ELECTROMAGNETIC JOINING

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Industry Meet
At
NAL Bengaluru
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CSIR-Advanced Materials and Processes Research Institute (AMPRI) Bhopal
Overview

- Introduction
- Process/Physics
- Application
- EMF/EMJ@AMPRI
- Futuristic product development @ AMPRI
Introduction: Pulsed Power

**Pulsed power:** Concentration of energy in very small space and time and its sudden release

**Best analogy:** Reverse process of a droplet of water falling on still liquid

Pic from: http://wordsofjoy75.blogspot.in/2013/06/breaking-silence.html, Nov 2015
High Velocity Forming/HERF: Forming process at high strain rate of $10^2$/s (Velocity > 10 m/s) and above

- Chemical: Explosive, Propellant, Gas Mixture
- Electrical: Magnetic Field, Spark Discharge
- Mechanical: Gravity and Pneumatic Hammer
  - Explosive Forming
  - Electromagnetic Forming (EMF)
  - Electrohydraulic Forming (EHF)
Electromagnetic Joining/ Crimping

- Capacitor is discharged causing a time varying current to flow through a coil (EMF)/vaporizing wire (EHF).

- Current in the coil produces a transient magnetic field that induces eddy currents in the workpiece (EMF). Eddy currents generate an opposing magnetic field - causes the coil to repel the workpiece into the die.

- Current passed through an electrode pair placed in die cavity (filled with fluid) with or without bridgewire. Shockwave generated and same is applied to the workpiece (EHF)
ADVANTAGES OF HERF PROCESSES

• High Productivity, Simple tooling (one-sided die and no punch), same tools can be used for various thickness and materials
• Non contact method, high surface finish and less tool wear
• No lubrication, post cleaning rarely necessary
• Automation friendly and reduces springback and prevents wrinkles, Uniform strain distribution
• Pressure transmitted through a fluid medium- advantages of hydroforming are partially incorporated (EHF)

Challenges in using HERF Process

• HERF processes are not suitable for large components and thick sheets
• Working with High Voltage – safety concern
• Higher capital investment for the equipment, Limited equipment suppliers
• Deformation behaviour and formability at very high strain rates is not well understood in case of all the materials. Modelling of the processes is difficult.
Application of EMF/EMJ in Industries

- Research institute
- Nuclear
- Home Appliances
- Power

- Medical (wheelchairs, walkers, canes etc.)
- Aerospace (flight control rods and torque tubes)
- Air conditioning (valve components)
- Automobile (dissimilar metal - torque tubes and shock absorbers etc.)

Welding

Crimping

Forming

Cutting Piercing

Electromagnetic joining & Forming:

- Expertise on design of Coil and Field shaper (FS) for joining of symmetric and non-symmetric geometry
- Electromagnetic Joining of Cu-SS, SS-Nb, SS-Ti, Al-Al, Al-SS, Al-MS, Al-Cu, Cu-Cu, Al-Al

(rectangular profile)

(circular profile joining)

Rect. Profile
Study on design of Coil

- Effect of no. turns of coil, ID, OD, turn thickness on output (Inductance- current.. )
- Effect of web width and material/slit geometry of FS on process parameters
- Effect of coil configuration/design on force/deformation (using FEA)
Effect of coil Design on the discharge current

Table- Different dimension of coil

<table>
<thead>
<tr>
<th>Coil</th>
<th>ID/OD (mm)</th>
<th>N</th>
<th>Turn Thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>91/220</td>
<td>4.40</td>
<td>8</td>
</tr>
<tr>
<td>C2</td>
<td>91/220</td>
<td>4.33</td>
<td>8</td>
</tr>
<tr>
<td>C3</td>
<td>55/200</td>
<td>2.4</td>
<td>3</td>
</tr>
<tr>
<td>C4</td>
<td>91/210</td>
<td>4.33</td>
<td>8</td>
</tr>
<tr>
<td>C5</td>
<td>101/210</td>
<td>4.33</td>
<td>8</td>
</tr>
</tbody>
</table>

Variation in parameters

<table>
<thead>
<tr>
<th>Variation in parameters</th>
<th>Change in current $\Delta I$ (kA)</th>
<th>Change in frequency $\Delta f$ (kHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coil ID (91-101)</td>
<td>-9</td>
<td>-0.3</td>
</tr>
<tr>
<td>Coil OD (210-220)</td>
<td>32</td>
<td>1.7</td>
</tr>
<tr>
<td>N (4.40-4.33)</td>
<td>-31</td>
<td>0.9</td>
</tr>
</tbody>
</table>
Design of Coil and FS

Rectangular FS

Elliptical FS

Flat forming coil
Sample Design:

**Al-Al Joining joint design**

Weld Zone

Part 1

Part 2

Failure criteria between part 1 and weld

(i) $D_1^2 - D_2^2 > 10D_3$ : Zone 1

(ii) $D_1^2 > D_2^2 + 10D_2 - 30$ : Zone 2

(iii) $t_f = \frac{[\sqrt{(D_3^2 + 10D_3)} - D_3]}{2}$

<table>
<thead>
<tr>
<th>Set 1</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>Thickness</th>
<th>SOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Al</td>
<td>16 mm</td>
<td>8 mm</td>
<td>2.5 mm</td>
<td>1.5 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Set 2</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>Thickness</th>
<th>SOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>SS-Al</td>
<td>14.2</td>
<td>8</td>
<td>1.6</td>
<td>1.5 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Set 3</th>
<th>$D_1$</th>
<th>$D_2$</th>
<th>Thickness</th>
<th>SOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al-Al</td>
<td>14.2</td>
<td>8</td>
<td>1.6</td>
<td>1.5 mm</td>
</tr>
</tbody>
</table>

Electromagnetic Joining

**Al-MS electromagnetic joining**

Interlayer Thickness

EDS 3 bank 1.5 SOD

Compressive Load (kN) vs Displacement (in mm)
SS-Nb Joint

SS-Ti Joint

Helium Leak proof test

<table>
<thead>
<tr>
<th>Job description</th>
<th>Leak Tightness (mbar-l/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. SS to Nb</td>
<td>&lt; 1E-10</td>
</tr>
<tr>
<td>2. SS to Nb</td>
<td>&lt; 1.2E-10</td>
</tr>
<tr>
<td>3. SS to Ti</td>
<td>1E-5</td>
</tr>
<tr>
<td>4. SS to Ti</td>
<td>1E-5</td>
</tr>
</tbody>
</table>

Cu-SS joining

Leak proof test carried out at RRCAT
DEVELOPMENT OF AL WAVEGUIDE AND SIMILAR PROFILE COMPONENTS

- Reduction of weight
- Better performance

Source: ISRO exhb. BVM


Beerwald, C., Beerwald, M., Dirksen, U., et al., 2010, “Impulse hydroforming method for very thin sheets from metallic or hybrid Materials”, 4th International Conference on High Speed Forming, Columbus Ohio, USA, 150-158.


