INFLUENCE OF AXIAL WORKPIECE POSITION IN THE COIL FOR ELECTROMAGNETIC PULSE JOINING

Shed some light on the black box

J. Bellmann\textsuperscript{1,3}, J. Lueg-Althoff\textsuperscript{2}, A. Lorenz, S. Schulze\textsuperscript{1}, S. Gies\textsuperscript{2}, A. E. Tekkaya\textsuperscript{2}, E. Beyer\textsuperscript{1,3}

\textsuperscript{1}Fraunhofer Institute for Material and Beam Technology (IWS)
\textsuperscript{2}Institute of Forming Technology and Lightweight Construction (IUL), TU Dortmund
\textsuperscript{3}Institute of Manufacturing Technology (IF), TU Dresden
Content

1. Motivation and former research work

2. Experiments & simulations

3. Results
1. Motivation and former research work

Welding parameters

- Front conditions estimated using welding windows
- Conditions have to be applied to part design and setup
- Geometric factors:
  - Coil-flyer standoff
  - Parent-flyer standoff
  - Parent-flyer contouring
  - **Working length**
1. Motivation and former research work

“Traditional” welding front regimes

One sided Front:
+ Longer path for jet development
+ Lower deformation energy
  - Higher shear in flyer

Two front process:
+ Less shear in flyer
  - Higher deformation energy
  - Reduced weld length

Questions:
- How does the working length affect the front development in MPW?
- What is the optimal working length?
1. Motivation and former research work

2. Experiments & simulations

3. Results
2. Experiments and simulations

Experimental setup

MP 50 kJ/ 25 kV (Bmax)

Coils (CuZnZr1, $\varnothing_{\text{inner}} = 42$ mm)

$\varnothing_{\text{outer}} = 33$ mm

$\varnothing_{\text{outer}} = 40$ mm

<table>
<thead>
<tr>
<th>Charging energy [kJ]</th>
<th>WORKING LENGTHS [mm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l_{\text{coil}}$ [mm]</td>
<td>4</td>
</tr>
<tr>
<td>Coil 1 15</td>
<td>x</td>
</tr>
<tr>
<td>Coil 2 10</td>
<td>x</td>
</tr>
</tbody>
</table>
2. Experiments and simulations

Experimental sequence

Preparation

Joining

- Flyer velocity (time): PDV
- Current (time): Rogowski Current Probe

Analysis

Surface observation

Flyer elongation
2. Experiments and simulations
Measuring the flyer elongation

Application of marks on the flyer outside

Joining

Analysis of the elongation

Calculation of the elongation for each flyer segment
2. Experiments and simulations

Simulation

- Flyer velocity (time)
- Flyer deformation (time, position)
- Current (time)
- Magnetic field (time, position)

LS-DYNA

Calibration
Input
Output
Output
2. Experiments and simulations
Simulation with Finite Element Method Magnetics (FEMM)

Input:
- Setup data
- Current amplitude
- Current frequency

Output:
- Field formation

www.femm.info
Content

1. Motivation and former research work

2. Experiments & simulations

3. Results
3. Results
Simulation of the magnetic field for different $l_w$

- Magnetic field at workpiece surface larger for smaller working length, but not directly proportional
- Increase in magnetic field at the workpiece edge, decreases with increasing working length
3. Results

Simulation of the magnetic field for two flyer orientations

**Orientation 1:**
- Working length relative to 90° coil edge

**Orientation 2:**
- Working length relative to 45° coil edge

Magnetic field at workpiece surface larger for flyer direction to the 90° coil edge

\[ w_l = 7 \text{ mm} \]
\[ l_{coil} = 10 \text{ mm} \]
\[ I_{max} = 500 \text{ kA} \]
\[ f_{circuit} = 20 \text{ kHz} \]
3. Results
Experiments & simulation of the one-front process

- $l_w \leq 0.5 \, l_{\text{coil}}$
- Deformation begins at flyer edge
- Continuous deformation along one front
- Easy ejection of jet away from joining front

Optimal for welding
3. Results
Welding experiments using the one-front process

Welding in samples with $I_w \leq 0.5 \, I_{coil}$
- Non-uniform wavy interfacial structure
- Thin intermetallic layer
- Weld length increases with $I_w$

4 mm $\rightarrow$ 15.7 kJ

7 mm $\rightarrow$ 16.8 kJ
3. Results
Experiments & simulation of the two-front process

- $I_{\text{coil}} < I_w$
- First contact near coil center
- Front propagation outwards in two directions
- Smaller deformation angles than single-front

Coil width suboptimal for two-sided welding front
3. Results
3. Results
Experiments & simulation of the transition-front process

- 0.5 \( l_{\text{coil}} < l_w < l_{\text{coil}} \)
- Flyer deformation in flat manner \( \rightarrow \) Reduced deformation angles
- Jet hindered or trapped between joining partners

Suboptimal for welding
3. Results
Experiments & simulation of the transition-front process

- Samples pulsed at various energies to compare front characteristics
- $l_w = 10$ mm

Same basic features for all samples.
3. Results

Shear stress simulation at the contact zone

- Shear stress at flyer edge increases with decreasing working length
- Increase in shear stress for transition regimes (7…13 mm) at 7 mm distance from flyer edge
3. Results

Visioplastic measuring of the flyer elongation

- Highest elongation at the flyer edge
- Increase in elongation for transition regimes (7…13 mm) at 7 mm distance from flyer edge
## Conclusion

- Three front regimes related to the working length were identified:

<table>
<thead>
<tr>
<th>Geometric relation</th>
<th>One-sided Front</th>
<th>Transition Front</th>
<th>Two-sided Front</th>
</tr>
</thead>
<tbody>
<tr>
<td>$l_w &lt; 0.5 \ l_{coil}$</td>
<td>$0.5 \ l_{coil} &lt; l_w &lt; l_{coil}$</td>
<td>$l_{coil} &lt; l_w$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Jet escape</th>
<th>easy</th>
<th>trapped</th>
<th>easy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weld formation</td>
<td>optimal</td>
<td>no</td>
<td>suitable</td>
</tr>
</tbody>
</table>

- Pulse energy does not have large effect on deformation flyer shape
- Good correlation between calc. shear stress and measured elongations
Thank you for your attention.

This work is based on the results of the subproject A1 within the priority program SPP 1640 of the Deutsche Forschungsgemeinschaft (DFG). This project is executed together with the IUL at Technische Universität Dortmund. The authors would like to thank the DFG for the financial support.