MONDRAGON UNIBERTSITATEA

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ESCUELA POLITÉCNICA SUPERIOR

4th International Conference on High Speed Forming

Warm Electromagnetic Forming of AZ31B Magnesium Alloy Sheet

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labein tecnalia

Columbus, 09 March, 2010

OUTLINE

- Introduction and motivation
- Electromagnetic forming experiments
  - EMF drawing
  - EMF bending
- Conclusions and ongoing work

INTRODUCTION

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

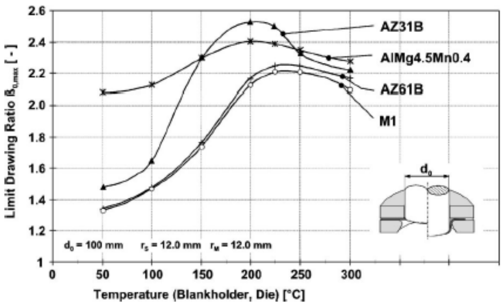
	Al	Mg	Steel	Ti
ρ	2.8	1.74	7.83	4.5
E	70	45	210	110
R_m	150-680	100-380	300-1200	910-1190
$R_m/\rho^{(1)}$	54-243	57-218	38-153	202-264
$E/\rho^{(2)}$	25.0	25.9	26.8	24.4
$\sqrt{R_m}/\rho^{(3)}$	9.3	11.2	4.4	7.7
$\sqrt[3]{E}/\rho^{(4)}$	14.7	20.4	7.6	10.6

[Kleiner et al. 2003]

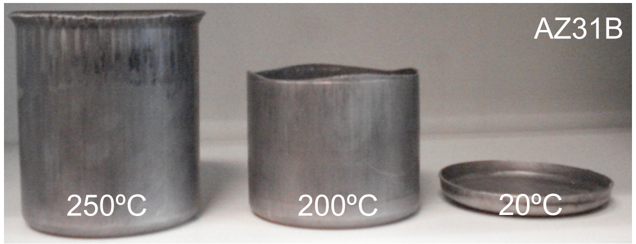
MOTIVATION

Strategies to increase formability:

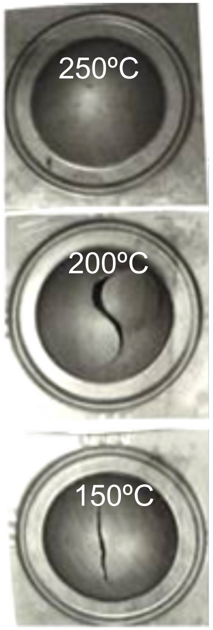
Increasing Temperature: Warm Forming



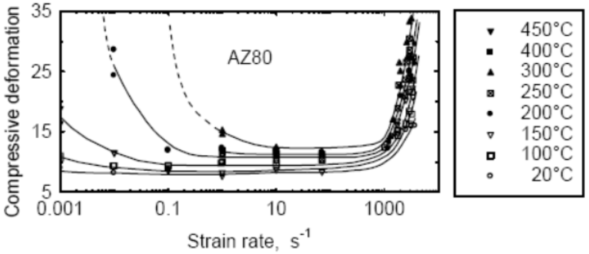
[Doege et al. 2001]



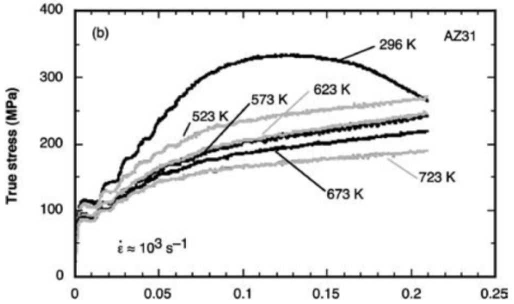
[Ulacia et al. 2008]



Increasing Strain Rate (EMF, EHF and explosive forming)



[El-Magd et al. 2004]



[Ishikawa et al. 05]

MOTIVATION

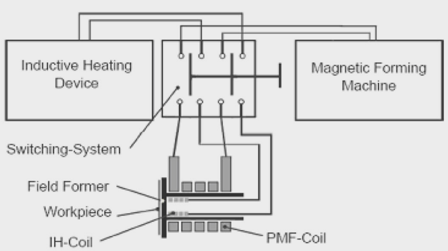
Previous work in EMF of Mg alloys:

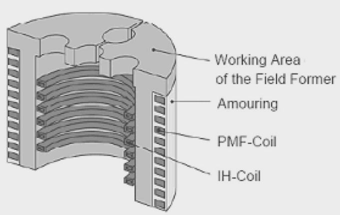
Tube

TU Berlin, Germany
[Uhlmann *et al.* 2004]

A **tool** for combining Inductive Heating and Magnetic Forming was shown.

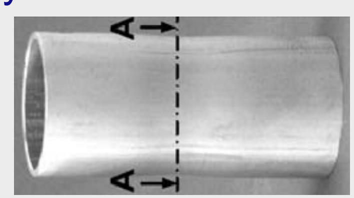
No deformed parts or values were shown





IUL Dortmund, Germany
[Psyk *et al.* 2006]

Suitability of different **extruded Mg tubes** for EMF was characterised



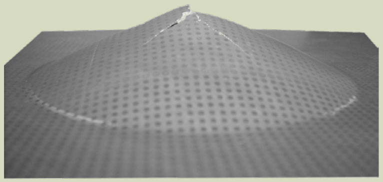
Sheets

VTT and Helsinki University, Finland
[Revuelta *et al.* 2007]

Increase of formability was reported for AZ31B, although deformation values were not shown

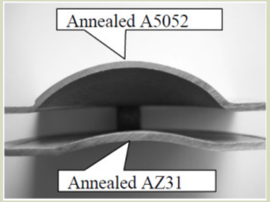
Labein and Mondragon Univ., Spain
[Ulacia *et al.* 2008]

Increase of formability was measured for AZ31B at Room Temp



AIST, Japan
[Murakoshi *et al.* 2008]

EMF at different temp.



APPROACH

Current research:

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

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

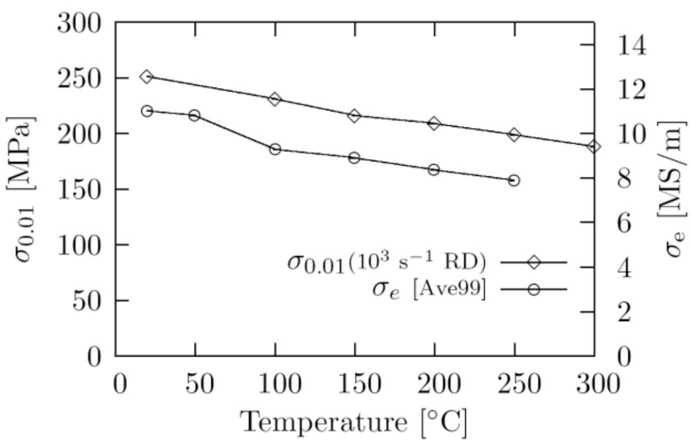
Element	Zn	Al	Si	Cu	Mn	Fe	Ni	Ca	Sn	Others
wt%	0.96	2.7	0.01	$\leq$0.01	0.21	0.002	$\leq$0.001	$\leq$0.01	0.00	$\leq$0.30

<u>Increasing temperature</u>

Decrease of electrical conductivity −

Decrease of yield strength +

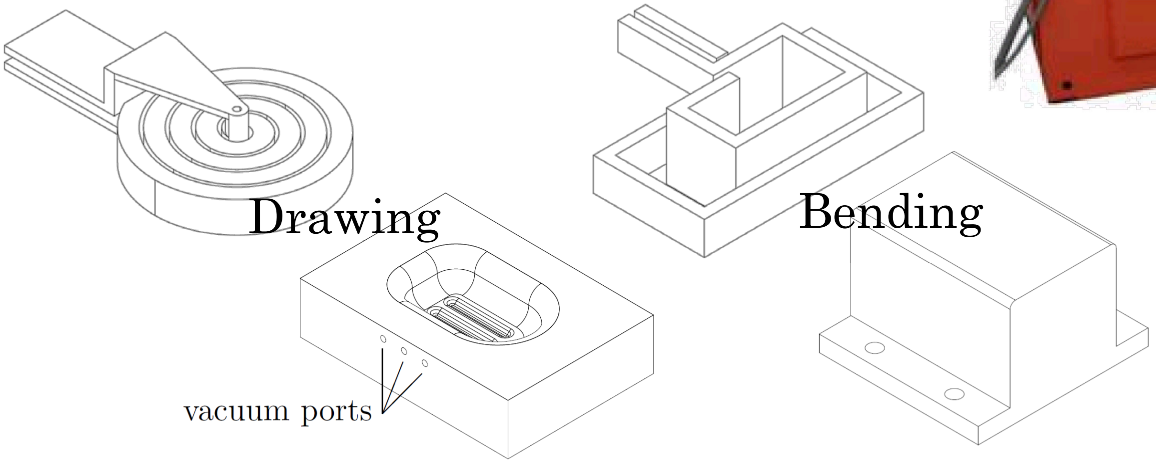
Increase of active def. mechanisms +



EMF at different temperatures:

Machine: Maxwell Magneform at *Labein-Tecnalia*

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



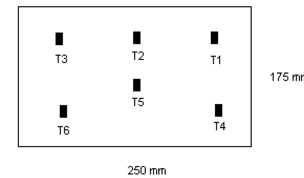
Test conditions:

- **Temperatures:** R.T., 100ºC, 150ºC, 200ºC, 250ºC
- **Discharged Energies:** 6 kJ - 15 kJ (Drawing)
  1 kJ – 6 kJ (Bending)

EXPERIMENTAL PROCEDURE

EMF at different temperatures:

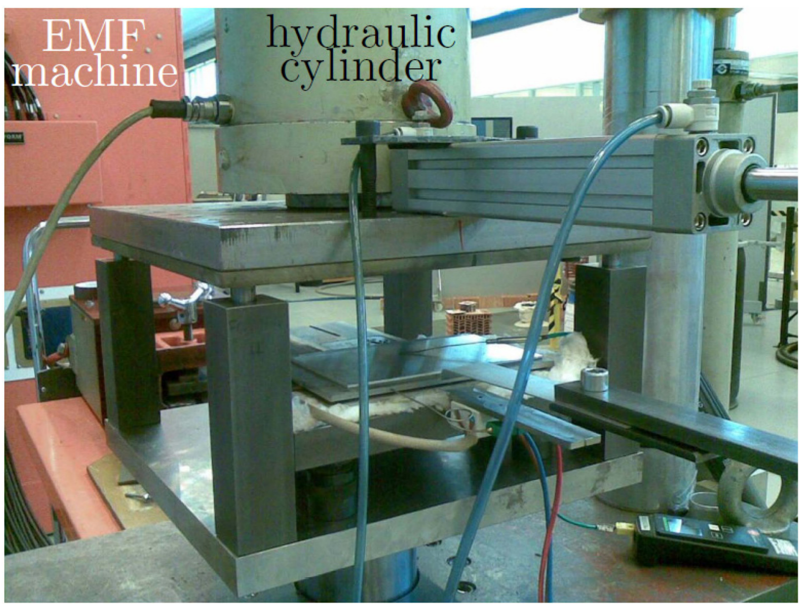
Heating Strategy: Heating outside the forming position



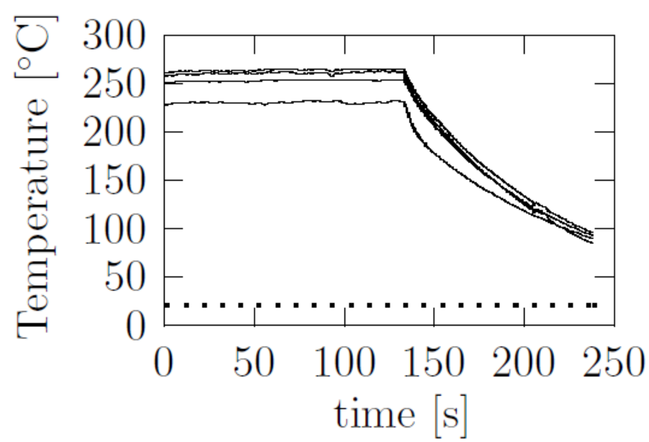
Step 1. Heating: Temperature was controlled with thermocouples

Step 2. Automatic Transfer: Temp drop measured (Cooling curves for each Temp)

Step 3. Closing and EMF discharge:
Time for discharging measured → Initial Temp.

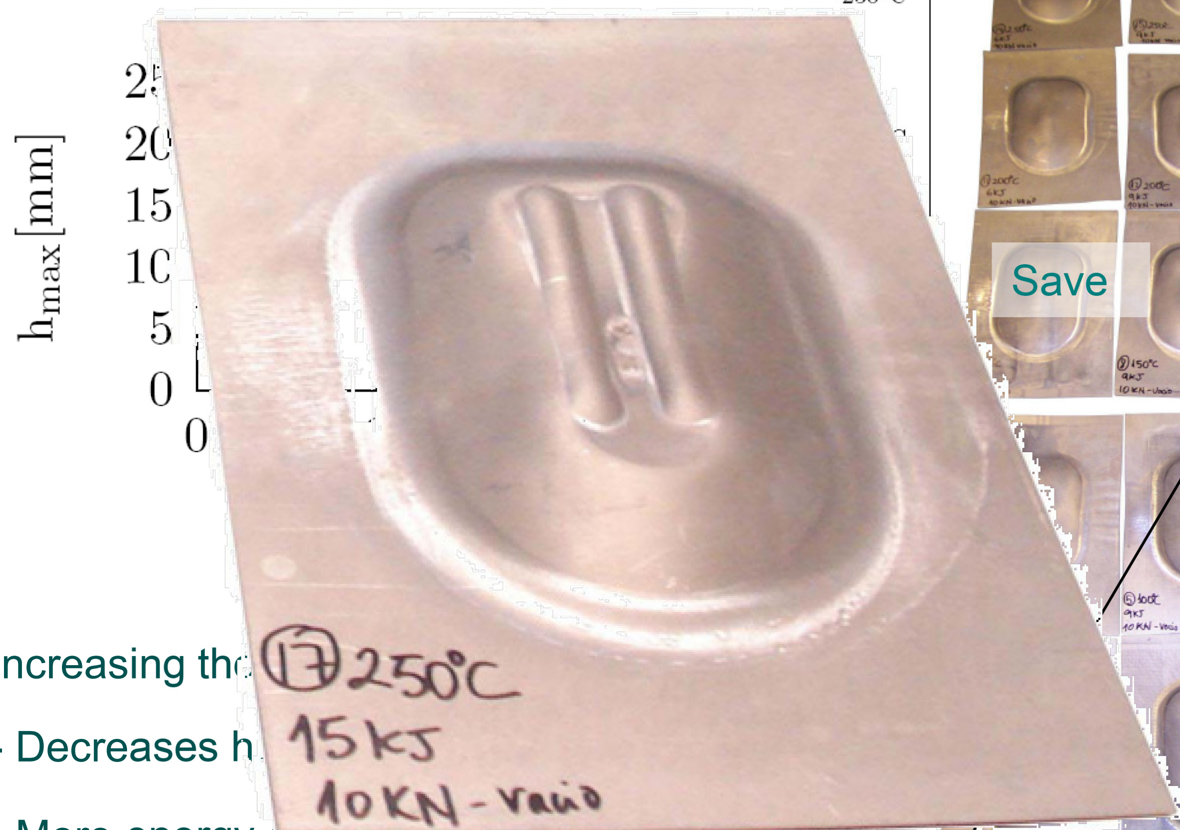


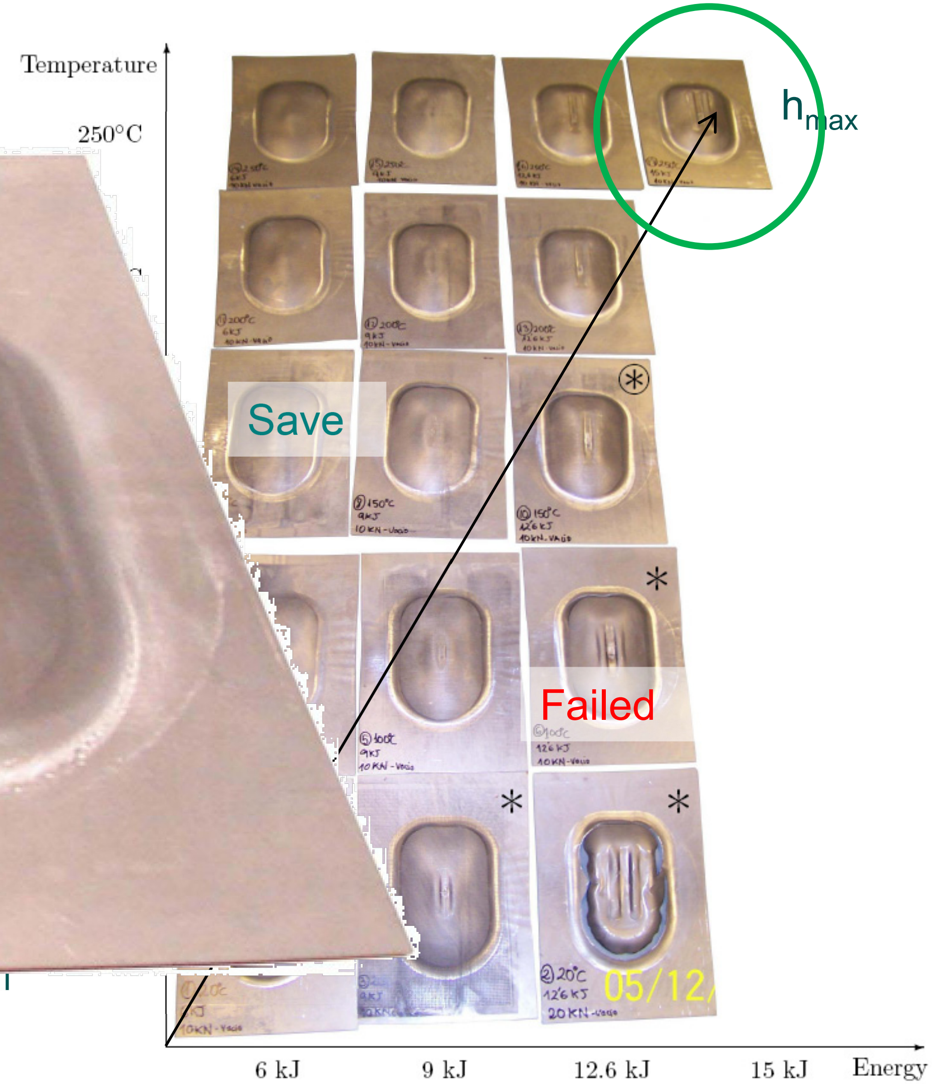
Cooling curve for 250ºC



EXPERIMENTAL RESULTS

EMF Drawing





Increasing th

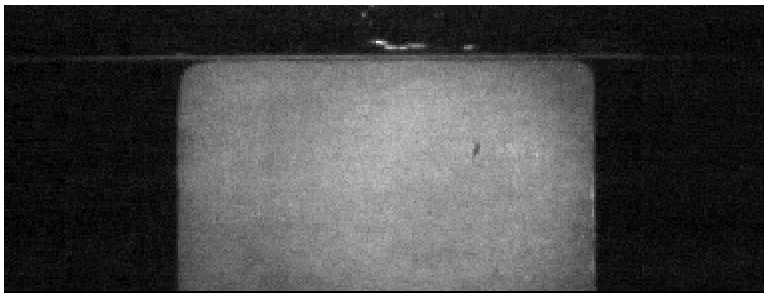
- Decreases h
- More energy … obtain

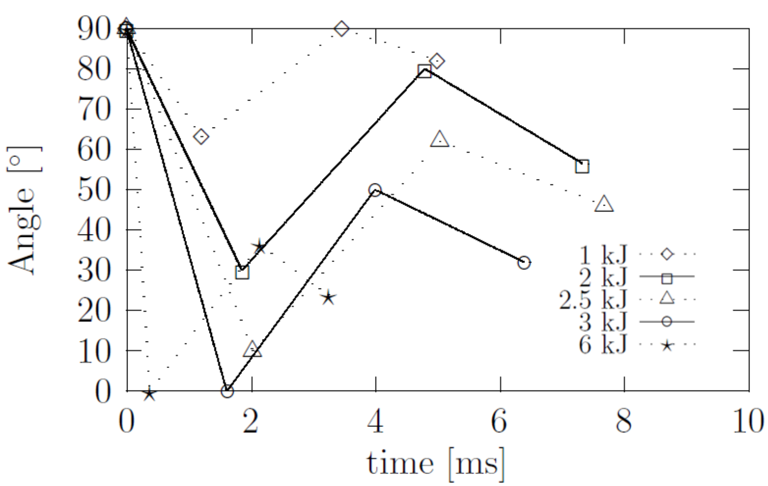
EXPERIMENTAL RESULTS

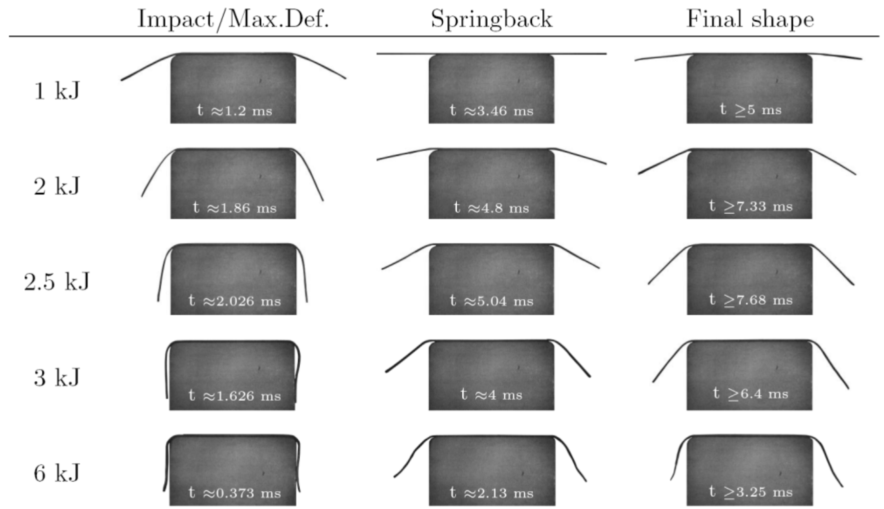
EMF Bending

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 ↑ (Elect. Conductivity ↓) → Forces (Acceleration) ↓ → Impact vel. ↓

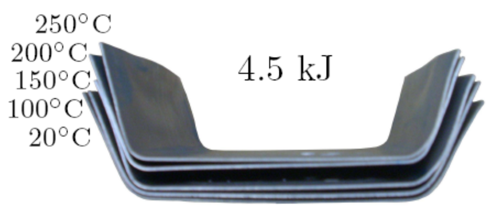
Then, from the previous results we should expect that:

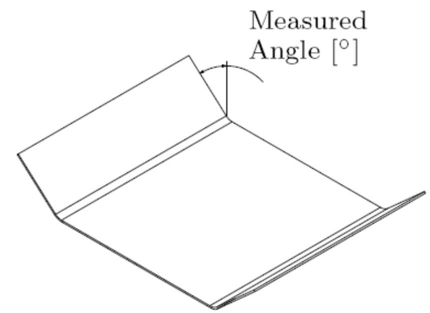
The final springback will increase with temperature.

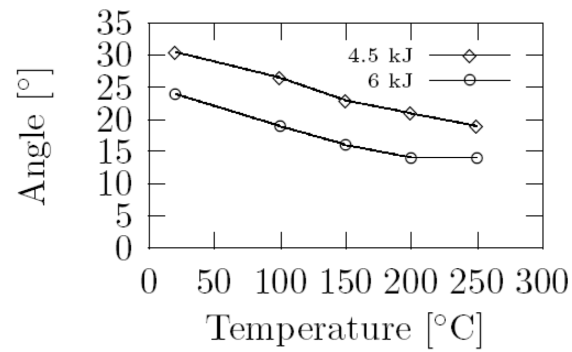
EXPERIMENTAL RESULTS

EMF Bending

Different temperatures







*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

CONCLUSIONS

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

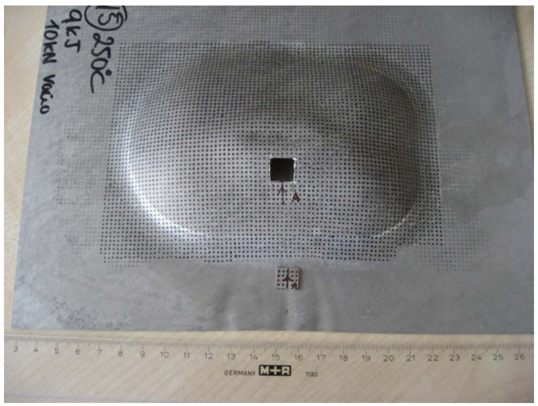
It is shown that temperature has different effect depending on the EMF operation:

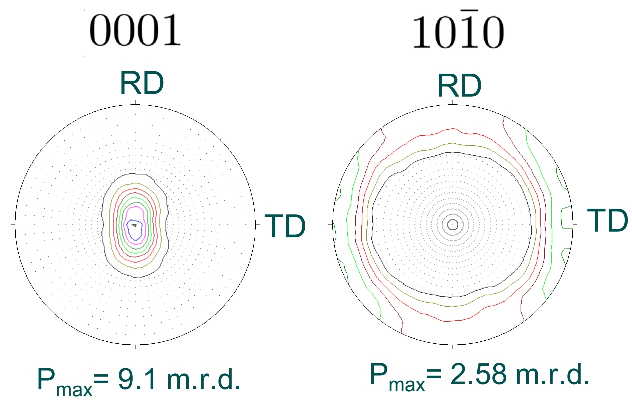
- The decrease of electrical conductivity is important in drawing operations
- The decrease of yield stress is more important in bending

ONGOING WORK

Material Characterization at high strain rate biaxial loading:

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





- Compare with uniaxial results

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

- Weaker initial texture

Thank you for your attention!

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