Bipolar Plate Technologies
and Ex-Situ Tests for Material Selection

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1 ZBT Institute

2 Bipolar Plate Technologies
   Injection Molded Composite Plates
   Hydroformed Metallic Plates

3 Ex-Situ Tests for Material Selection
   Project BREEZE
   Qualification Methods
   Approaches and Specific Results – Project BREEZE
   Metallic Bipolar Plates
   PEMFC coolant / coolant cycle materials
BPP Technologies at ZBT

Metallic Bipolar Plates

Example:
Stack of 80 cells
Active area 50 cm²

Composite Bipolar Plates

Cell height ~ 5,8 mm (*)

 automotiv e

...transportable...

stationary

(*) ZBT values

Cell height ~ 1,6 - 2,0 mm (*)

16,0 cm

1,33 kg

46,4 cm

5,12 kg
Challenges with Injection Molding:

- High melt viscosity → requires high pressures
- High thermal conductivity of the material → fast solidification
- Size of bipolar plates is limited by material & machine parameters

Benefits:

- Mass producability → production cycle < 20 s
  (clamping force 5000 kN, maximum working space 300 cm²)
- High reproducibility
- High accuracy
- Thermoplastics are recyclable

▪ **Material and Process Technology is valid for Low Temperature** and **High Temperature PEMFC!**
2 Injection Molded Composite Plates

1. IM- bipolar plates
2. Injection molding

Feedstock → Extrusion → Compound

FC-stack
2 Hydroformed Metallic Plates

**ZBTs partner:**

- maximum clamping force: 65.000 kN
- maximum working space: 400 cm²

1. Sheet insertion, close press
2. Insertion of the active fluid medium with up to 4000 bar ➔ Expansion of the sheet into the die
3. Nearly stress-free device

**Hydroforming: PowerBoxx ®**

**Substrate materials for hydroformed bipolar plates:**

- 1.4301, 1.4303, 1.4306, 1.4372
- 1.4401, 1.4404
- 1.4539
- 1.4562 (Nicrofer, 3127 hMo)
- 2.4856 (Nicrofer, 6020 hMo)
- 1.4760 (Crofer 22 APU)
- 1.4750 (Crofer 22H)
- Titan Grade 1 (Ticrutan)
- Aluminum
- Multilayered metals

➡ Electrolyzers!
2 Hydroformed Metallic Plates

Production process

Hydroforming → Semi-shell plate, uncutted → Laser cutting

Metallic Bipolar Plates

Laser welding

Cutted semi-shell
BREEZE: Fuel Cell Range Extender Module (REM) for Battery Electric Vehicles

- Zero emissions during REM operation
- Significant NVH advantages compared to ICE REMs
- High efficiency
- Heat available for cabin heating
### Table 1 Performance requirements for PEM fuel cell bipolar plates.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
<th>Value</th>
<th>Available tests at ZBT:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tensile strength – ASTM D638</td>
<td>MPA</td>
<td>&gt;41</td>
<td>being established</td>
</tr>
<tr>
<td>Flexural strength – ASTM D790</td>
<td>MPA</td>
<td>&gt;59</td>
<td>established</td>
</tr>
<tr>
<td>Electrical conductivity</td>
<td>S cm(^{-1})</td>
<td>&gt;100</td>
<td>established</td>
</tr>
<tr>
<td>Corrosion rate</td>
<td>µA cm(^{-2})</td>
<td>&lt;1</td>
<td>established</td>
</tr>
<tr>
<td>Contact resistance</td>
<td>mΩ cm(^{2})</td>
<td>&lt;20</td>
<td>established</td>
</tr>
<tr>
<td>Hydrogen permeability</td>
<td>cm(^{3}) (cm(^{2}) s(^{-1}))</td>
<td>&lt;2.10(^{-6})</td>
<td>established</td>
</tr>
<tr>
<td>Mass</td>
<td>kg/kW</td>
<td>&lt;1</td>
<td>established</td>
</tr>
<tr>
<td>Density – ASTM D792</td>
<td>g cm(^{-3})</td>
<td>&lt;5</td>
<td>established</td>
</tr>
<tr>
<td>Thermal conductivity</td>
<td>W (m K(^{-1}))</td>
<td>&gt;10</td>
<td>being established</td>
</tr>
<tr>
<td>Impact resistance (unnotched) ASTM D-256</td>
<td>J m(^{-1})</td>
<td>&gt;40,5</td>
<td>not established</td>
</tr>
</tbody>
</table>

3 Metallic Bipolar Plates

- Main Criteria for Material Selection
  - Chemical stability
  - Interfacial contact resistance
  - Formability
  - Material costs

- Investigation of: 4 substrates + 1 coating
- Performing all tests on the basis of a small, hydroformed bipolar plate

- Ø 50 mm
- 1.4301 (AISI 304)
- 1.4404 (a) (AISI 316L)
- 1.4404 (b) (AISI 316L)
- 2.4856 (Nicrofer ® 6020 hMo)
- 1.4301 + graphite coating
3 Metallic Bipolar Plates

Mass Loss of Hydroformed Bare Stainless Steel Substrates
Immersed in 1.0 M $\text{H}_2\text{SO}_4$ at 70°C and Air Purged

- Complete Dissolution during the immersion test

<table>
<thead>
<tr>
<th>Immersion time [h]</th>
<th>mass loss [g/m²]</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>1.4301</td>
</tr>
<tr>
<td>1000</td>
<td>1.4404-a</td>
</tr>
<tr>
<td></td>
<td>1.4404-b</td>
</tr>
<tr>
<td></td>
<td>2.4856</td>
</tr>
<tr>
<td>1000</td>
<td>19.37 (Complete Dissolution)</td>
</tr>
</tbody>
</table>
Leaching products from uncoated and coated hydroformed stainless steel bipolar plates in 1.0 M H2SO4 at 70°C with air purge.
3 Metallic Bipolar Plates

Interfacial Contact Resistance of uncoated and coated, hydroformed Stainless Steels Bipolar Plates

- 1.4301 (304)
- 1.4404-a (316L)
- 1.4404-b (316L)
- 2.4856 (Nicrofer® 6020 hMo)
- 1.4301 graphite coated

Compaction pressure [bar]

ICR [mΩ cm²]

DOE target
### 3 Metallic Bipolar Plates

<table>
<thead>
<tr>
<th>Material</th>
<th>Formability (standardized on 1.4301)</th>
<th>Material costs* (standardized on 1.4301)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4301 (AISI 304)</td>
<td>100%</td>
<td>1</td>
</tr>
<tr>
<td>1.4404 (a) (AISI 316L)</td>
<td>75%</td>
<td>1,6 – 2,2</td>
</tr>
<tr>
<td>1.4404 (b) (AISI 316L)</td>
<td>75%</td>
<td>3</td>
</tr>
<tr>
<td>2.4856 (Nicrofer ® 6020 hMo)</td>
<td>&lt; 50%</td>
<td>16</td>
</tr>
</tbody>
</table>

Hydroforming | Stamping

- 100% | 90%
- 75% | 65%
- 75% | 65%
- < 50% | < 40%

Reasonable selection: 1.4404 (b) + graphite coating
### Requirements for coolant media acquisition:

- Non corrosive
- Non conductive

(- Heat capacity)

<table>
<thead>
<tr>
<th>Coolants</th>
<th>A1</th>
<th>A2</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Automotive Coolant</td>
<td>Designated Fuel Cell Coolant</td>
<td>Perfluorinated Polyether</td>
<td>CPU Coolant</td>
<td>CPU Coolant (biodegradable)</td>
<td>DI-water</td>
</tr>
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### Tested cooling media

- Coolants A1 A2 B C D E
- Description:
  - Automotive Coolant
  - Designated Fuel Cell Coolant
  - Perfluorinated Polyether
  - CPU Coolant
  - CPU Coolant (biodegradable)
  - DI-water

### Materials:

- **Gaskets:** Silicons
- **Tubing:** PP, PA, PE
- **Heat Exchanger:** Cu, Al, brass
- **Bipolar plates:** SS 304, Nicrofer ® 6020 hMo

### Immersion of all materials at the same time for 500 h / 70 °C in each coolant

- Reduce testing time
- Provoke a measurable increase of conductivity within 500 h
- Cross effects do exist in real cooling cycles
### Coolant Selection:

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<tr>
<td>Description</td>
<td>Automotive Fuel</td>
<td>Designated Fuel Cell Coolant</td>
<td>Perfluorinated Polyether</td>
<td>CPU Coolant</td>
<td>CPU Coolant (bio-degradable)</td>
<td>DI-water</td>
</tr>
<tr>
<td>Conductivity before immersion [µS]</td>
<td>5360</td>
<td>3,05</td>
<td>0,01 (instrument sensitivity)</td>
<td>1484</td>
<td>430</td>
<td>1,42</td>
</tr>
<tr>
<td>Conductivity after 500 h immersion [µS]</td>
<td>5360</td>
<td>3,91</td>
<td>0,01 (instrument sensitivity)</td>
<td>1551</td>
<td>475</td>
<td>8,46</td>
</tr>
<tr>
<td>suitability</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>possibly</td>
</tr>
<tr>
<td>attribute</td>
<td>conductivity too high</td>
<td>non corrosive, low conductivity</td>
<td>harmful to environment, low thermal capacity</td>
<td>conductivity too high, corrosive</td>
<td>conductivity too high, corrosive</td>
<td>Conductivity increases with time. An ion exchanger has to be used.</td>
</tr>
</tbody>
</table>

### Example Aluminum:

- **A1**: DI-water as coolant only suitable with ion exchanger. Some materials need to be avoided.
  - corrosive to Al, Cu and PA6 / Intense increase of Electrical conductivity

- **A2**: Coolant A2 is suitable as fuel cell coolant.
  - non corrosive to projected cooling cycle materials / Increase of electrical conductivity very low
Summary

- Stationary applications are addressed by injection molded composite bipolar plates for low temperature and high temperature PEMFC at ZBT
- Automotive applications are addressed by hydroformed metallic bipolar plates in cooperation with industrial partners
- Many ex-situ (and also in-situ) methods are available for materials, components and stacks
  - Pre-Assessment of metallic substrates for bipolar plates is conducted by ICR-measurement, immersion test and analysis of leached ions
  - A graphite coating was found to be a promising candidate for corrosion protection
  - A cooling medium was selected from 6 candidates as suitable for PEMFC application without ion exchanger by ex-situ immersion test
Acknowledgements:

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Thank you for your attention!