Process Model and Design for Magnetic Pulse Welding by Tube Expansion

V. Psyk, G. Gerstein, B. Barlage, B. Albuja, S. Gies, A. E. Tekkaya, F.-W. Bach
Agenda

- Introduction
- Joining by Electromagnetic Forming
- Design Strategy for MPW
  - Model Experiment
  - Electromagnetic forming experiments
- Summary and Outlook
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- Introduction
- **Joining by Electromagnetic Forming**
- Design Strategy for MPW
  - Model Experiment
  - Electromagnetic forming experiments
- Summary and Outlook
Principle of Magnetic Pulse Welding (MPW)

Advantages of MPW
- Metallic bonding in case of *proper impacting parameters*
- Joining without mechanical contact
- Joining of similar and dissimilar metals
- Avoidance / Reduction of:
  - heat-affected zones
  - intermetallic phases
Current problems in MPW

- Which impacting parameters are required?
- How can the process be adjusted to reach the required parameters?

Research objective:

Design strategy for MPW by electromagnetic tube expansion

- Determination of the required collision parameters (values for $\alpha$ and $v$)
- Instruments for a proper adjustment of the collision parameters
Introduction

Joining by Electromagnetic Forming

Design Strategy for MPW
- Model Experiment
- Electromagnetic forming experiments

Summary and Outlook
Sub-target I: Identification of suitable impact parameters:

- **angle** and **velocity**

Process design strategy: Magnetic pulse welding

Sub-target II: Systematic adjustment of impact parameters via process parameters

- **equipment** and **charging energy**
Model Experiment - Setup -

Joining unit

- Mounting device
- Joining specimen (dynamic)
- Dynamic support (0.337 kg)
- Joining specimen (static)
- Static support
- Acceleration tube (length: 1000 mm)

Acceleration unit

- Mass (0.066 kg)
- High-velocity valve
- Acceleration chamber
- Pressure chamber

Influencing parameters:
- Angle
- Impact velocity
- Material
Model High Speed Joining Experiment  
- Exemplary Results -

Specimen material: EN AW-1050  
Specimen thickness: 0.3 mm

<table>
<thead>
<tr>
<th>Workpiece material</th>
<th>Acceleration mass parameters</th>
<th>Support parameters</th>
<th>Impact angle</th>
<th>Weld quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specimen I</td>
<td>Specimen II</td>
<td>Material</td>
<td>Weight $m_m$ in kg</td>
<td>Velocity $v_m$ in m/s</td>
</tr>
<tr>
<td>EN AW-1050</td>
<td>EN AW-1050</td>
<td>Steel</td>
<td>3.2</td>
<td>8</td>
</tr>
</tbody>
</table>

Joint geometry and process design to reach this collision parameters?

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- **Workpiece material:** EN AW-1050
- **Specimen thickness:** 0.3 mm

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### Model High Speed Joining Experiment - Exemplary Results -

- **Specimen material:** EN AW-1050
- **Specimen thickness:** 0.3 mm

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**Workpiece material** | **Acceleration mass parameters** | **Support parameters** | **Impact angle** | **Weld quality**
--- | --- | --- | --- | ---
Specimen I | Specimen II | Material | Weight $m_m$ in kg | Velocity $v_m$ in m/s | Weight $m_s$ in kg | Velocity $v_s$ in m/s | |
EN AW-1050 | EN AW-1050 | Steel | 3.2 | 8 | 0.31 | 16 | 3.2° | ++ |

Joint geometry and process design to reach this collision parameters?
**Electromagnetic Experiments**

- **Setup**

<table>
<thead>
<tr>
<th>Machine: SMU 1500</th>
</tr>
</thead>
<tbody>
<tr>
<td>maximum charging energy $E_{\text{max}}$</td>
</tr>
<tr>
<td>maximum charging voltage $U_{\text{max}}$</td>
</tr>
<tr>
<td>capacitance $c$</td>
</tr>
<tr>
<td>inner inductance $L_i$</td>
</tr>
<tr>
<td>inner resistance $R_i$</td>
</tr>
<tr>
<td>short circuit frequency $f$</td>
</tr>
</tbody>
</table>

**Tool coil:** expansion coil
- outer diameter: 36 mm
- effective length: 27 mm
- number of turns: 13

**Workpiece:** EN AW-1050
- outer diameter: 40 mm
- wall thickness: 2 mm
- length: 100 mm

Introduction  | Joining by Electromagnetic Forming  | Design Strategy for MPW  | Summary & Outlook
Electromagnetic Experiments
- Free Forming -

<table>
<thead>
<tr>
<th>Charging energy</th>
<th>1000 J</th>
<th>1250 J</th>
<th>1500 J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity</td>
<td>108 m/s</td>
<td>120 m/s</td>
<td>186 m/s</td>
</tr>
<tr>
<td>Gap width</td>
<td>1.2 mm</td>
<td>1.2 mm</td>
<td>2.0 mm</td>
</tr>
<tr>
<td>Inner diameter of hub</td>
<td>42.4 mm</td>
<td>42.4 mm</td>
<td>44.0 mm</td>
</tr>
</tbody>
</table>

**Forming machine:** SMU 1500

**Tool coil:**
- Outer diameter: 36 mm
- Length: 27 mm
- Turns: 13

**Tube:**
- EN AW-1050
- Diameter: 40 mm
- Wall thickness: 2 mm
- Length: 100 mm

**Graph:**
- Displacement $dr$ in mm against forming velocity $v_r$ in m/s.
- Z values: 0 mm, 3 mm, 6 mm, 9 mm.
- Forming machine: SMU 1500
- Tool coil:
  - Outer diameter: 36 mm
  - Length: 27 mm
  - Turns: 13
- Tube:
  - EN AW-1050
  - Diameter: 40 mm
  - Wall thickness: 2 mm
  - Length: 100 mm
Electromagnetic Experiments
- Free Forming -

Nearly parallel expansion of the tube wall \((z \approx 0 - 6 \text{ mm})\)

Assumption: Same deformation in joining experiments before impact
## Electromagnetic Experiments - Joining -

<table>
<thead>
<tr>
<th>Phase</th>
<th>Process parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>free forming</td>
<td>charging energy, gap width</td>
</tr>
<tr>
<td></td>
<td>1000 J, 1250 J, 1500 J, 1.2 mm, 2.0 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>joining</th>
<th>Impact velocity, angle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>120 m/s, 156 m/s, 186 m/s, 0°, 3°, 5°</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>charging energy</th>
<th>gap width</th>
<th>impact velocity</th>
<th>impact angle α</th>
</tr>
</thead>
<tbody>
<tr>
<td>1250 J</td>
<td>1.2 mm</td>
<td>120 m/s</td>
<td>0°, 3°, 5°</td>
</tr>
<tr>
<td>1250 J</td>
<td>2.0 mm</td>
<td>156 m/s</td>
<td>0°, 3°, 5°</td>
</tr>
<tr>
<td>1500 J</td>
<td>2.0 mm</td>
<td>186 m/s</td>
<td>0°, 3°, 5°</td>
</tr>
</tbody>
</table>
Electromagnetic Experiments
- Joining -

<table>
<thead>
<tr>
<th>Tube</th>
<th></th>
<th>Hub</th>
</tr>
</thead>
<tbody>
<tr>
<td>material:</td>
<td>EN AW-1050</td>
<td>material:</td>
</tr>
<tr>
<td>outer diameter:</td>
<td>40 mm</td>
<td>inner diameter:</td>
</tr>
<tr>
<td>wall thickness:</td>
<td>2 mm</td>
<td>hub angle:</td>
</tr>
<tr>
<td>length:</td>
<td>100 mm</td>
<td>length:</td>
</tr>
</tbody>
</table>

Image: Diagram of the joining process with labeled parts: Hub, Tube, Tool coil, Collar, Supporter, and Cross table.
**Electromagnetic Experiments - Exemplary Results**

**Forming velocity** $v_r$ in m/s

![Graph showing forming velocity vs displacement](image1.png)

- **1250 J**
- **gap width 1.2 mm**

**Welding quality vs Axial position $z$ in mm**

- **Hub angle:** $0^\circ$; $3^\circ$; $5^\circ$

**Forming machine:** SMU 1500

**Tool coil:**
- outer diameter: 36 mm
- length: 27 mm
- turns: 13

**Tube:**
- EN AW-1050
- diameter: 40 mm
- wall thickness: 2 mm
- length: 100 mm
Forming machine: SMU 1500

Tool coil:
- outer diameter: 36 mm
- length: 27 mm
- turns: 13

Tube:
- EN AW-1050
- diameter: 40 mm
- wall thickness: 2 mm
- length: 100 mm

Welding quality

Displacement $dr$ in mm

Axial position $z$ in mm

Forming velocity $v_r$ in m/s

Gap width 2 mm

1500 J

Hub angle: 0°; 3°; 5°
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Model experiment for the determination of suitable impacting parameters for MPW

Joining experiments proved that model experiment is especially suitable to determine the optimum collision angle

Tapered joining partner for a proper adjustment of the collision angle during MPW process

Further investigations should concentrate on an improved prediction quality for the impacting velocity