Commercialization of Fuel Cell Bipolar Plate Manufacturing by Electromagnetic Forming

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Outline

• Functional requirements of PEM fuel cell plates
• Electromagnetic forming to manufacture fuel cell plate
• Preliminary results
• Velocity measurement and simulation
• Coil durability and die wear
• Summary
PEM Fuel Cell Bipolar Plates

- Functional requirements:
  - Strong, light, thin
  - Corrosion resistant
  - Joinable
  - Formable into complex shapes
Candidate Materials

• Plate material selection
  – Meet functional requirements
  – Material and manufacturing costs have historically been the largest contributor to total plate cost.

• Stainless steels as candidate materials
  – Corrosion resistance, formability, high strength, low cost, joinable,
    • Austenitic SS (304, 316, 201, …)
    • Ferritic SS (409, 430, 439, …)
Production needs

Volume requirements are potentially very large:
– 2 plates (anode + cathode) per bipolar plate assembly
– ~ 500 bipolar plate assemblies per stack (per vehicle)
– Potential market 1,000,000 vehicles per year

A high volume and low cost manufacturing process is needed.
Possible Forming Methods

- Machining
- Hydro-forming
- Conventional stamping
- High velocity forming
  - Electromagnetic forming
Basic Layout of Electromagnetic Forming

**Diagram:**
- **Charging System** connected to **Capacitors**.
- **Capacitors** connected to a **High current switch**.
- **Workpiece** connected to **Coil**.
- **Die** connected to the **Workpiece**.

**Legend:**
- **Charging System**
- **Capacitors**
- **High current switch**
- **Workpiece**
- **Coil**
- **Die**
Press Forming vs. Electromagnetic Forming

<table>
<thead>
<tr>
<th></th>
<th>Traditional Stamping</th>
<th>Electromagnetic Forming</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tool</strong></td>
<td>Must have die and Punch</td>
<td>Single-side die</td>
</tr>
<tr>
<td><strong>Alignment</strong></td>
<td>Carefully aligned for punch and die</td>
<td>Simple alignment</td>
</tr>
<tr>
<td><strong>Formability</strong></td>
<td>Good formability is required</td>
<td>Better formability because of high velocity and strain rate</td>
</tr>
<tr>
<td><strong>Late Stage Changes</strong></td>
<td>Difficult due to tolerance requirements for die and punch</td>
<td>Easy because of single-side die</td>
</tr>
<tr>
<td><strong>Pressure</strong></td>
<td>Press tonnage, heavy tooling</td>
<td>Large pressure from high velocity impact. Lighter tooling are possible</td>
</tr>
</tbody>
</table>
Apply Electromagnetic Forming to manufacture PEM fuel cell plate

Challenges:

(1) Low conductivity of stainless steel ---- Driver plate needed;
(2) Uniform pressure needed;

Direct Approach  Indirect Approach

Die

Metal sheet

Driver plate

Coil
Compliant Layer Electromagnetic Forming

Advantages: (1) Driver plate is re-usable, which reduces cost;
(2) Uniform pressure;
(3) Easy automation;
# Technologies of high velocity press

<table>
<thead>
<tr>
<th>Technology</th>
<th>Speed</th>
<th>Ram Mass</th>
<th>Drive means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drop hammer press</td>
<td>2-5 m/s</td>
<td>Massive</td>
<td>Gravity</td>
</tr>
<tr>
<td>Airam press</td>
<td>~ 10 m/s</td>
<td>Modest</td>
<td>Air driven</td>
</tr>
<tr>
<td>Lourdes-Neutronic press (Winset)</td>
<td>~10 m/s</td>
<td>Modest</td>
<td>EM solenoid</td>
</tr>
<tr>
<td>Cell impact press (Morphic)</td>
<td>~50 m/s</td>
<td>Modest - light</td>
<td>Hydraulic actuation</td>
</tr>
<tr>
<td>LMC press</td>
<td>~ 50 m/s</td>
<td>Modest - light</td>
<td>Spring driven</td>
</tr>
<tr>
<td>EM Compliant Layer (AmTrim)</td>
<td>&gt;50 m/s</td>
<td>Light</td>
<td>EM actuator</td>
</tr>
<tr>
<td>Direct EM actuation</td>
<td>&gt;150 m/s</td>
<td>None</td>
<td>EM actuator</td>
</tr>
</tbody>
</table>
Concept of Fuel Cell Plate Manufacturing by Electromagnetic Forming

- Automation is easily applied to the process.
- One sided die eliminates alignment and complexity issues.
- Quick tool change is easy to implement.
Alpha Machine in AmTrim with Preliminary Results
Setup and Sub-Sized Bipolar Plates Formed by Alpha Machine

Setup

A typical formed plate

(0.1mm Stainless Steel 201)

ICHSEF 2010
Preliminary Results

Die scanning (311µm channel depth)

Formed part scanning (0.1mm 439SS, 9 kJ, 260µm channel depth)
Photo of One Channel

Formed part (0.1mm 439SS, 9 kJ, 260µm channel depth)
Velocity Measurement by Photon Doppler Velocimeter

- PDV probes
- Die
- Metal sheet
- Compliant layer
- Driver plate
- Coil
The energy input was 2.4 kJ and only driver plate was applied.

*Data were provided by OSU.
Result of OSU PDV Measurements

The energy input was 2.4 kJ.

*Data were provided by OSU.
The energy input was 2.4 kJ and only driver plate was applied.
Comparison between Measurement and Simulation

![Graph showing velocity over time for measurement and simulation with different energy inputs.]

Only driver plate was applied.

ICHSF 2010
Coil Durability

Scanning along the middle line of the coil (after around 500+ hits, initially flat)
Die Wear

Scanning of one channel of the die (before and after 500+ hits)
Technical Challenges of Electromagnetic Forming Commercialization

Further investigations needed for the following challenges

• Thermal management of coil and driver plate
• Coil life (higher energy, more hits)
• Die wear (higher energy, more hits)
• Compliant layer life
• Improvement of micro-channel depth and geometry control
• Scaling up of the process for full scale fuel cell plate manufacturing

• …..
Summary

• A coil-to-coil electromagnetic forming machine was successfully developed to run 5-second cycle times, demonstrating the process is commercially viable and much more cost effective than conventional forming methods;

• The preliminary results are encouraging--- 87% of target channel depth was reached at 9 kJ using the compliant layer approach;

• The velocity of the compliant layer approach was measured and simulated. Simulation results closely matched with physical measurements;

• Coil durability is good--- Only 0.24mm deflection was detected for over 500 hits;

• Die wear is good--- No die wear was detected for over 500 hits;

• Further development is required to verify the scaled up process and to improve thermal management techniques;