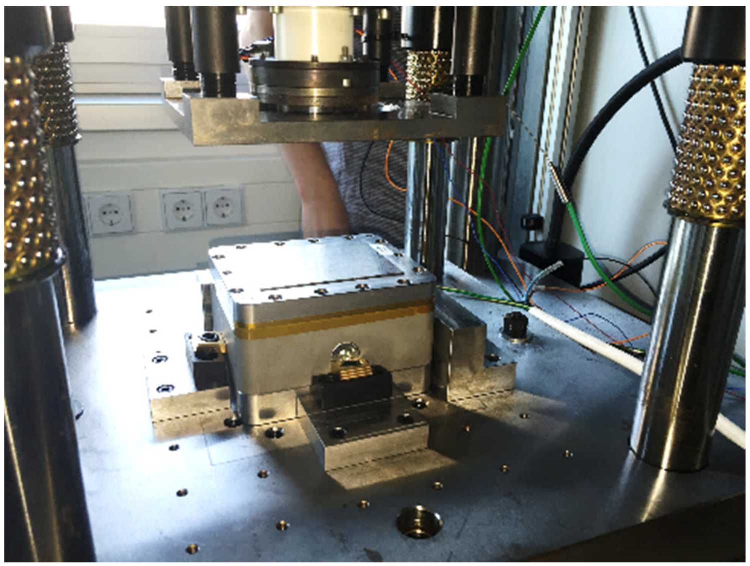
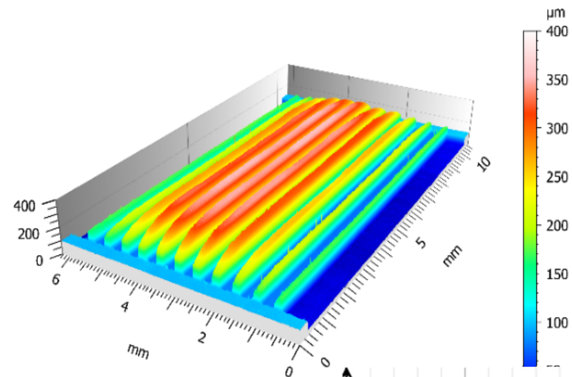
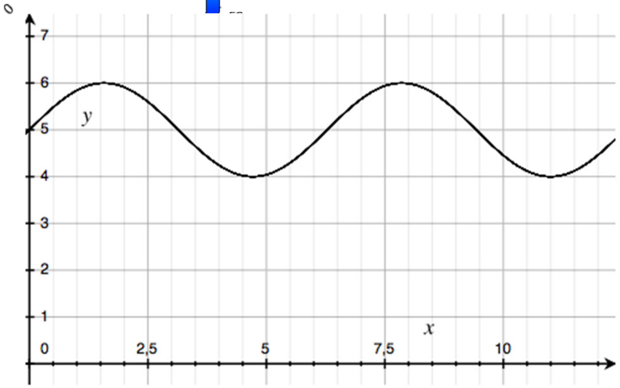
Collaborative Research Centre/Transregio 39 PT-PIESA
High-Volume Production-Compatible Technologies for Light Metal and Fibre Composite-Based Components with Integrated Piezoceramic Sensors and Actuators

Technology development and control concept for vibration assisted forming of micro-channels in aluminium sheets







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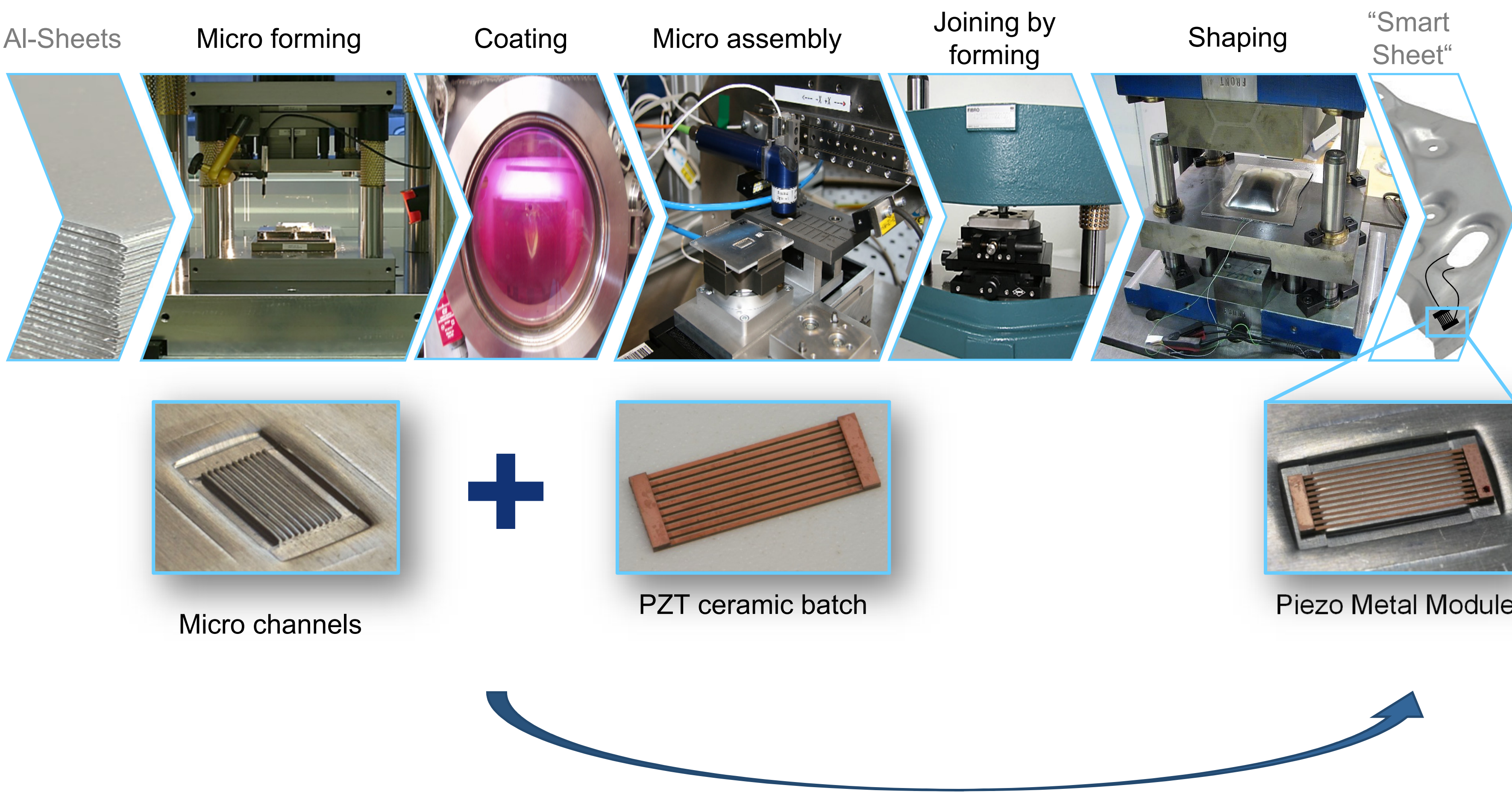
Outline

- **Motivation**
- Experimental Procedure
- Integration of Piezo Actuator
- Results
- Summary and Conclusions

Motivation I

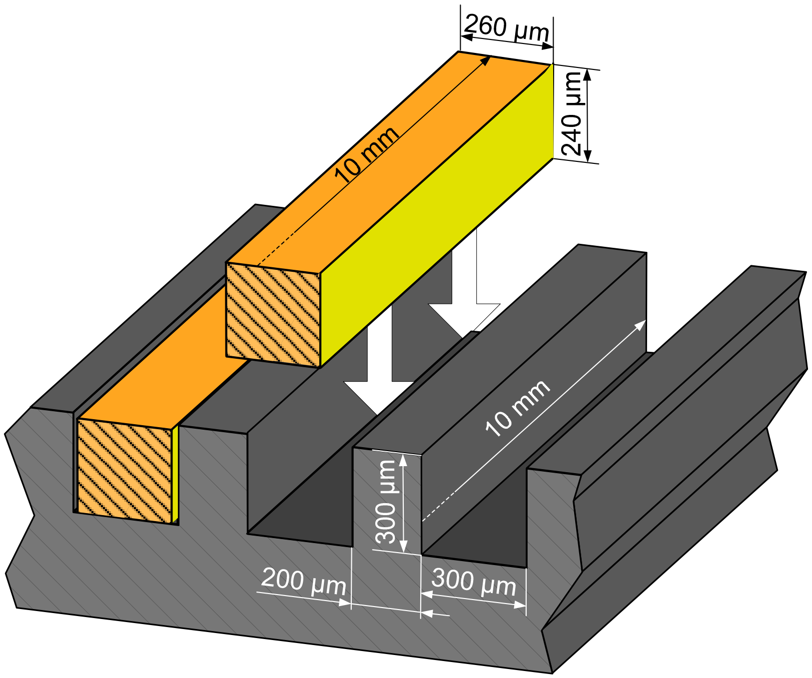
Process Chain

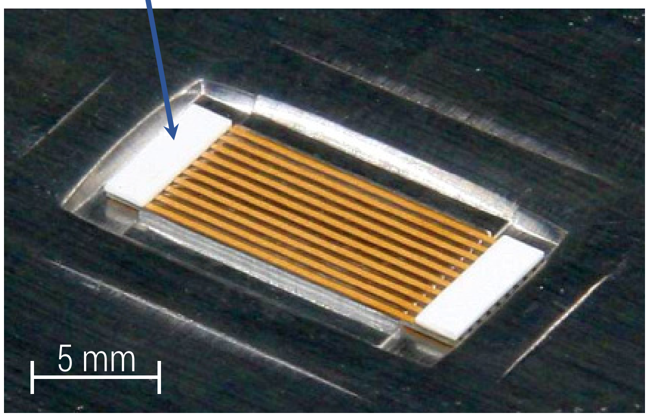


Motivation II

Piezo Metal Module – Design principle

- PZT ceramic batch → 10 elements
- Rod dimensions: 0.26 × 0.24 × 10 mm^3
- Centre interface electrode for polarisation
- Collecting electrode for electrical interconnection





Objectives in forming of micro channels:

- **High** degree of deformation at **lowest possible** forming forces → **low bulging** and **low cross-sectional influence** of the sheet
  - Friction reduction: vibration assisted micro forming
  - Relative motion between tool and sample → improved lubrication transport

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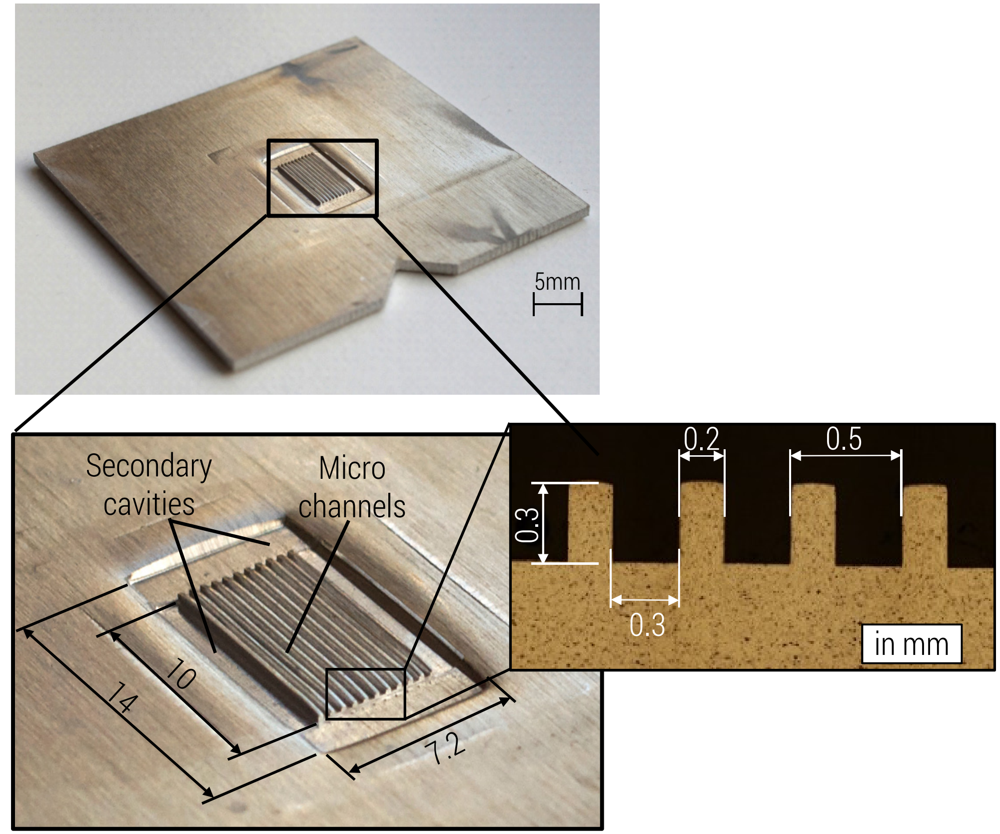
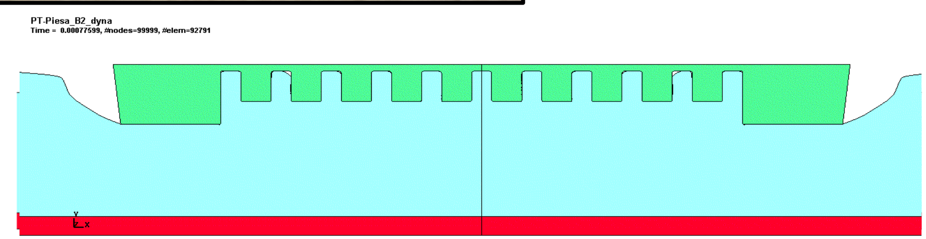
Micro structured aluminium sheet:

- Alloy: AlMg4.5Mn0.7 (EN AW-5083)
- Sheet thickness d_0 = 1.5 mm
- 10 channels: 0.3 × 0.3 × 10 mm^3 (each)
- Secondary cavities: collecting electrode and flow barrier

Structural demands / challenges:

- Uniform material flow over the entire structure
- Thin webs
- Steep flanks
- Low surface roughness values at channel wall and ground
- High reproducibility: sheet to sheet and pitch



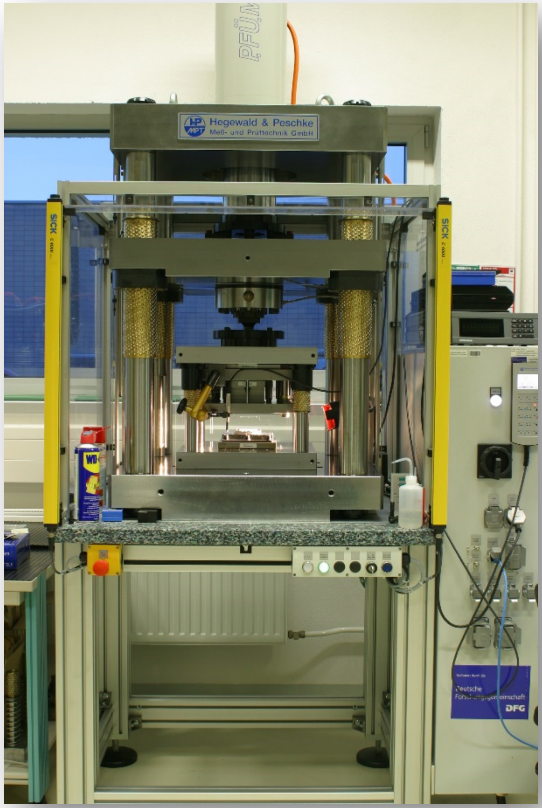


Neugebauer et al.: Deep Drawing of Metal Sheets with Integrated Piezo-Metal Substructures. *Proceedings of the 4th Scientific Symposium of the CRC/Transregio 39, Nuremberg* 2013, pp. 37-42

Experimental Procedure II

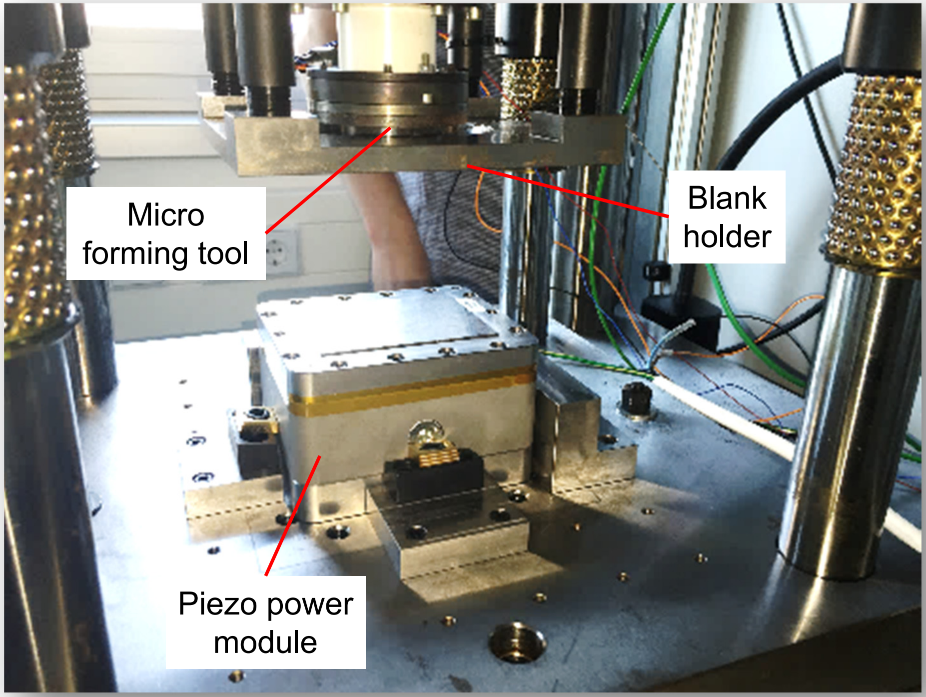
Precision forming press:

- 200 kN servo precision press
- Force or position controlled
- Position accuracy: 1µm



Piezo actuator:

- CeramTec Piezo Power Module
- Parallel connection of several piezo stacks, hermetically housed
- Blocking force *F* = 80 kN
- Frequency *f* up to 50 Hz
- Vibration assistance during entire forming process



Experimental Procedure III

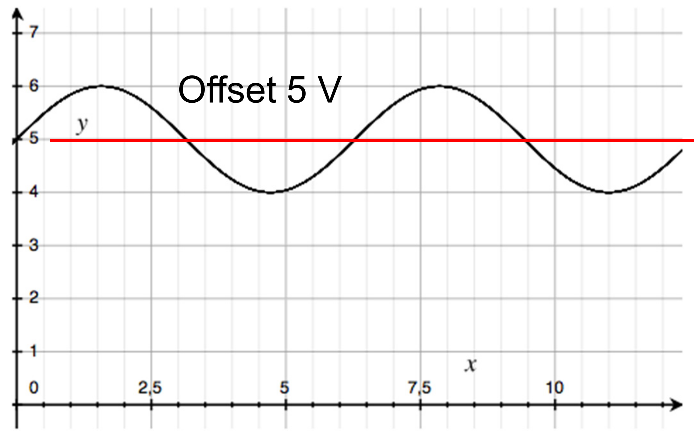
Test parameters and characterization

- Reference samples
  → without vibration assistance
- 2 samples for each parameter set
- Characterization:
  - Optical measurement
  - Channel depth (main characterization parameter regarding material flow)
  - 3D profiles

Parameter	Values
Forming force	70 kN
Frequency *f*	(10; 20; 50) Hz
Amplitude of sine input signal *y*	(1.25; 2) V
Lubrication	Fuchs Plantoform MBO 2797 (viscosity: 49 mm^2/s); OEST Platinol V 1937/11 (viscosity: 163 mm^2/s)

Measuring microscope

3D laser scanning microscope



Sine wave used for vibration assistance

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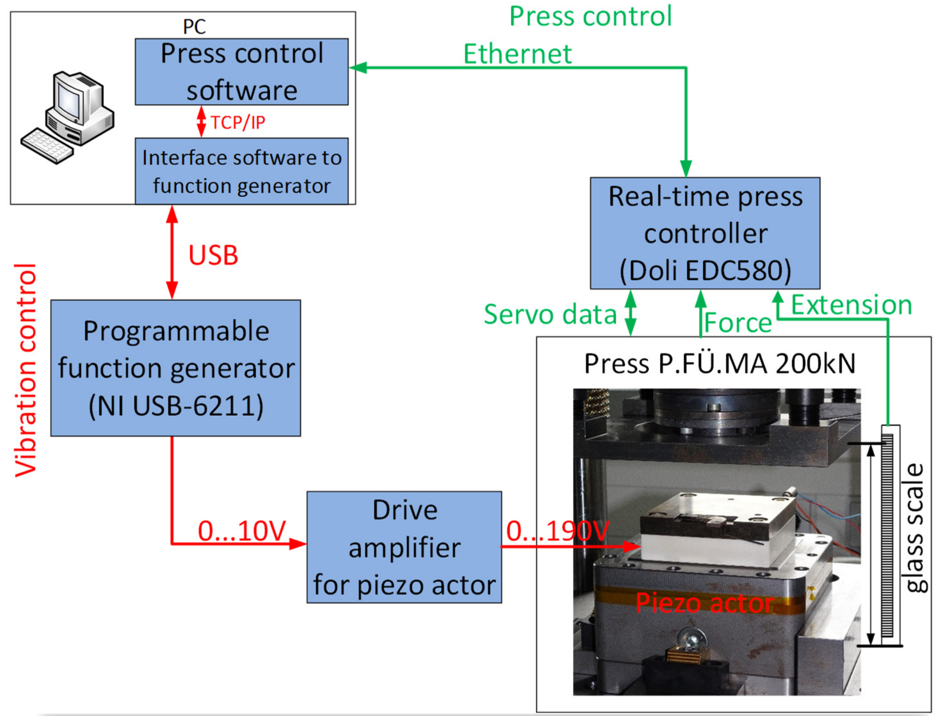
Integration of piezo actuator into the control system of the press

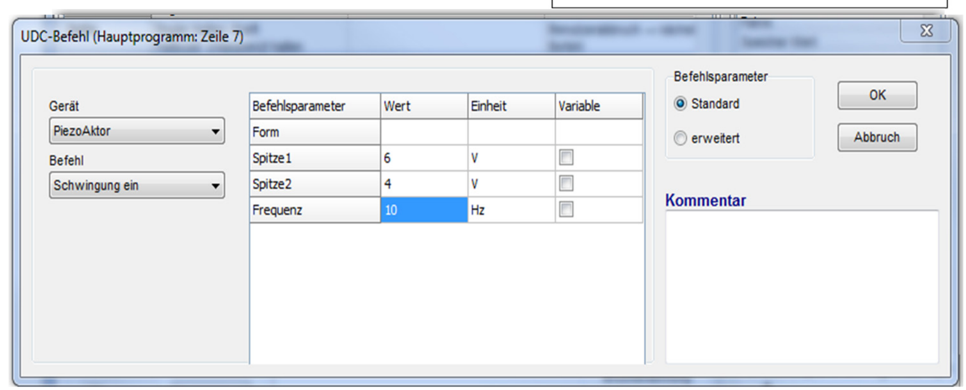
Hardware

- Drive amplifier for piezo actuator with analogue input for command signal
- Programmable function generator with 0...10 V output and USB-interface to industry PC for press control

Software

- Interface software (LabVIEW) to programmable function (via USB) generator and press control software (via TCP/IP)
- Command definition for integration of piezo actuator control in block programme:
  - Waveform definition (form, amplitude, offset, frequency)
  - Vibration: On / Off





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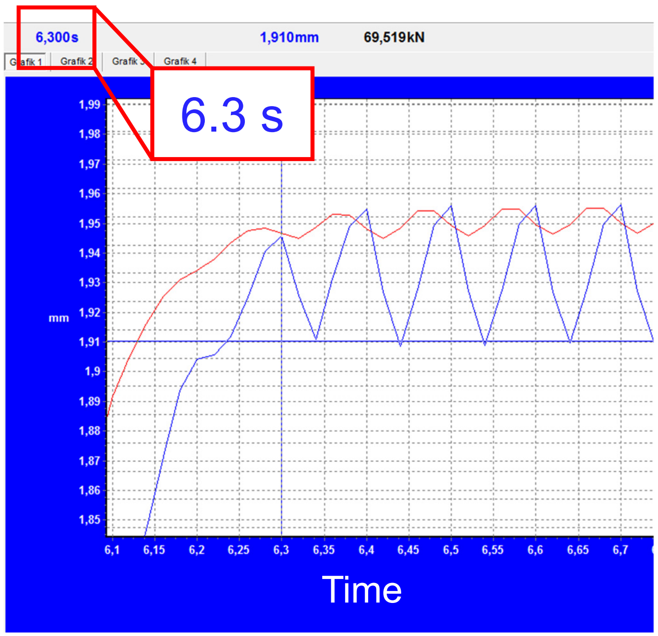
Results I

Characterization of Piezo actuator during forming process (frequency *f*)

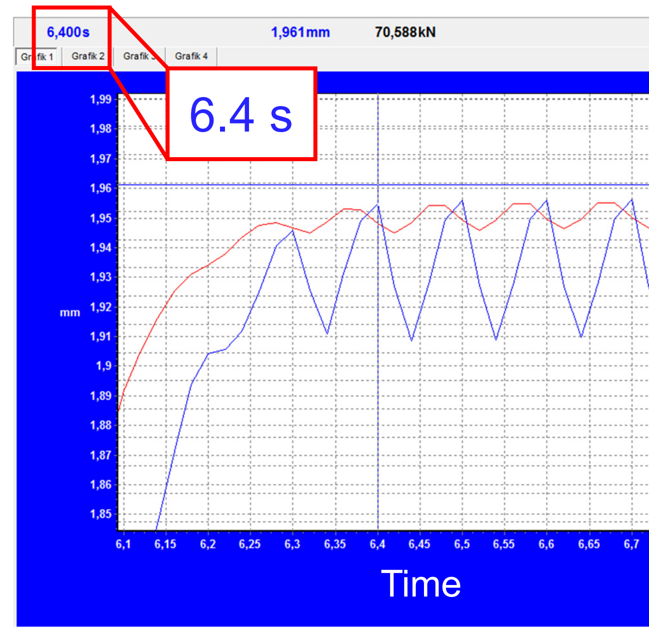
- Real time data from the press control
- Test at F = 70 kN with f = 10 Hz



$$\Delta T = 0.1s$$

$$f = \frac{1}{T}$$

$$f = 10\ Hz$$

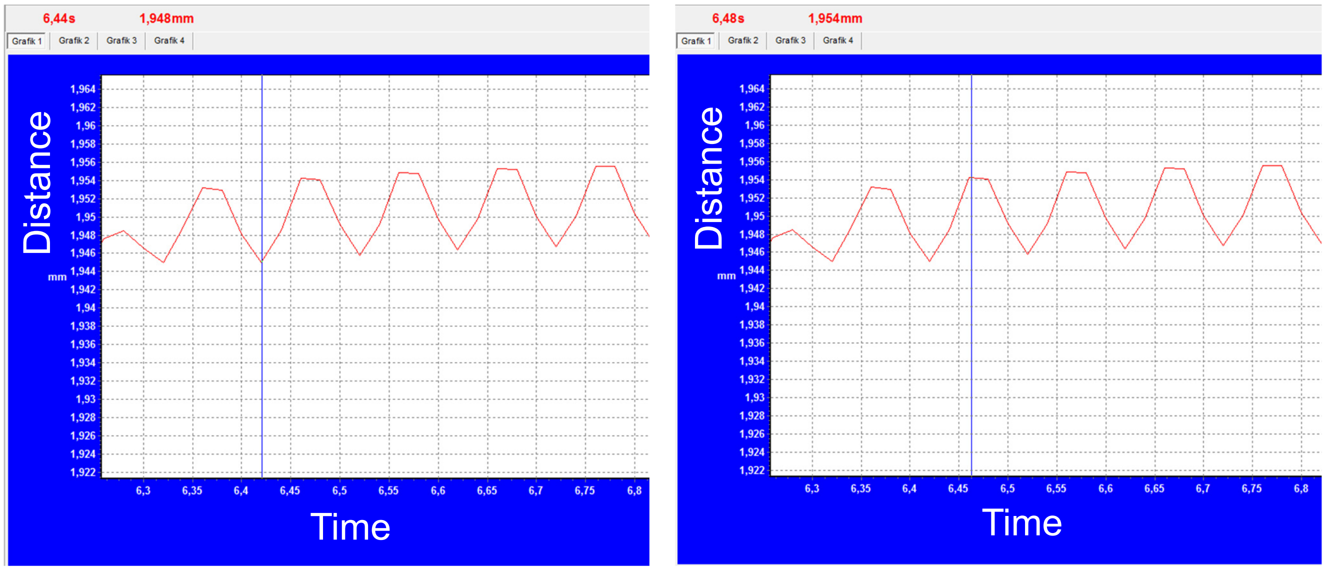


Real time data from the press control; Force vs. time (blue line)

Results II

Characterization of Piezo actuator during forming process (amplitude *y*)

- Real time data from the press control



$$y = 1.954\ mm - 1.948\ mm$$

$$y = 6\ \mu m$$

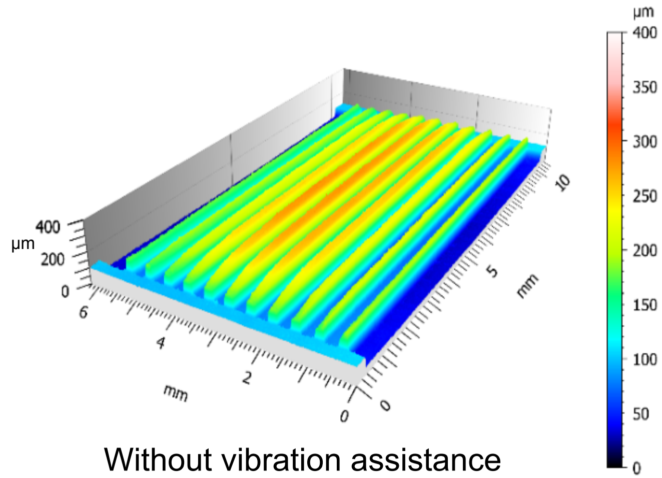
Real time data from the press control; Distance vs. time (red line)

F = 70 kN

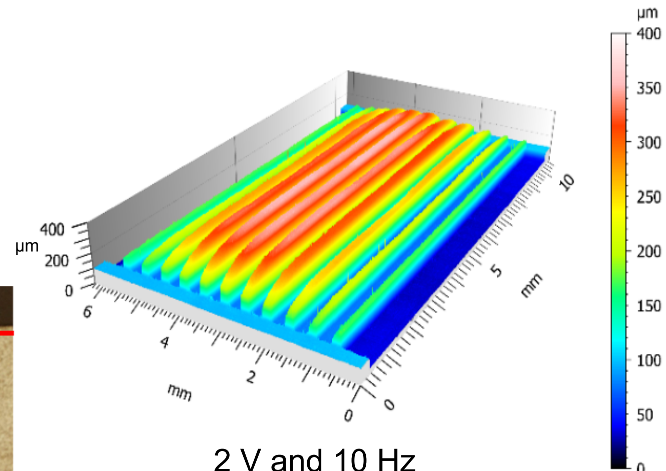
Parameter	Amplitude
10 Hz; 1.25 V	5…6 µm
10 Hz; 2 V	9 µm
20 Hz; 1.25 V	2 µm
20 Hz; 2 V	3…5 µm

Results III

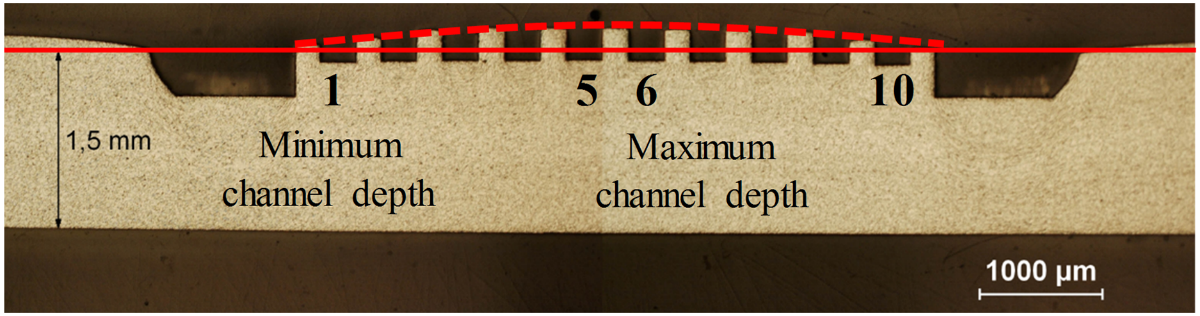
- At F = 70 kN not enough stress is induced into the sample to generate a complete uniform channel array (dashed line, figure below)
- Beginning of the forming process: material flow starts in the middle of the structure (channel 5 and 6) → highest structure depths
- Deformation starts at the edge of the structure (channels 1 and 10) at the latest → lowest channel depths
- Parameter: "Maximum channel depth" → deepest channel of a sample
- Parameter: "Minimum channel depth" → lowest channels at border of the structure



Without vibration assistance



2 V and 10 Hz

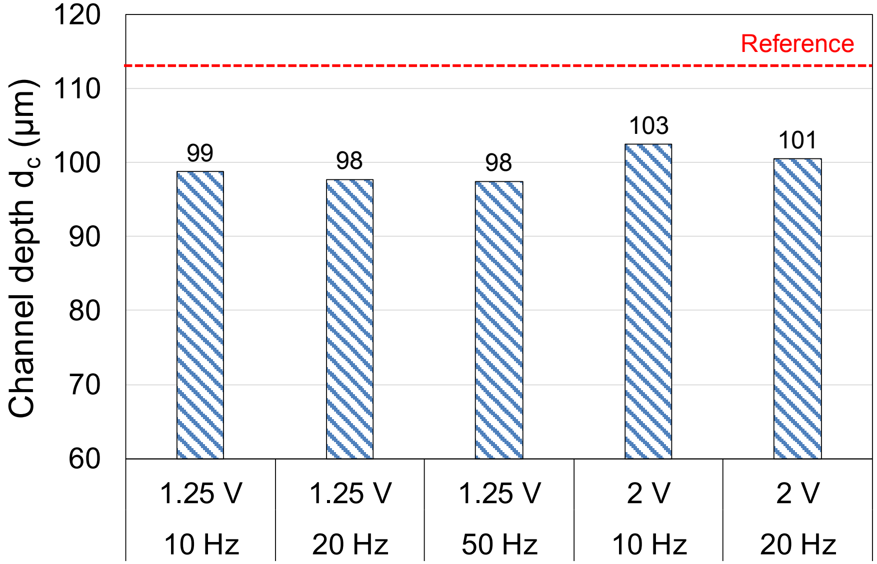


Results IV

Results with forming oil Plantoform

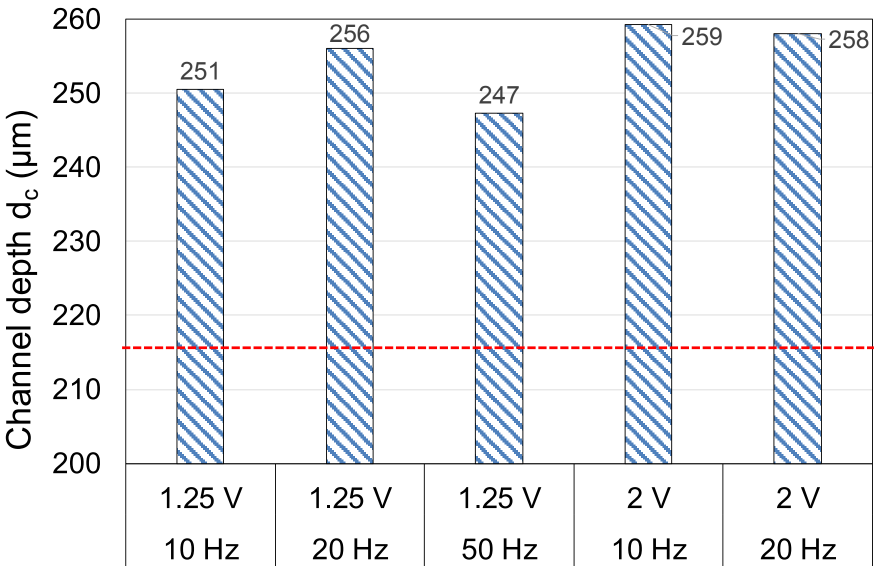
Minimum channel depths

- Increasing frequency *f* → no significant influence
- Increasing oscillation amplitude *y* → higher minimum channel depths are achieved
- Minimum channel depths of all vibration-assisted samples are significantly below the reference (9…14 %)



Maximum channel depths

- No clear influence of the frequency onto the channel depth
- Results with higher oscillation amplitude show slightly higher channels depths
- At the centre of the structure all vibration assisted samples show a significant improvement compared to the reference



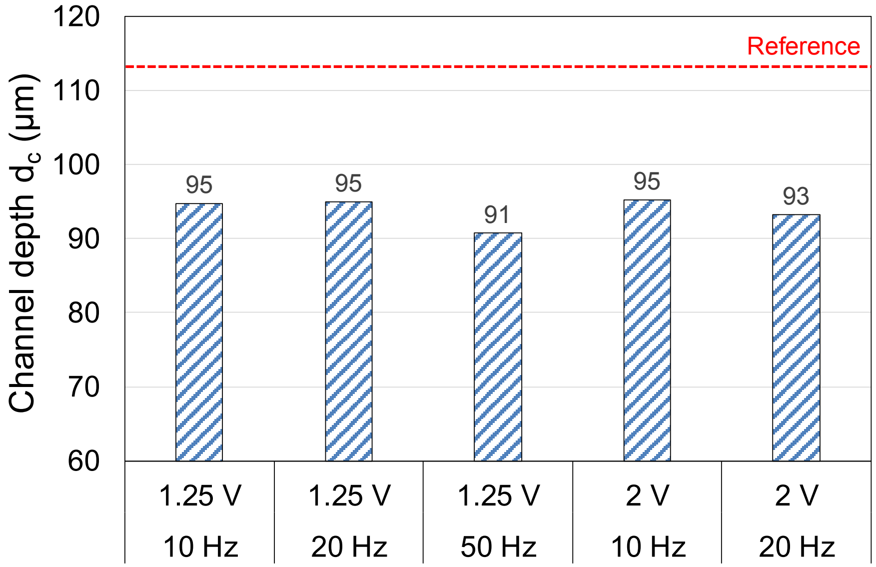
Results with forming oil Platinol

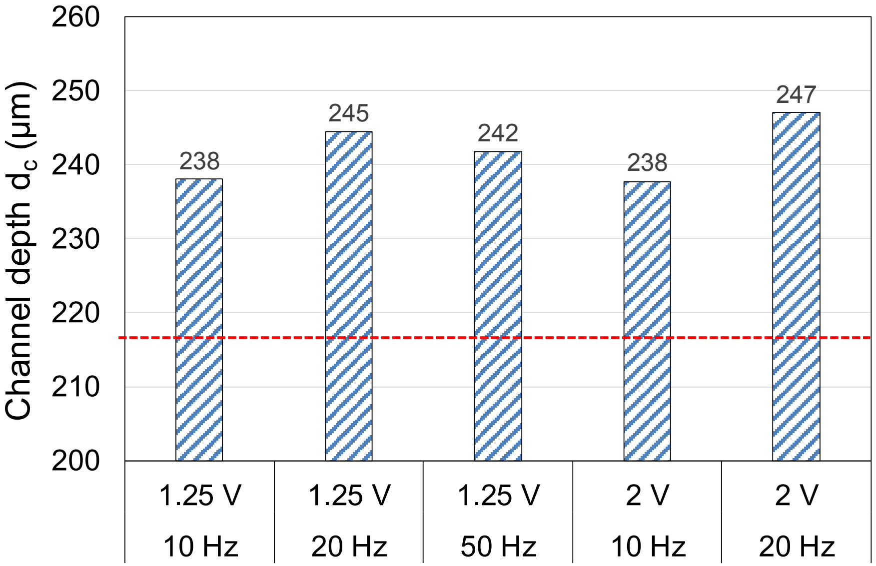
Minimum channel depths

- Minimum channel depths are also below the reference
- Channel depths of none parameter combination exceeds d_c = 95 µm, whereas this is the case for all experiments with Plantoform

Maximum channel depths

- Best channel depths of the Platinol test series (d_c = 247 µm) is not better than the lowest Plantoform result (d_c = 247 µm)
- All maximum channel depths of vibration assisted Platinol samples are above the reference value





Results VI

“Thin oil” Plantoform

	Overall mean channel depth / µm	Δd_c / µm	Increase
Ref.	170	47	-
1.25 V 10 Hz	182	69	7.1 %
1.25 V 20 Hz	184	72	8.2 %
1.25 V 50 Hz	179	68	5.3 %
2 V 10 Hz	191	68	12.4 %
2 V 20 Hz	186	72	9.4 %

“Thick oil” Platinol

	Overall mean channel depth / µm	Δd_c / µm	Increase
Ref.	170	47	-
1.25 V 10 Hz	175	63	2.9 %
1.25 V 20 Hz	180	65	5.9 %
1.25 V 50 Hz	172	69	1.2 %
2 V 10 Hz	174	63	2.4 %
2 V 20 Hz	178	69	4.7 %

- Stronger improvement with low viscosity oil
- Nearly all parameter setups with Plantoform result in higher increase in mean channel depth compared to Platinol

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Summary and Conclusions

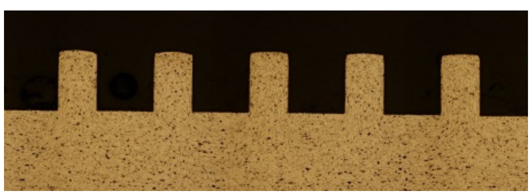
- Experiments concerning vibration assisted micro forming of channels into aluminium sheets were conducted.
- Therefore, lubrication conditions, the oscillating amplitude and the frequency were varied and their influence onto the achievable channel depth and the material flow was studied.
- The vibration assistance in combination with the low-viscosity forming lubricant Plantoform shows a significant improvement regarding deeper channels compared to reference samples.
- A slight trend that a higher amplitude can lead to deeper channels was found.
- With the vibration assistance a larger deformation or material flow could be achieved → improvement in channel depth d_c, slightly more than 12 %.

Summary and Conclusions

Results for forming of micro channels

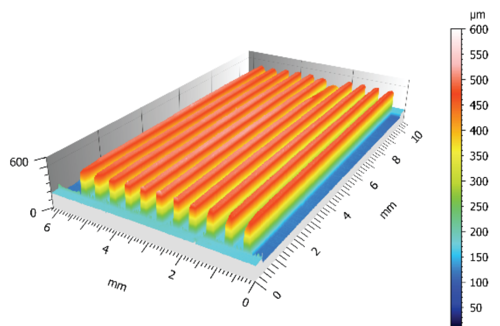
Cold micro forming

- Nearly complete tool filling at *F* = 105 kN
- High tool loads
- High elastic deformation for steel tools
  - Tungsten Carbide tools → brittle



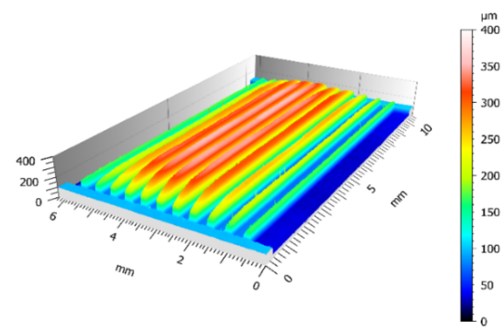
Warm micro forming

- Formed at ϑ = 200 °C
- Even material flow over entire structure → same height of the structure in cross section and longitudinal
- **Complete** tool filling at *F* = 80 kN



Vibration assisted micro forming

- Friction reduction compared to cold forming without vibration
- Limited to *F* = 70 kN (due to actuator)
- Non complete tool filling



Thank you for your attention

The authors thank the
German Research Foundation
for the financial support.