Development of fuel cell stacks and their optimization in terms of production technology with long tool life

11 April 2024

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5th WORKSHOP Forming and Punching

Motivation

Green value chain - production and utilization of hydrogen

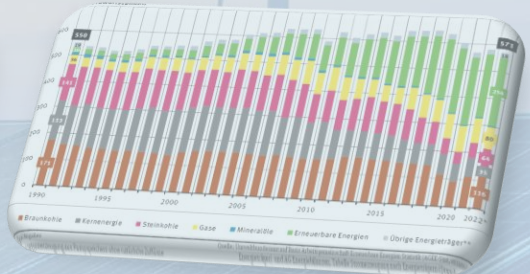
- **H_2** is suitable as a **practical storage element** for energy
- **H_2** enables the **storage of large amounts of energy**
- **H_2** is suitable for use in various areas of mobility, heating (building technology), industrial processes, etc.

$$\eta_{H_2O\text{-Electrolysis}} \sim 70 - 95\ \%$$

Schiffenen Dam in Fribourg, Western Switzerland.(Picture: Groupe E)

Source: Graphic by Andreas Mohrmann

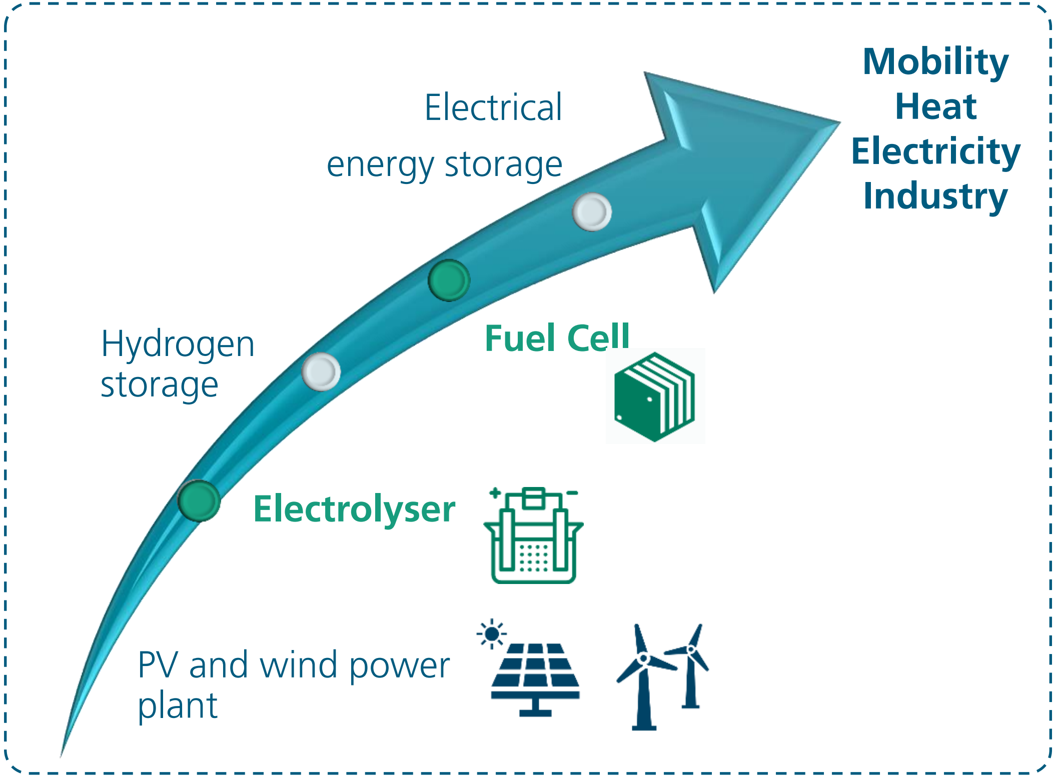
Source: Fraunhofer ISE



Source: Umweltbundesamt, 06844 Dessau-Roßlau.

Initial situation

Green value chain - production and utilization of hydrogen



- **The fuel cell is an essential part** of the green chain for the production and utilization of hydrogen
- The central task of **production** engineering is the development of manufacturing technologies for the **mass production of highly efficient and cost-effective fuel cells**
- A key core element in fuel cells is the **bipolar plate (BPP)**

Initial situation

Bipolar plates - Tasks and functionalities

Tasks

- Manage media flow to membrane
- Manage coolant flow
- Collect electrical current
- Carry sealing
- Carry connectors

Fig.: BPP - IWU Design for PEM-Fuel-Cell

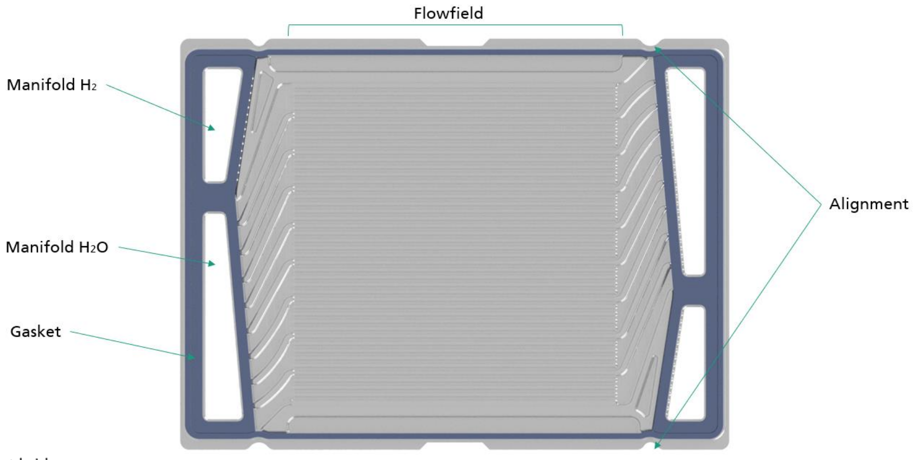


Fig.: BPP - IWU Design for PEM-Electrolyzer-Cell

Initial situation

Bipolar plates - Design process

Challenge

- Get best compromise between function, flow and formability
- Manage huge, detailed models

Focus

- Formability
- No cracks, less thinning
- Less wrinkles

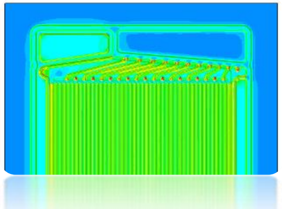
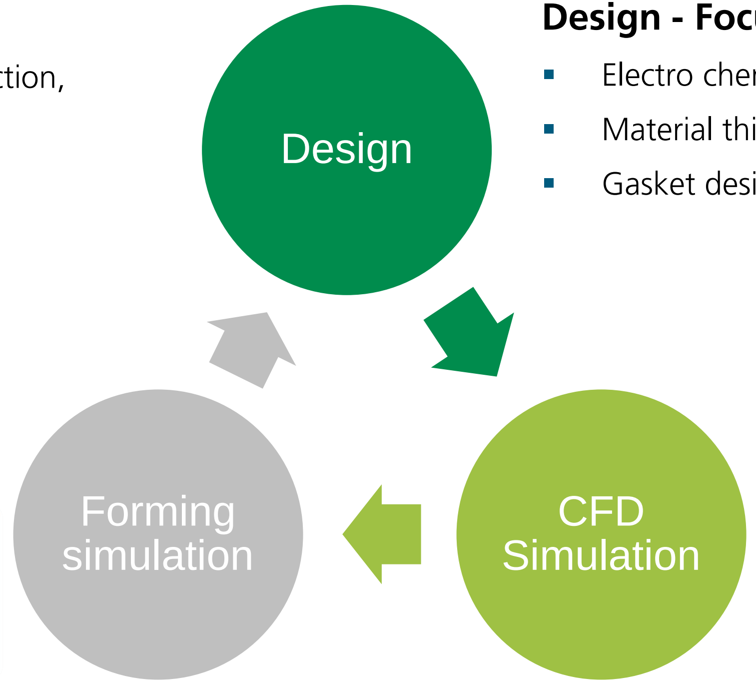


Fig.: Forming simulation for PEM - Electrolyzer



Design - Focus

- Electro chemical functionality
- Material thickness
- Gasket design

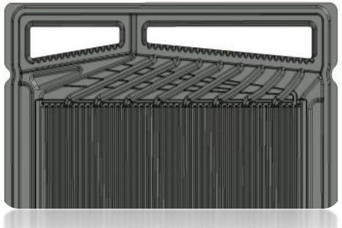


Fig.: BPP - IWU Design for PEM - Electrolyzer

CFD - Focus

- Equal flow distribution
- Low pressure drop
- Low eddies

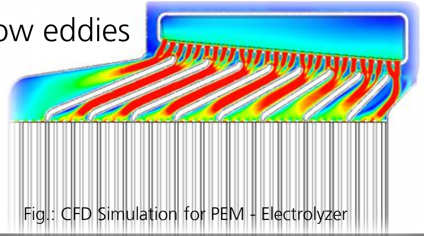


Fig.: CFD Simulation for PEM - Electrolyzer

Initial situation

Requirements for Bipolar Half Plates Forming Processes

Challenges

- Material Titan or Stainless Steel thickness 50 – 100 µm (PEM-Fuel Cell)
- Forming process requires **highest dimensional and shape accuracy < 5 µm as well as surface quality on the forming tools**
- Tooling and process technology must meet these requirements
- Tool life of the active parts

Boundary conditions for tooling

- Profile shape tolerance +/-5 µm
- Roughness depth Rz < 2.0 µm

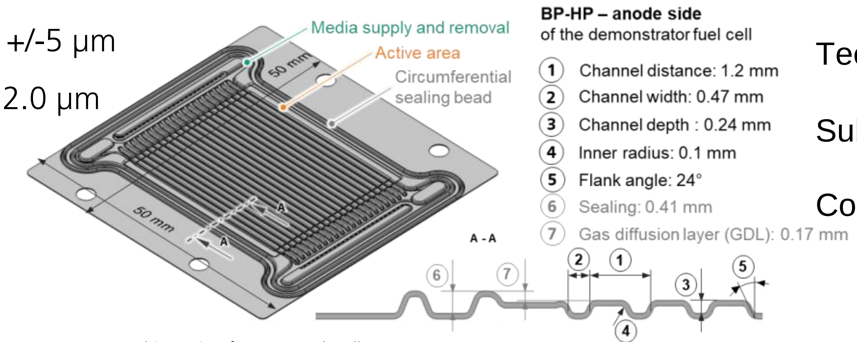


Fig.: BPP - IWU&ISE Baltic Design for PEM-Fuel-Cell

Flatness

Process-specific different springback effects

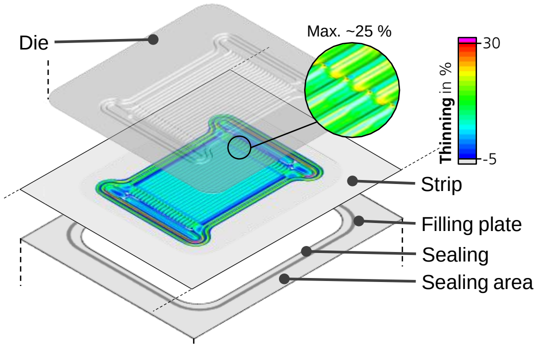
Forming process

Semi-finished product	Thinning
Technology	Wrinkling
Subsequent processes	Flatness
Component transport	Production rate

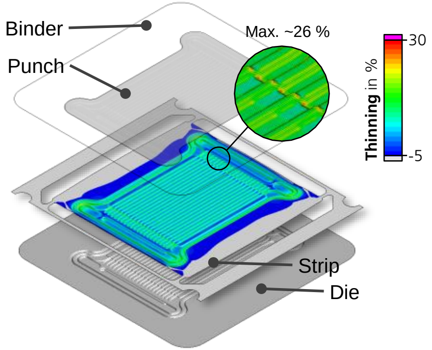
Forming Technologies for metallic Bipolar Half Plates (BP-HP)

Process comparison

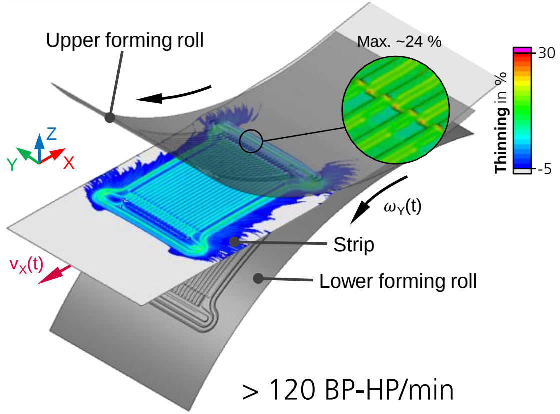
Hydroforming	Hollow embossing	Hollow embossing rolling



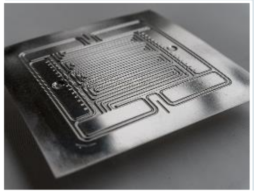
Production rate: 7 BP-HP/min
(without parallelization)



30 - 60 BP-HP/min

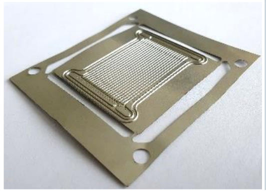


> 120 BP-HP/min



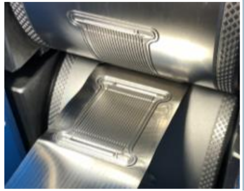
- Only one die set
- High BP-HP quality
- Potentials by passive hydroforming

Small batch size



- Higher production rate
- Most established industrial forming technology

Medium batch size



- Lowest process forces and energy consumption
- Currently low TRL

Mass production potential

Forming Technologies for metallic Bipolar Half Plates

Process comparison

Production of BPP by high-pressure sheet forming (HBU)

Process advantages:

- Only one mold active part required
- Fast prototype production
- High sheet flatness

Development approaches:

- Plant engineering (sealing concepts)
- Technology of the passive Hydroforming
  - Can be implemented on a wide range of presses
  - No external pressure intensifier
  - Increase in production rate

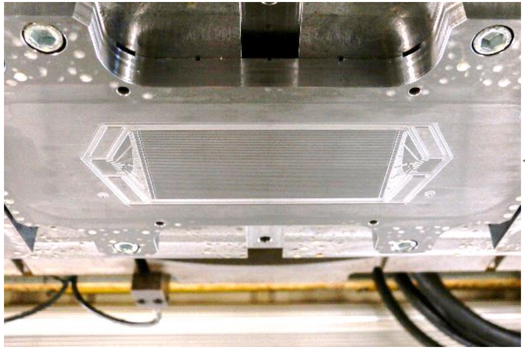


Fig.: Hydroforming tool in installed condition.

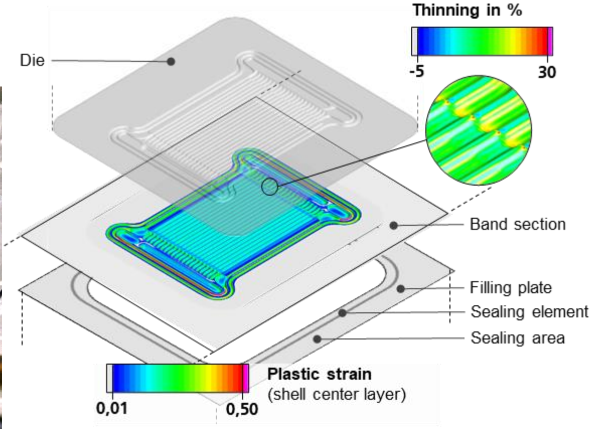
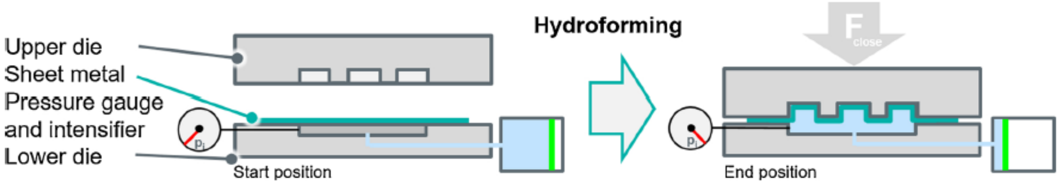


Fig.: Simulation of HBU process demonstrator geometry.



Reference: [Passives Hydroforming zur Herstellung von Bipolarplatten]

Production of BPP by hollow embossing forming

Process advantages:

- High-rate production technology
  → 30 – 60 BP-HP/min
- Comparable flatness to hydroforming

Development approaches:

- Shape and position tolerance of the tools
- Tool wear
- Synchronization with subsequent processes

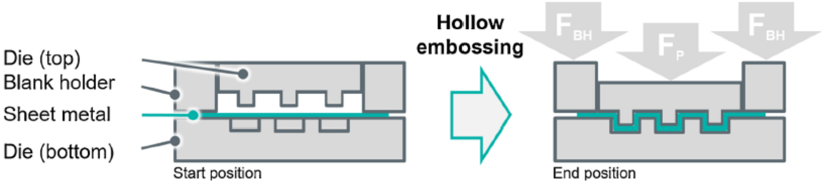


Fig.: Schematic representation of the hollow embossing forming process

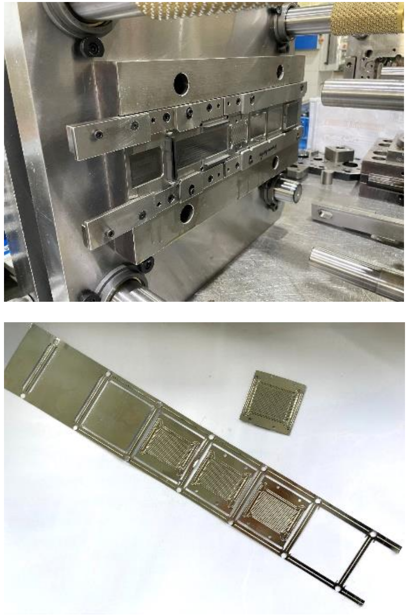


Fig.: Upper part of the progressive die and strip pattern for the hollow embossing process

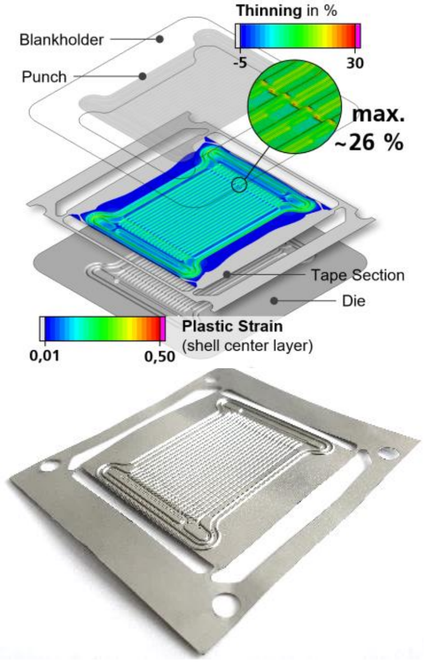


Fig.: Simulation of hollow stamping compared to real formed component

Production of BPP by hollow embossing forming

Hydraulic fineblanking press FB one 11.000 H2

- High-rate production technology
- High Forces up to 11.000 kN (1.100 t)

Start-up scheduled for November 2024

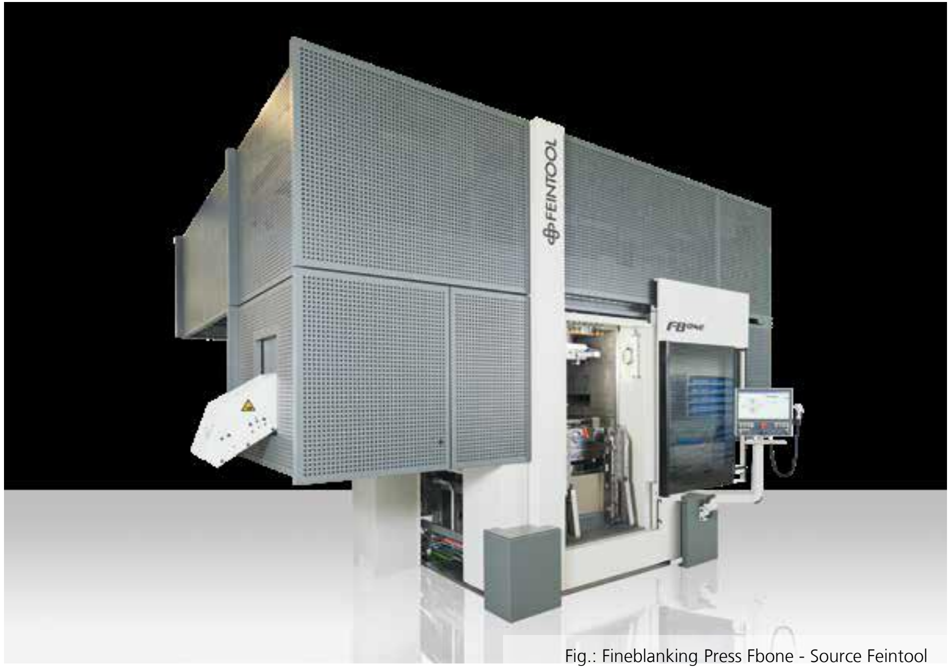


Fig.: Fineblanking Press Fbone - Source Feintool

Production line @ Fraunhofer IWU

Production of BPP by hollow embossing rolling

Process advantages:

- High-rate production technology
  → > 120 BP-HP/min
- Incremental process with low process forces

Development approaches:

- Robustness of the forming process
- Increase of the plate quality (flatness)
- Synchronization with subsequent processes

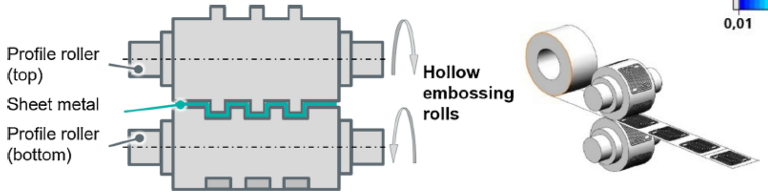


Fig.: Schematic representation of the hollow embossing rolling

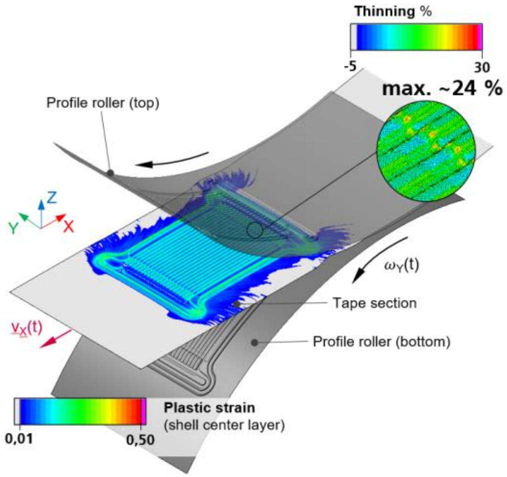
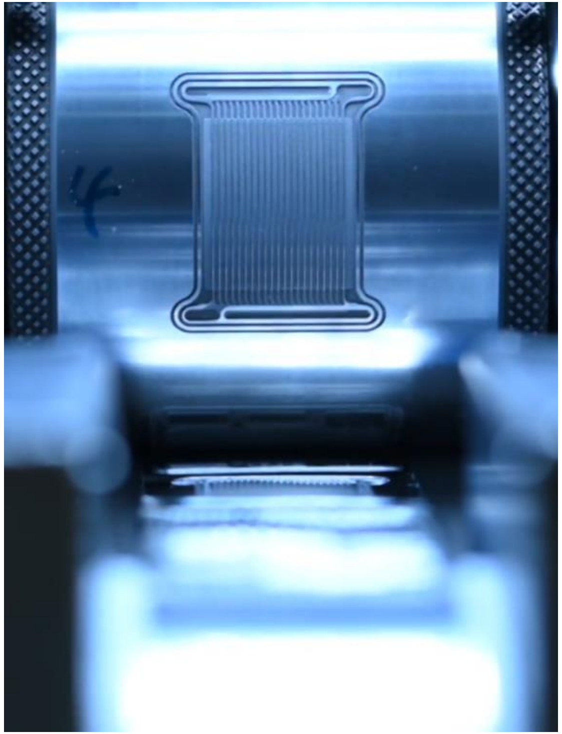


Fig.: Simulation of hollow embossing rolling process



Production of BPP by hollow embossing rolling

Plant technology:

Specification	Value
Number of stitches	3 +1, extendable
Stitch distance	700 mm
Max. production width	170 mm
Max. Roll diameter	240 mm
Pressure rollers in width direction	optional
Velocity	60 1/min
Max. Torque	730 Nm
Max. Contact force	25 kN
Max. Tractive force	20 kN
Installation area	4500 mm x 3300 mm

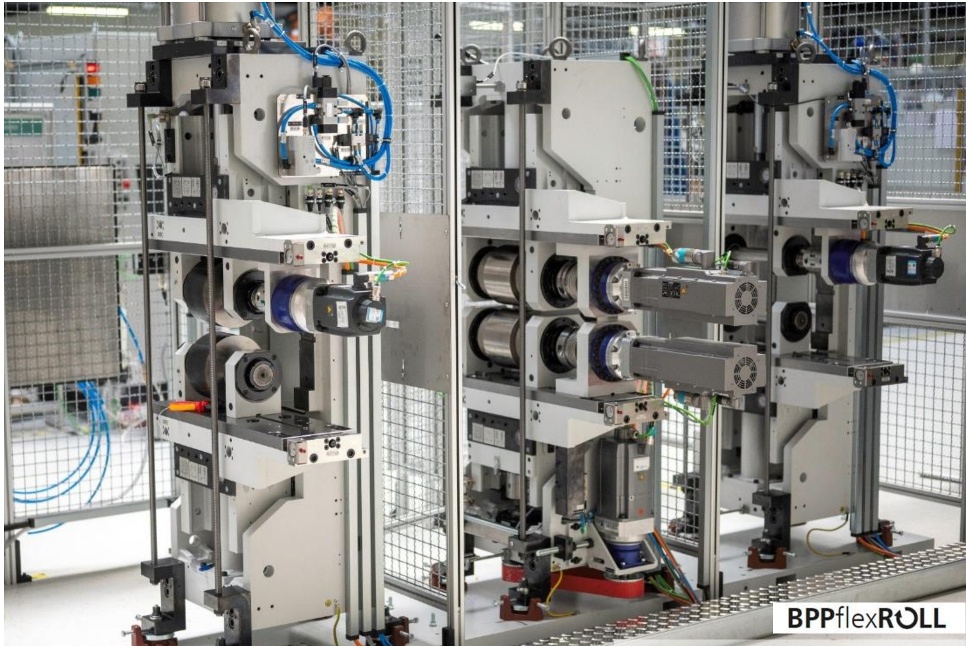


Fig.: Production line @ Fraunhofer IWU

Production line @ Fraunhofer IWU

Production of BPP by hollow embossing rolling for hydrogen electrolysis

Process differences:

- 5 to 10 times material thickness Compared to PEMFC

Development approaches:

- Forming process
- Machine and plant technology

Boundary conditions

- Material1.4404; s = 0,500 mm
- Simulation with 100 MPa counter holder tension
- Feeding straight

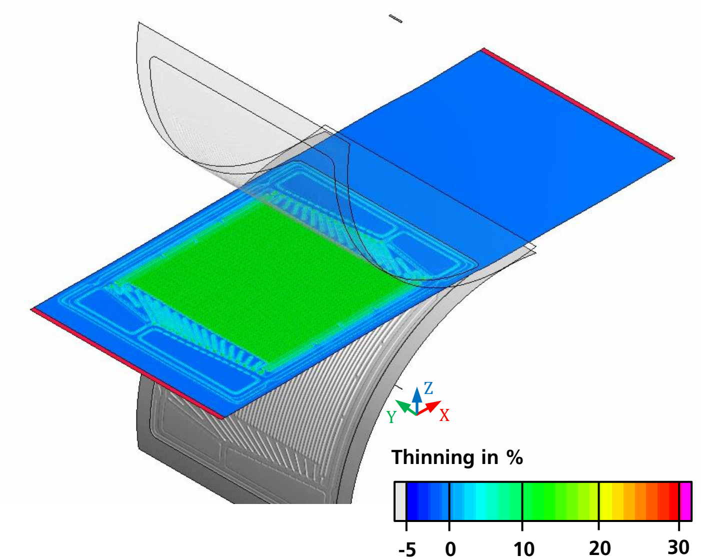


Fig.: FE Simulation hollow embossing rolling

Production of BPP by hollow embossing rolling for hydrogen electrolysis

Boundary conditions

- Material 1.4404; s = 0,500 mm
- Boundary conditions.
- Feeding diversion

Fig.: Hollow embossed BP half plate for PEM Electrolyzer application.

Fig.: Hollow embossing rolling process

Forming Technologies for metallic Bipolar Half Plates

Tool manufacture for high-precision forming tools

Production of forming tools by milling

Advantages

→ **High productivity,** especially through milling → Metal removal rate rough machining **30 mm³/min**

→ **High Quality** by grinding and polishing → Surface roughness R_z < 1 µm

→ **Manufacturability through process combination of roughing** with a defined cutting edge and **finishing** with an undefined cutting edge

Disadvantages:

→ **Tool geometry** → Cutting edge offset due to wear and tolerances leads to contour deviations

→ **Machining forces** → Tool displacement due to filigree tools with low rigidity

→ **Cooling lubrication and chip removal** required

Fig.: Milling of a tool component

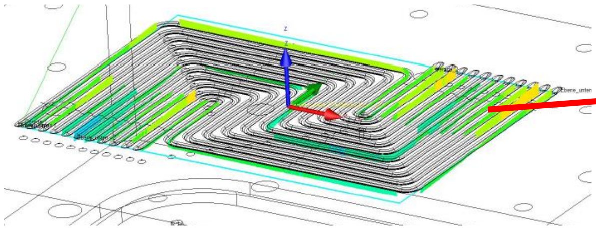
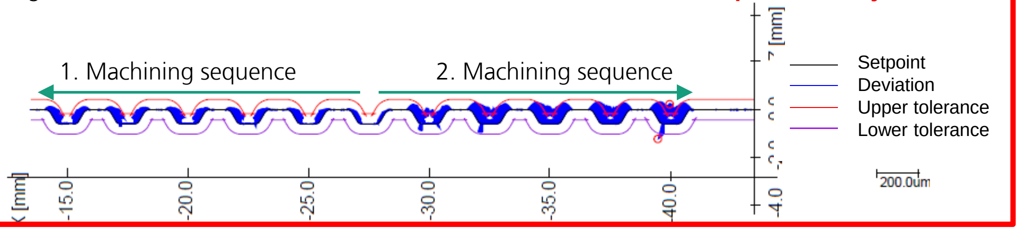


Fig.: Milled engraving structure and profile section (right)

- Milling a channel structure with a torus milling cutter, Material Toolox 44
- Significant tool wear **after 3 m feed distance ⇔ >100 m in the complete tool layout**



Production of forming tools by laser engraving

Advantages:

→ No tools required → **force-free and wear-free machining**

→ Laser beam can be controlled almost instantaneously in terms of space, time and energy

Disadvantages:

→ Low removal rates → **High** resulting **production times**

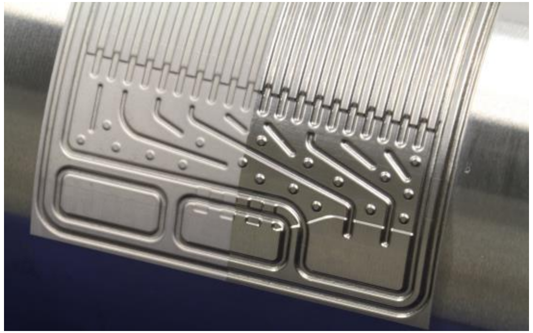


Fig.: Forming roll produced by laser engraving

Test made by IWU:

- Shape accuracy: 10 bis 15 µm achieved with laser
- Finishing: Removal rate: 0,41 mm³/min
  Surface roughness R_z: 2,0 µm
- **Rough machining:** Removal rate: **0,87 mm³/min**
  Surface roughness R_z: 4,0 µm

Boundary conditions:

- Testing under laboratory conditions (air-conditioned)Iterative
- Adjustment of process and layout parameters
- Pre-distortion contour, monitoring removal rate
- 6 h Processing time for 1 Channel (l = 40 mm)

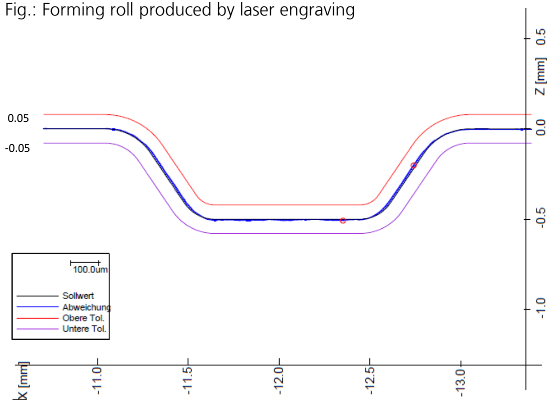


Fig.: Profile section of a channel structure produced by laser engraving

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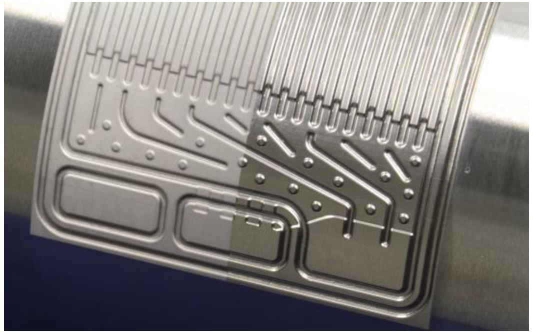

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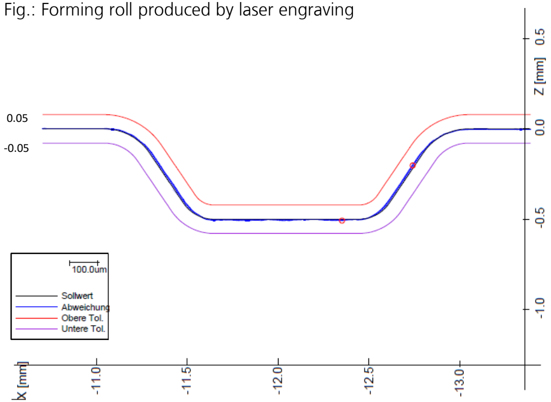

Fig.: Profile section of a channel structure produced by laser engraving

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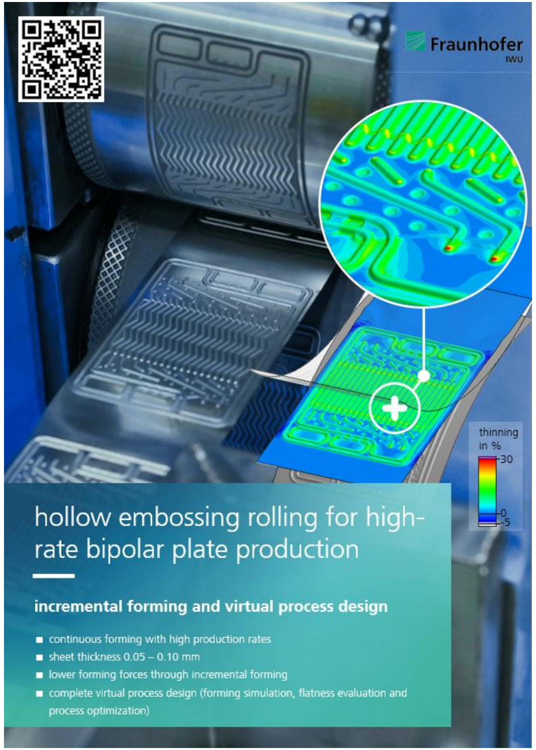
Thank you for your attention

Process comparison



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