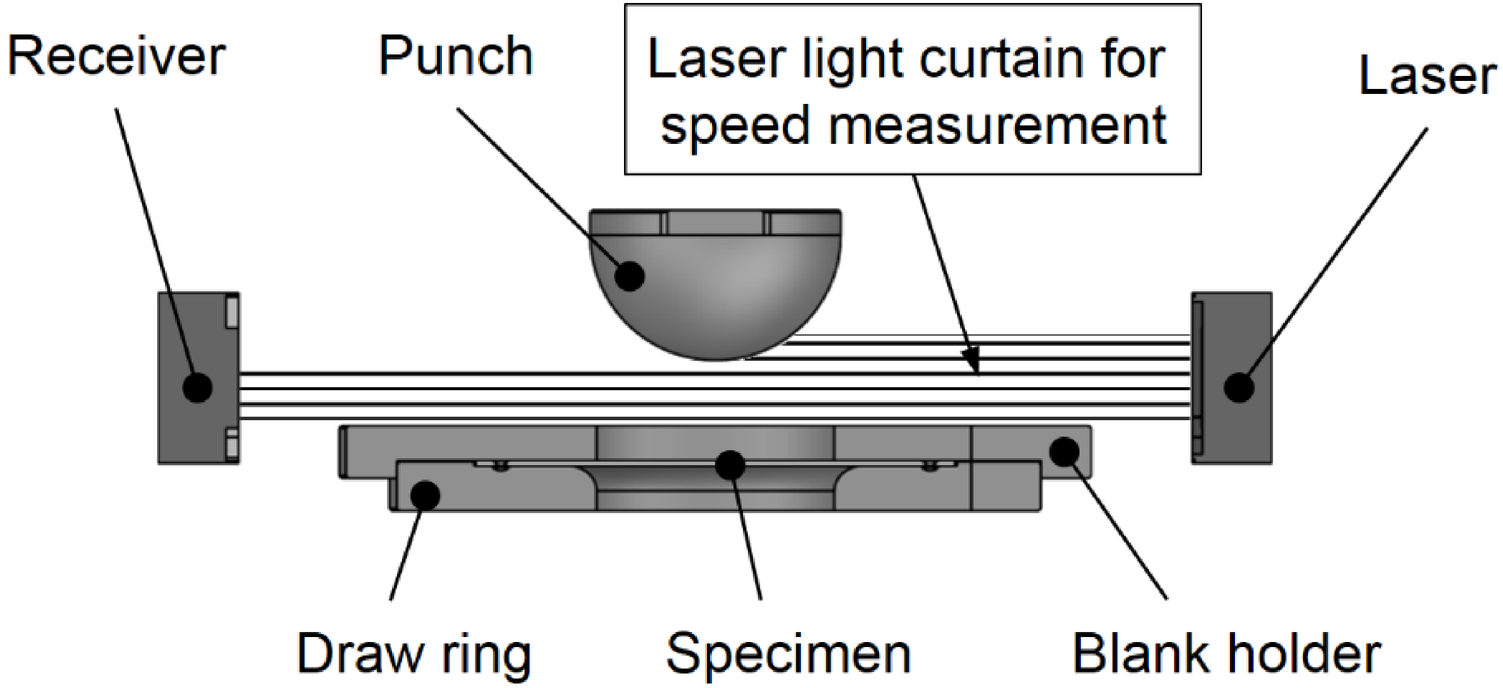
Optical speed measurement

- ODC1201-20 Laser Beam Sensor by MICRO-EPSILON Eltrotec GmbH
- Sensor output signal 0-12 V equals free laser light curtain of 0-20 mm
- Laser beam placed directly above blank holder (distance to sheet 10 mm)



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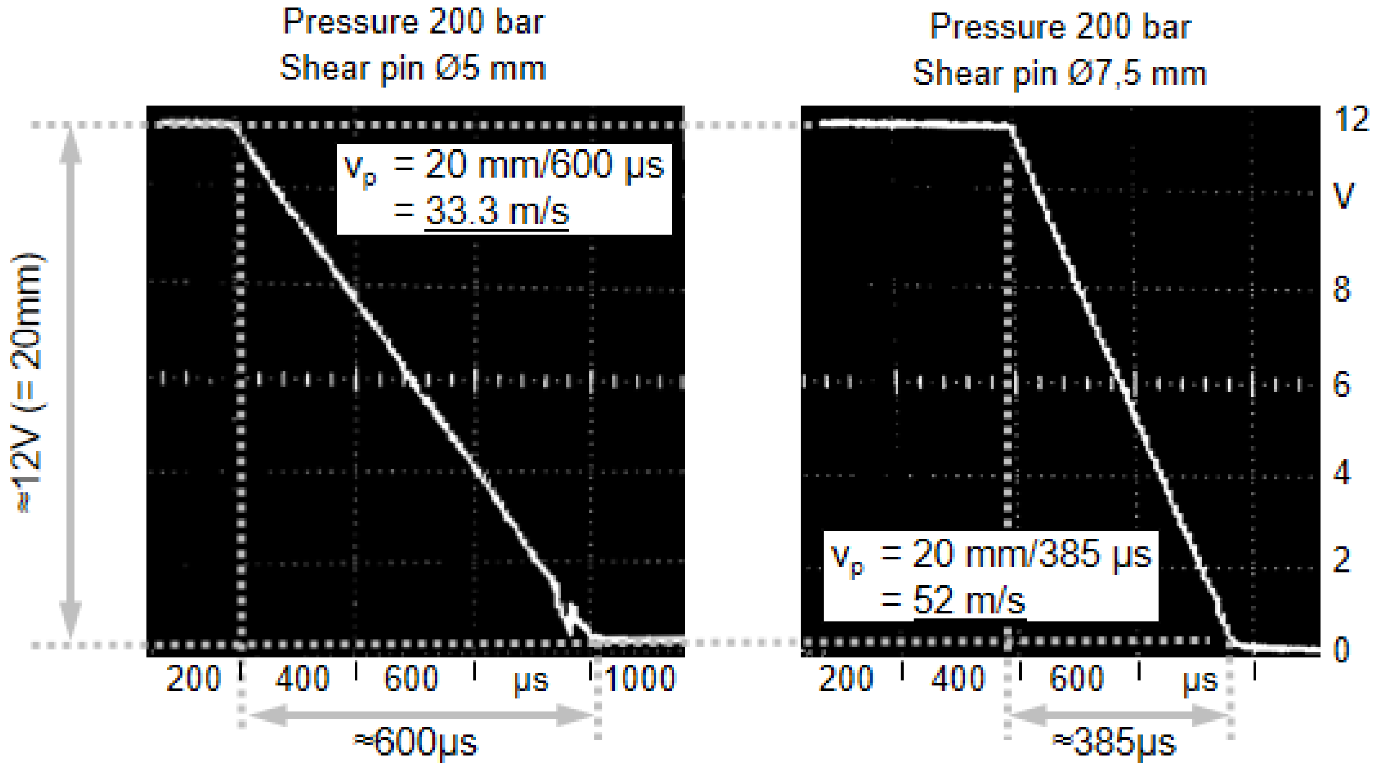
Experimental setup and forming device

Optical evaluation of punch speed

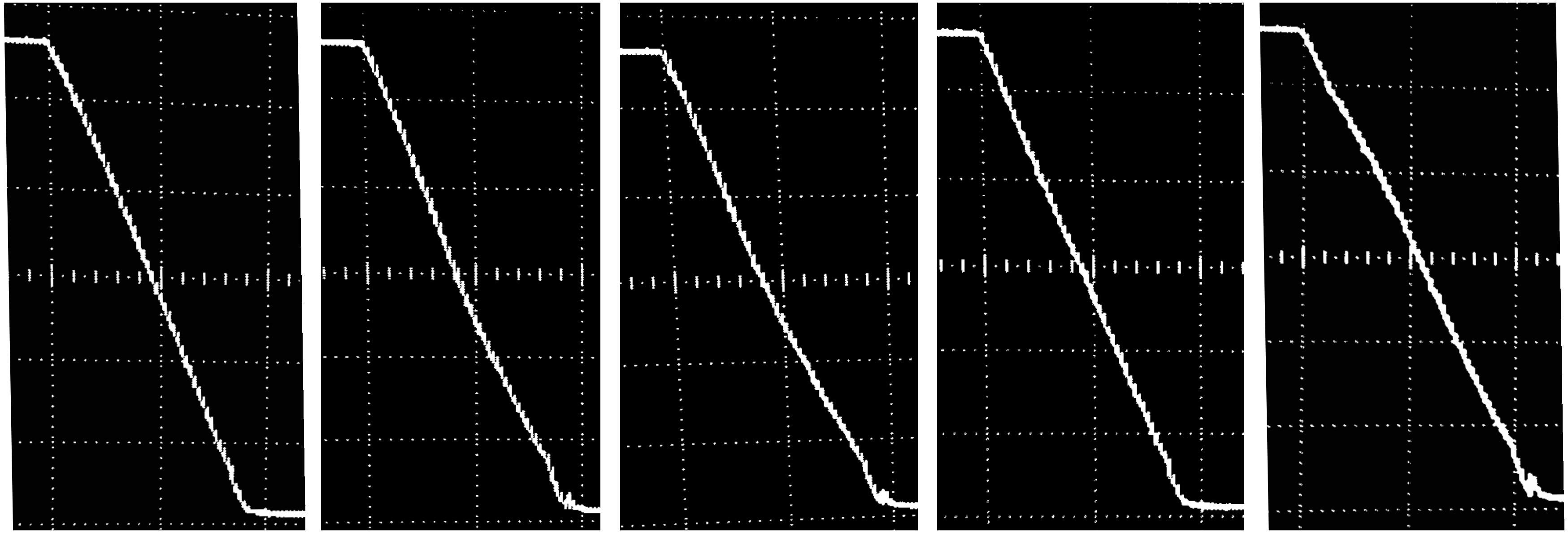
- Sensor output signal displayed on a storage oscilloscope
- Drop in signal equals measuring length
  → time for signal drop equals punch travel time through the laser light curtain



Experimental setup and forming device

Repeatability

- Several tests for different pressures and shear pin diameters were done
- Repeatability of speeds of up to 50 m/s has been verified
- Variation approximately 10-15 %



Sensor output of five trials / pressure 200 bar / shear pin diameter 7,5 mm
According signal drop time between 370 to 420 µs (≈ 48 to 54 m/s)

Experimental setup and forming device

Limitations in low speed mode

– Punch speed during testing in low speed mode equals crosshead speed of the universal testing device
– Maximum/minimum punch speed = maximum/minimum crosshead speed

Limitations in high speed mode

– Air pressures below 100 bar (≈ 18 m/s) result in a deformation energy not sufficient for specimens >45 mm (aluminum)
– Punch speed shows a high deviation of more than ±15 % for air pressures lower than 150 bar (friction / influence of pressure shock waves)
– Above 150 bar reproducible punch speeds with a standard deviation of about ±5 %
– The use of a shear pin allows for punch speeds of more than 50 m/s
– Punch speeds >35 m/s result in increasing possibility of part failure, e.g. fracture of the stem

Forming device summary

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General

- Modular set-up for high speed and low speed testing modes
- Device can be installed into a universal testing machine for low speed testing or used with pneumatic energy supply for high speed testing
- Punch speed adjustment through crosshead speed / variation of shear pin diameter and pneumatic pressure
- Speed measurement with a laser light curtain (cut-off frequency 100 kHz / dynamic resolution 100 µm) and storage oscilloscope

Technical data

- Hemispherical punch: Ø 50 mm
- Specimen diameter: Ø 100 mm
- Specimen thickness: 1 mm
- Maximum air pressure: 250 bar
- Maximum punch speed: ≈ 50 m/s
- Penetration depth: 20 mm (adjustable with washers)

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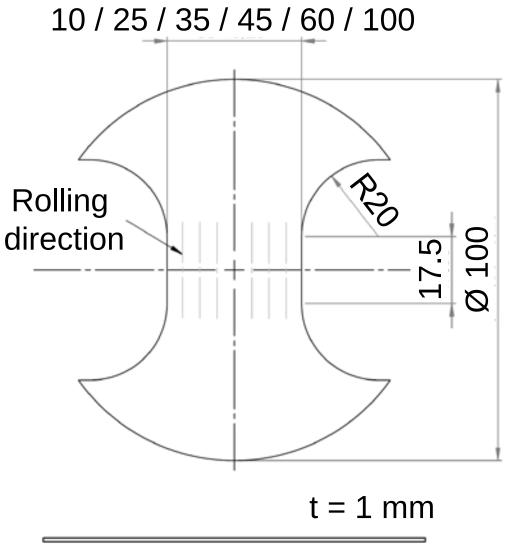
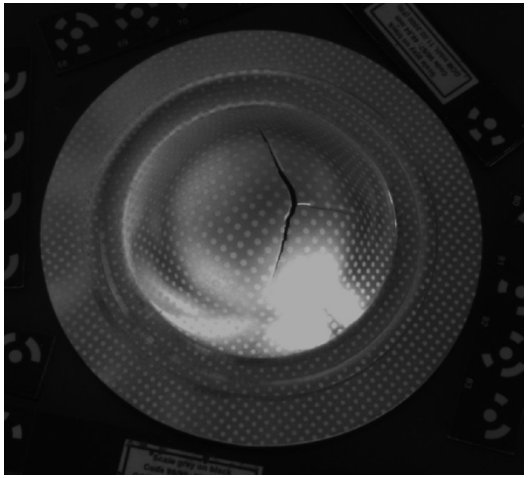
Experimental investigations

Material / Specimen dimensions

- EN AW-5083 (AlMg4,5Mn)
- Rolled sheet metal / thickness 1 mm
- Geometry according to DIN EN ISO 12004-2
- Specimen diameter of 100 mm
  (50% DIN EN ISO 12004-2)
- Specimen width varied 10 - 100 mm (full circle)
- Ø1 mm dot pattern by laser engraving





Forming analysis

- Specimens tested to fracture
- Strains of fractured specimens evaluated by Optical Forming Analysis with ARGUS System by GOM mbH

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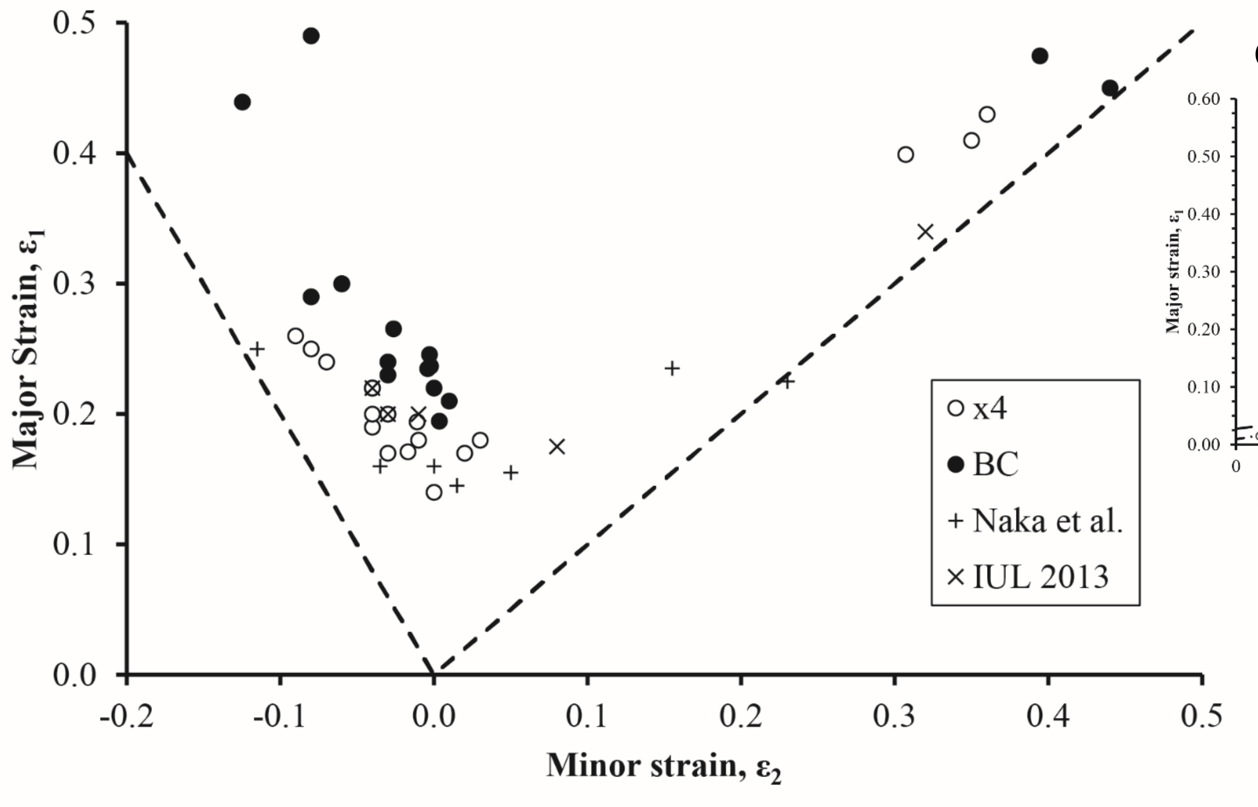
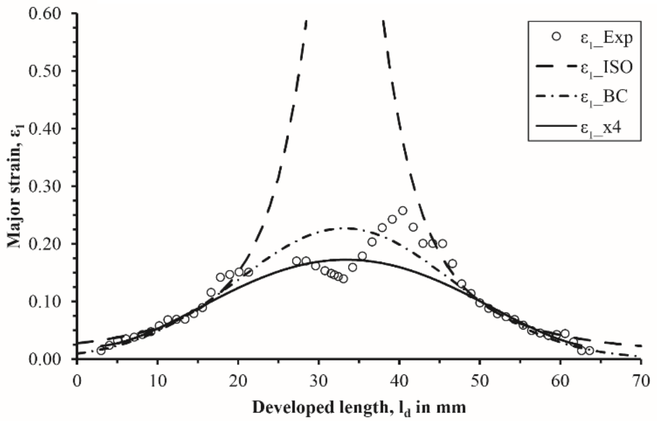
Forming limit diagram

- Results at low speed in good accordance with other researchers
- Forming device and specimen geometries are sufficient to determine FLCs



Comparison of curve-fit methods



x4: 4th order parabolic fit

BC: bell-shaped curve fit

Naka, T., Yoshida, F., 1998. Effect of temperature and forming speed on deep drawability of 5083 aluminium alloy sheet. Metals and Materials 4, 464–466.
IUL 2013: Unpublished / Ø100 mm punch / BUP 1000 by Zwick / Inst. of Forming Technology and Lightweight Construction (IUL), TU Dortmund
Own results from: Kiliclar et al., 2015, submitted to JMPT

High speed testing

Parameters

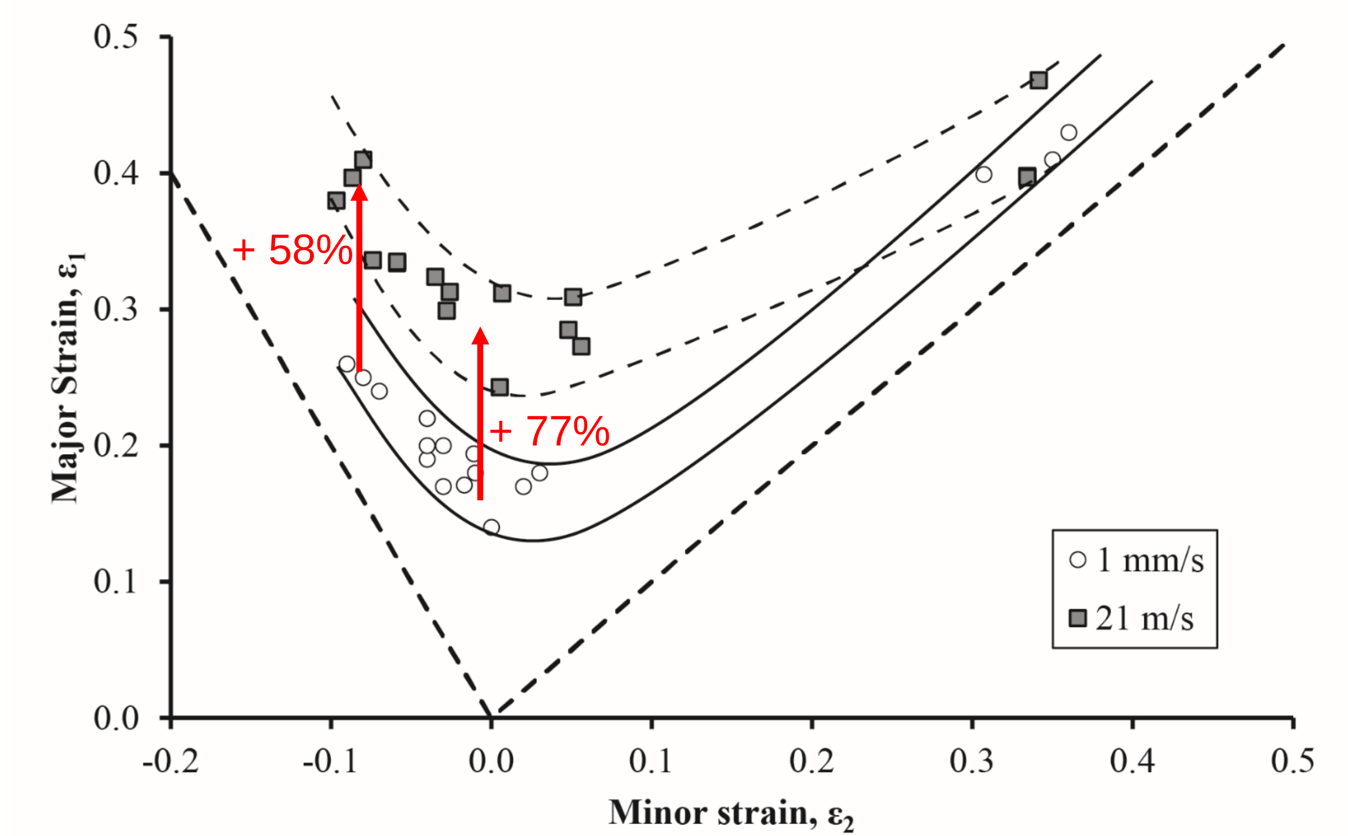
- Speed measurements showed limitations in minimum and maximum punch speed as well possible fracture of punch stem
- Aimed punch speed for first high speed testing set to air pressure of 150 bar without shear pin stating lowest parameters for reproducible punch speeds

➔ **Punch speed of approximately 21 m/s and specimen geometries of 10 mm, 25 mm, 35 mm, 45 mm, 60 mm as well as full circular specimens (100 mm) were chosen for the high speed testing**

High speed testing

Forming limit diagram

- Results show increased formability at a punch speed of 21 m/s for $\varepsilon_2 \leq 0.05$
- No change in strain paths



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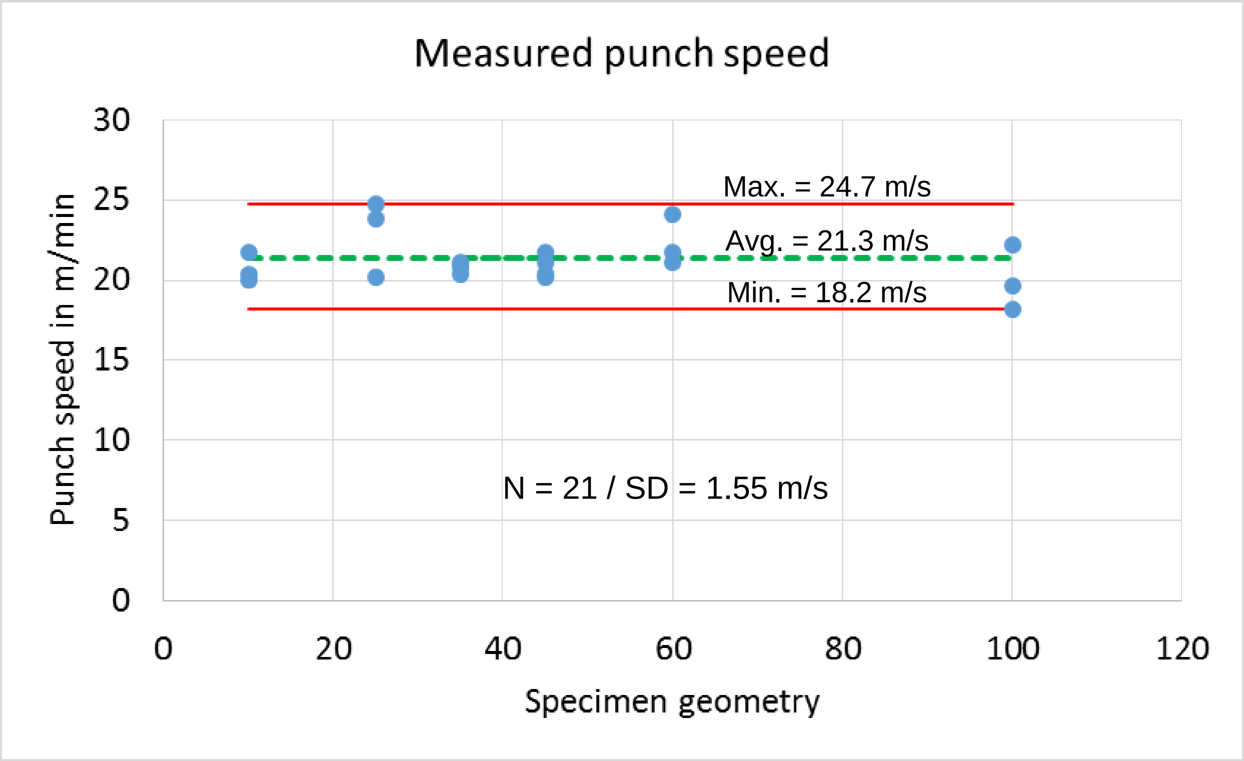
High speed testing

Speed measurements

- Punch speed for an air pressure of 150 bar and no shear pin varies between 18.2 m/s and 24.7 m/s with an average of about 21.2 m/s
- Standard deviation is 1.55 m/s (7.3 %)



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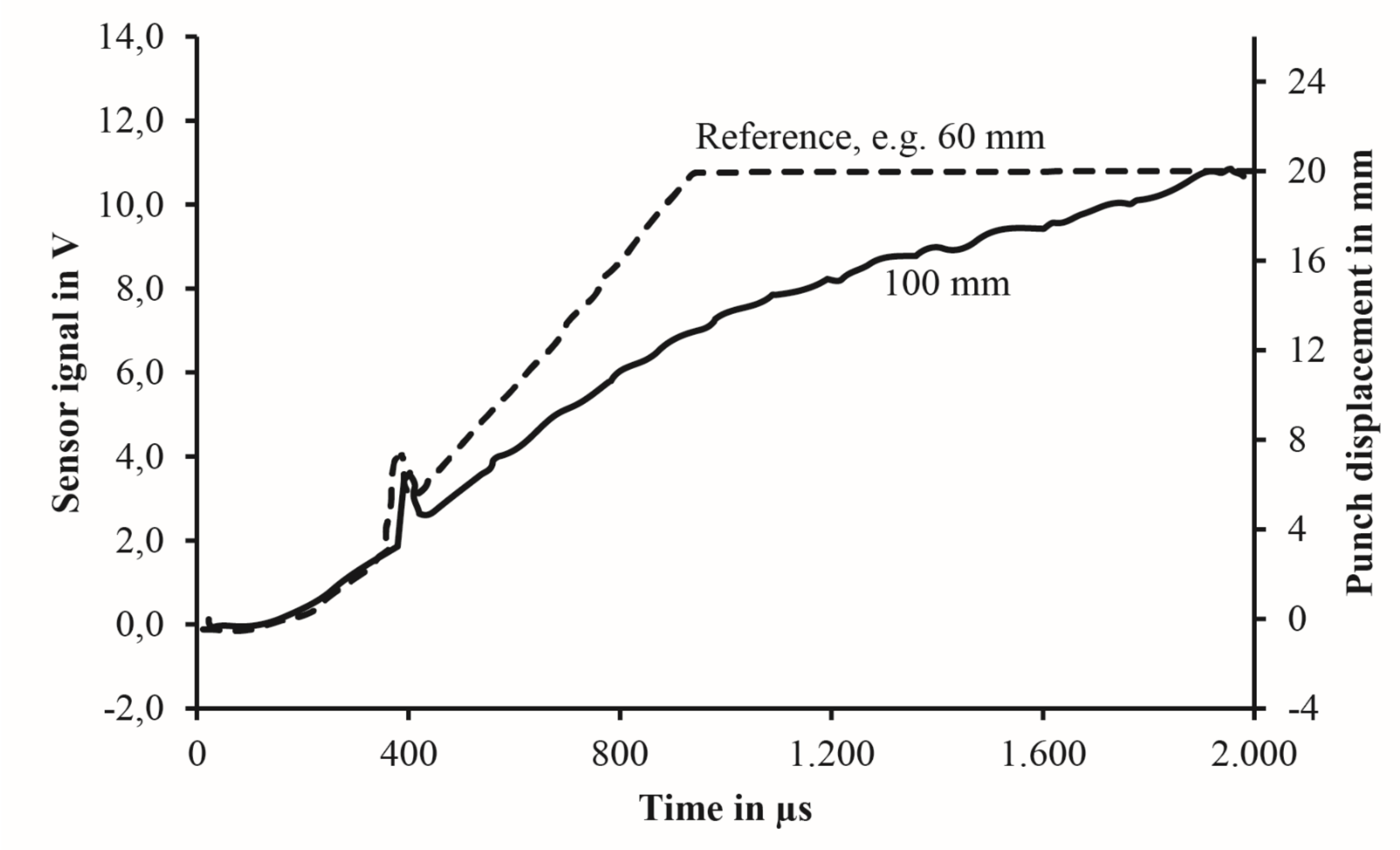
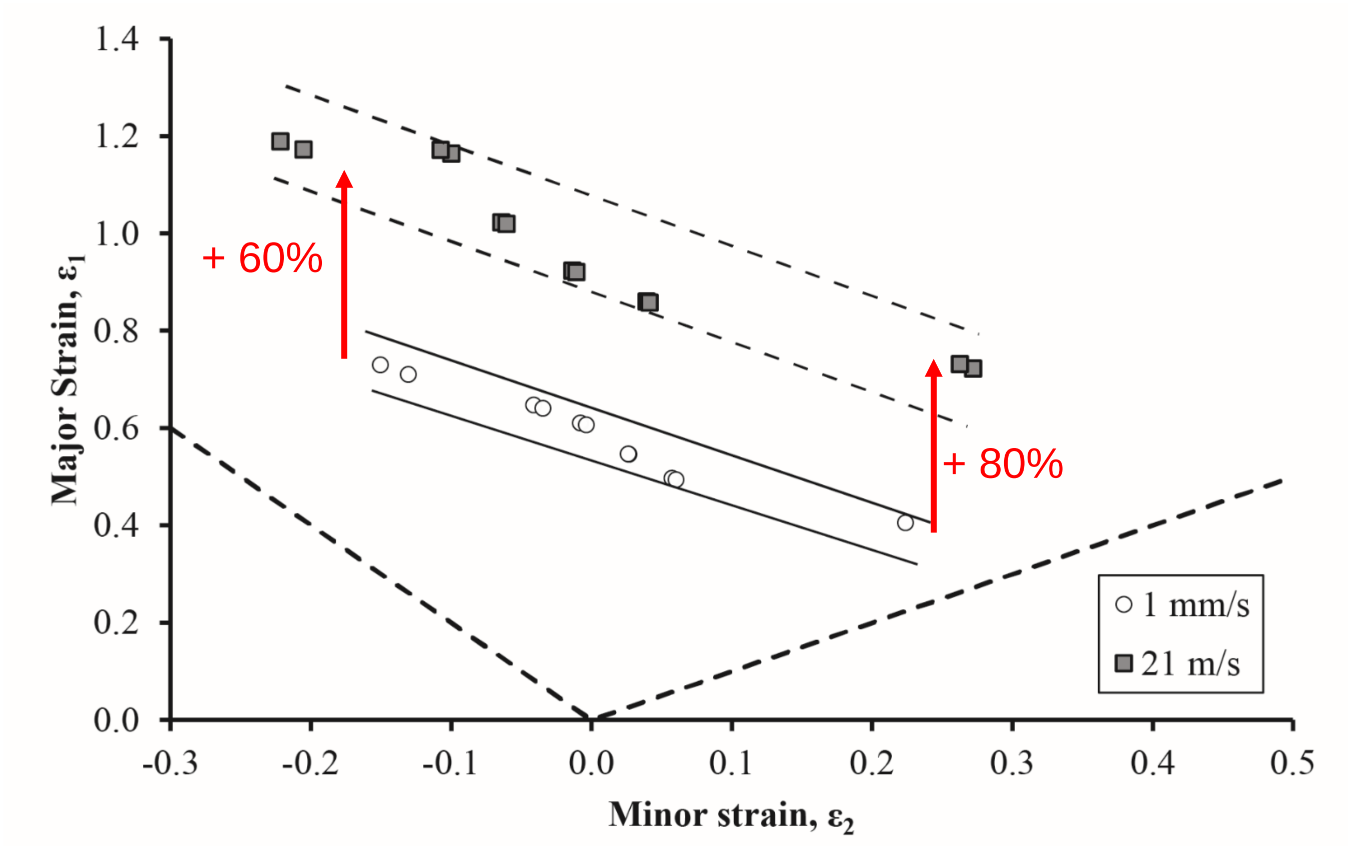


Kiliclar et al., 2015, submitted to JMPT

Fracture forming limit diagram

- Results show increased strains at a punch speed of 21 m/s
- Improvement for simple tension as well as biaxial tension



Kiliclar et al., 2015, submitted to JMPT

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Summary

- The design of a pneumatic-mechanical forming device for testing of forming limits at low (< 10 mm/s) and high punch speeds (>20 m/s) for sheet metal has been presented
- Experiments with different settings were executed to define the limitations of the forming device
- The forming device has proven capable of punch speeds higher than 50 m/s but further experiments are needed to evaluate the maximum capability of the forming device
- FLCs and FFLCs for a 1 mm thick EN AW-5083 aluminum alloy sheet metal at low (1 mm/s) and high (21 m/s) punch speeds were determined
- Results show increasing formability at high punch speed
  → ε_1 is significantly higher than that at low speeds (for $\varepsilon_2 \leq 0.05$)

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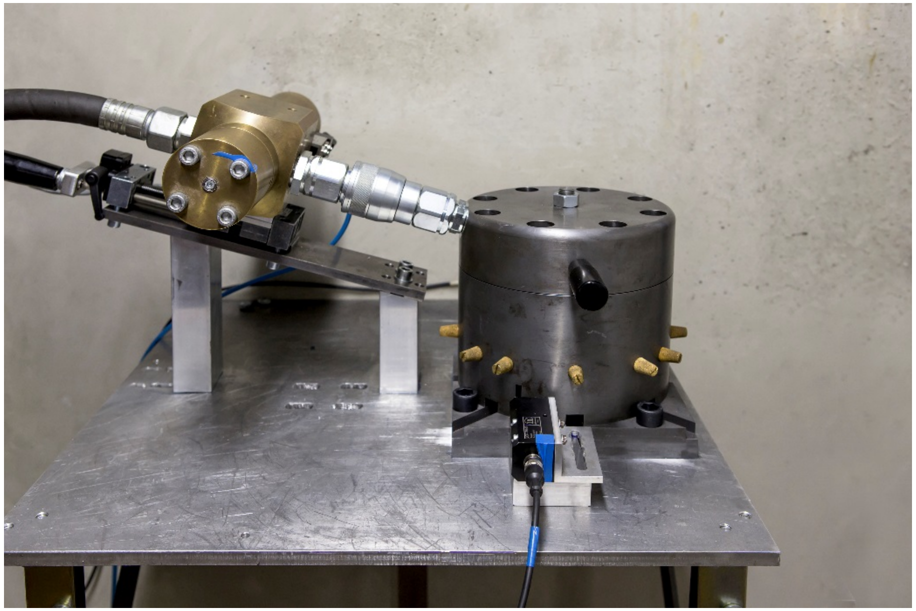
Outlook

- To gain a deeper insight in the mechanisms leading to higher formability at high speeds further analysis of
  - changes in sample thickness,
  - microstructure and textures,
  - pore evolution etc.

  is needed
- Improvement of the design of the forming device for improved reliability of parts at higher punch speeds



Acknowledgement

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DFG Deutsche Forschungsgemeinschaft

PAK 343 Methodenplanung