Warm Electromagnetic Forming of AZ31B Magnesium Alloy Sheet

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OUTLINE

- Introduction and motivation
- Electromagnetic forming experiments
  - EMF drawing
  - EMF bending
- Conclusions and ongoing work
There is a clear tendency for **weight reduction** in automotive and aeronautic industries.

“Cars on a diet”

The use of magnesium parts is expected to increase (e.g. Usamp 2007)

### Mg alloys

<table>
<thead>
<tr>
<th></th>
<th>Al</th>
<th>Mg</th>
<th>Steel</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \rho )</td>
<td>2.8</td>
<td>1.74</td>
<td>7.83</td>
<td>4.5</td>
</tr>
<tr>
<td>( E )</td>
<td>70</td>
<td>45</td>
<td>210</td>
<td>110</td>
</tr>
<tr>
<td>( R_m )</td>
<td>150-680</td>
<td>100-380</td>
<td>300-1200</td>
<td>910-1190</td>
</tr>
<tr>
<td>( R_m/\rho )</td>
<td>54-243</td>
<td>57-218</td>
<td>38-153</td>
<td>202-264</td>
</tr>
<tr>
<td>( E/\rho )</td>
<td>25.0</td>
<td>25.9</td>
<td>26.8</td>
<td>24.4</td>
</tr>
<tr>
<td>( \sqrt{R_m/\rho} )</td>
<td>9.3</td>
<td>11.2</td>
<td>4.4</td>
<td>7.7</td>
</tr>
<tr>
<td>( \sqrt{E/\rho} )</td>
<td>14.7</td>
<td>20.4</td>
<td>7.6</td>
<td>10.6</td>
</tr>
</tbody>
</table>

[Kleiner et al. 2003]
Strategies to increase formability:

**Increasing Temperature: Warm Forming**

[Doege et al. 2001] [Ulacia et al. 2008]

**Increasing Strain Rate** (EMF, EHF and explosive forming)

[El-Magd et al. 2004] [Ishikawa et al. 05]
MOTIVATION

Previous work in EMF of Mg alloys:

**Tube**
- **TU Berlin, Germany [Uhlmann et al. 2004]**
  - A tool for combining Inductive Heating and Magnetic Forming was shown.
  - No deformed parts or values were shown.

- **IUL Dortmund, Germany [Psyk et al. 2006]**
  - Suitability of different extruded Mg tubes for EMF was characterised.

**Sheets**
- **VTT and Helsinki University, Finland [Revuelta et al. 2007]**
  - Increase of formability was reported for AZ31B, although deformation values were not shown.

- **Labein and Mondragon Univ., Spain [Ulacia et al. 2008]**
  - Increase of formability was measured for AZ31B at Room Temp.

- **AIST, Japan [Murakoshi et al. 2008]**
  - EMF at different temp.
Current research:

**Aim:** Evaluate the effect of temperature on the electromagnetic forming of Mg AZ31 sheets

**AZ31B (commercial). 1 mm thickness. GS=10 µm**

<table>
<thead>
<tr>
<th>Element</th>
<th>Zn</th>
<th>Al</th>
<th>Si</th>
<th>Cu</th>
<th>Mn</th>
<th>Fe</th>
<th>Ni</th>
<th>Ca</th>
<th>Sn</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>wt%</td>
<td>0.96</td>
<td>2.7</td>
<td>0.01</td>
<td>≤0.01</td>
<td>0.21</td>
<td>0.002</td>
<td>≤0.001</td>
<td>≤0.01</td>
<td>0.00</td>
<td>≤0.30</td>
</tr>
</tbody>
</table>

**Increasing temperature**
- Decrease of electrical conductivity
- Decrease of yield strength
- Increase of active def. mechanisms
EMF at different temperatures:

**Machine:** Maxwell Magneform at *Labien-Tecnalia*

- **Capacitor bank:** 60kJ (1800 μf – 8.66 kV)
- **40 Tn Hydraulic Press**
- **Coils & dies:**

**Test conditions:**

- **Temperatures:** R.T., 100°C, 150°C, 200°C, 250°C
- **Discharged Energies:**
  - 6 kJ - 15 kJ (Drawing)
  - 1 kJ – 6 kJ (Bending)
EMF at different temperatures:

**Heating Strategy:** Heating outside the forming position

- Step 1. Heating: Temperature was controlled with thermocouples
- Step 2. Automatic Transfer: Temp drop measured (Cooling curves for each Temp)
- Step 3. Closing and EMF discharge: Time for discharging measured → Initial Temp.

![Cooling curve for 250ºC](image)
Increasing the temperature:
- Decreases $h_{\text{max}}$ (for a given $E$)
- More energy (strain energy) is gained to obtain

**EMF Drawing**

**EXPERIMENTAL RESULTS**
EMF Bending

Room temperature

Energy for impact?

- Non-symmetrical deformation (coil)
- Impact in 2.5-3 kJ
- Decrease of springback with increasing energy
  → Higher plastic deformation
  → High velocity impact
EXPERIMENTAL RESULTS

EMF Bending

Different temperatures

For a given energy, if:

Temperature $\uparrow$ (Elect. Conductivity $\downarrow$) $\rightarrow$ Forces (Acceleration) $\downarrow$ $\rightarrow$ Impact vel. $\downarrow$

Then, from the previous results we should expect that:

The final springback will increase with temperature.
EXPERIMENTAL RESULTS

EMF Bending

Different temperatures

250°C
200°C
150°C
100°C
20°C

4.5 kJ

250°C
200°C
150°C
100°C
20°C

6 kJ

*Non homogeneous deformation in the whole flange

Increasing temperature: final angle is closer to the target angle

→ Reduction of springback due to decrease of yield strength with temperature
Concluding remarks:

Warm EMF is studied: **Higher deformation** values could be obtained increasing **temperature**

→ It could be suitable to form **complex geometries** in Mg parts

**Springback** behavior of magnesium sheet at high strain rates was studied (EMF bending experiments). It was shown that:

- Increasing the discharged energy the springback decreases
- Increasing temperature also decreases the springback

It is shown that temperature has different effect depending on the EMF operation:
- The decrease of electrical conductivity is important in drawing operations
- The decrease of yield stress is more important in bending
ONGOING WORK

Material Characterization at high strain rate biaxial loading:

- Microstructure and texture analysis (EBSD & Neutron diff.)

P_{\text{max}} = 9.1 \text{ m.r.d.}
P_{\text{max}} = 2.58 \text{ m.r.d.}

- Compare with uniaxial results

EMF of other Mg alloys (e.g. ZE10)

- Weaker initial texture
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Thank you for your attention!

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