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Pulsed magnetic forming of the magnesium alloy AZ31 – Comparison to quasi-static forming

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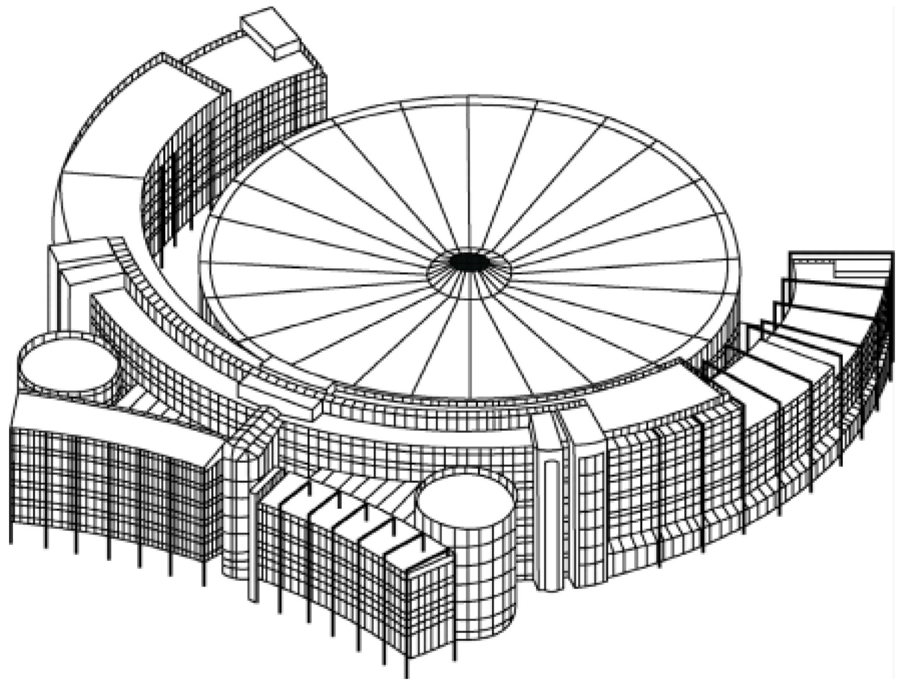

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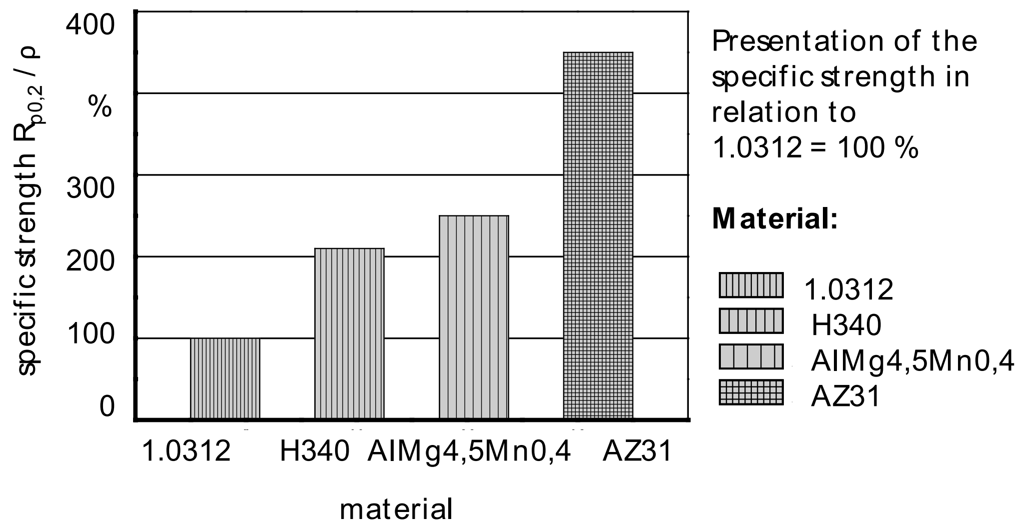
Introduction

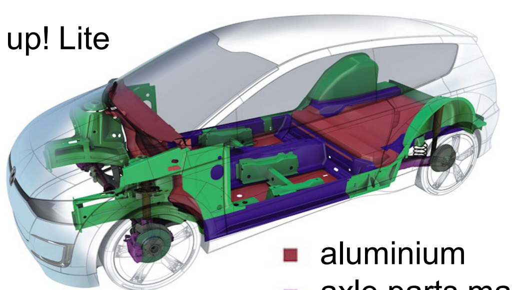
Motivation

- Lightweight designs preserve resources and thus eco-efficient
- Modular design using different materials
- Magnesium-based alloy lighter than steel or aluminium
- Magnesium alloy have high specific strength



Presentation of the specific strength of different materials

VW up! Lite



- aluminium
- axle parts made of magnesium
- hardened steel
- conventional steel

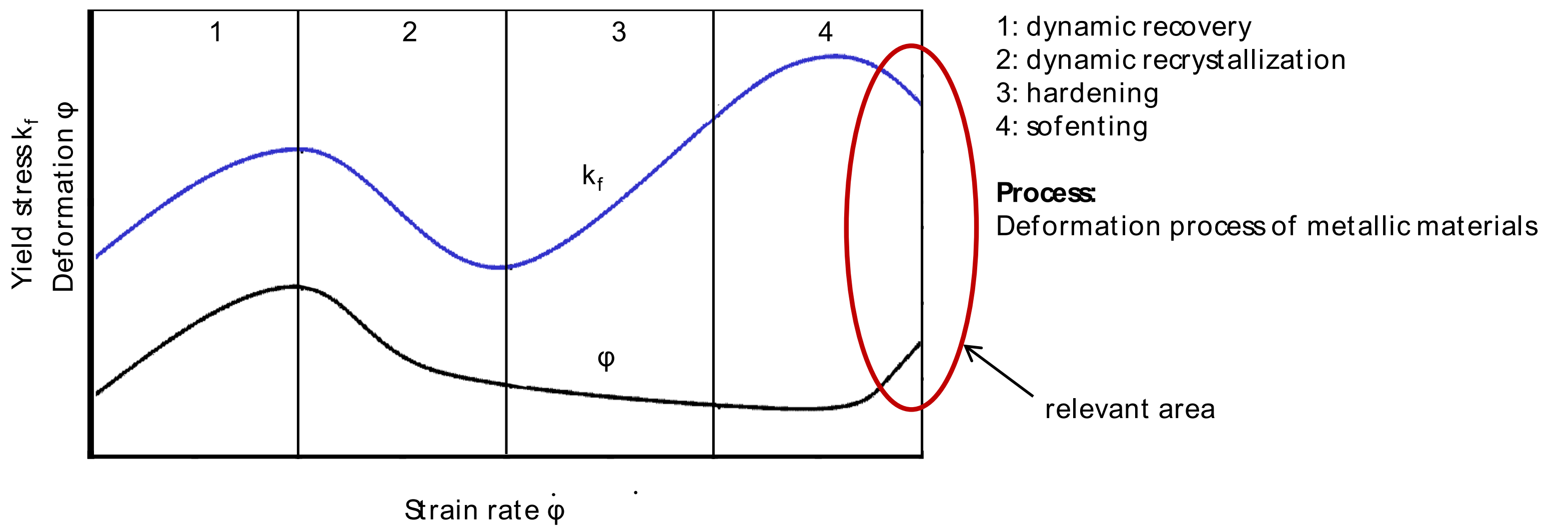
Picture: Autobild

Picture: Droeder, K. G.: Untersuchungen zum Umformen von Feinblechen aus Magnesiumknetlegierungen. Dissertation, Universität Hannover, 1999

Forming of Mg-alloy

Conditions

- Magnesium alloys have hexagonal lattice structure
- Limited formability at room temperature
- High speed forming is an approach



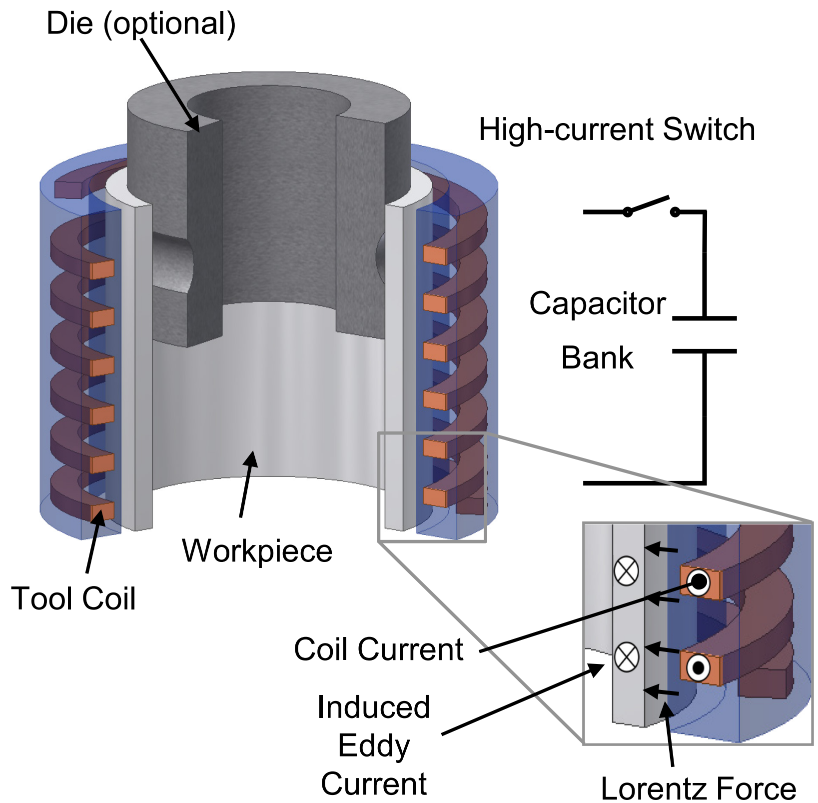
- Formability of magnesium alloy AZ80 increases at high strain rates and temperatures[1]

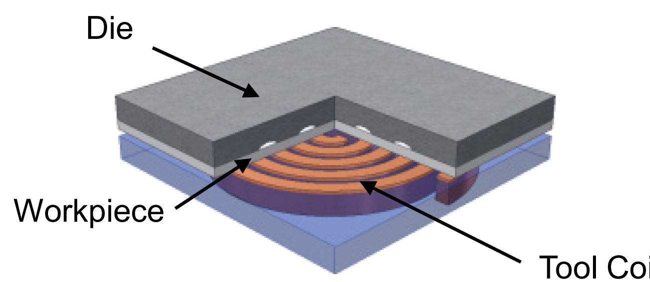
[1] El-Magd: „Einfluss der Umformgeschwindigkeit und -temperatur auf das Umformvermögen metallischer Werkstoffe unter Druckbelastung (Teilprojekt 1) und Zugbelastung (Teilprojekt 2)". In: Erweiterung der Formgebungsgrenzen bei Umformprozessen, Final report DFG-SPP 1074 - Ergebnisse aus 48 Forschungsprojekten (1999-2005)

Process

Electromagnetic Forming

- Alternating current through tool coil
- Temporarily varying magnetic field induces electrical currents inside workpiece
- Lorentz force acts on a current-carrying workpiece inside the magnetic field
- Process duration of 50 µs to 200 µs
- Non-contact forming
- Joining of different, also non-metallic materials
- High flexibility due to simple adjustment of the tool to workpiece geometries

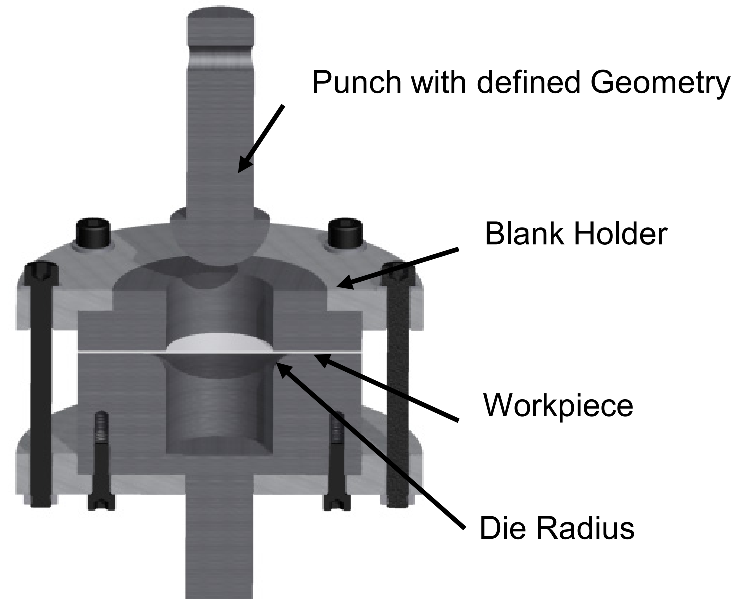


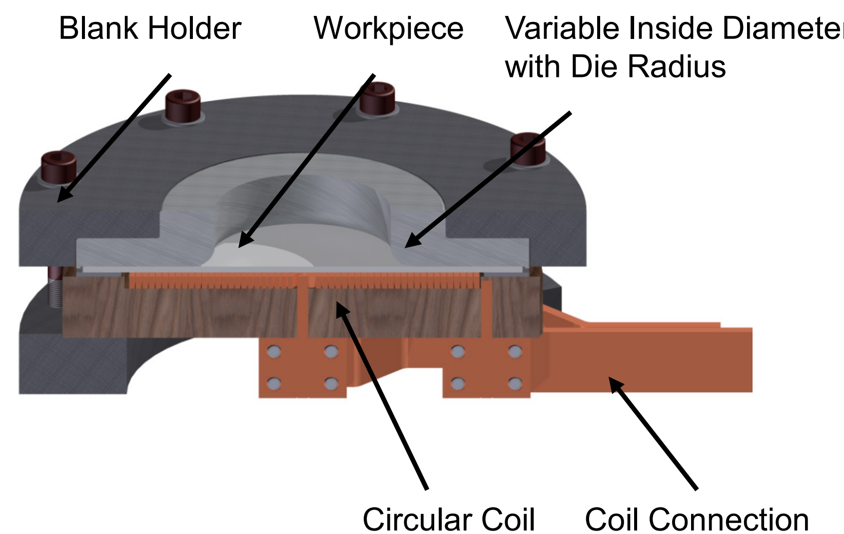


Experimental Setup

Approach

- Development of experimental setups
  for high-speed forming and quasi-static forming
- Warranty of comparing boundary conditions
- Forming of magnesium alloy AZ31
  - Different strain rates
  - Different deformation
- Evaluation of formed geometries
  - Evaluation of geometrical structure
  - Evaluation of hardness
  - Evaluation of texture



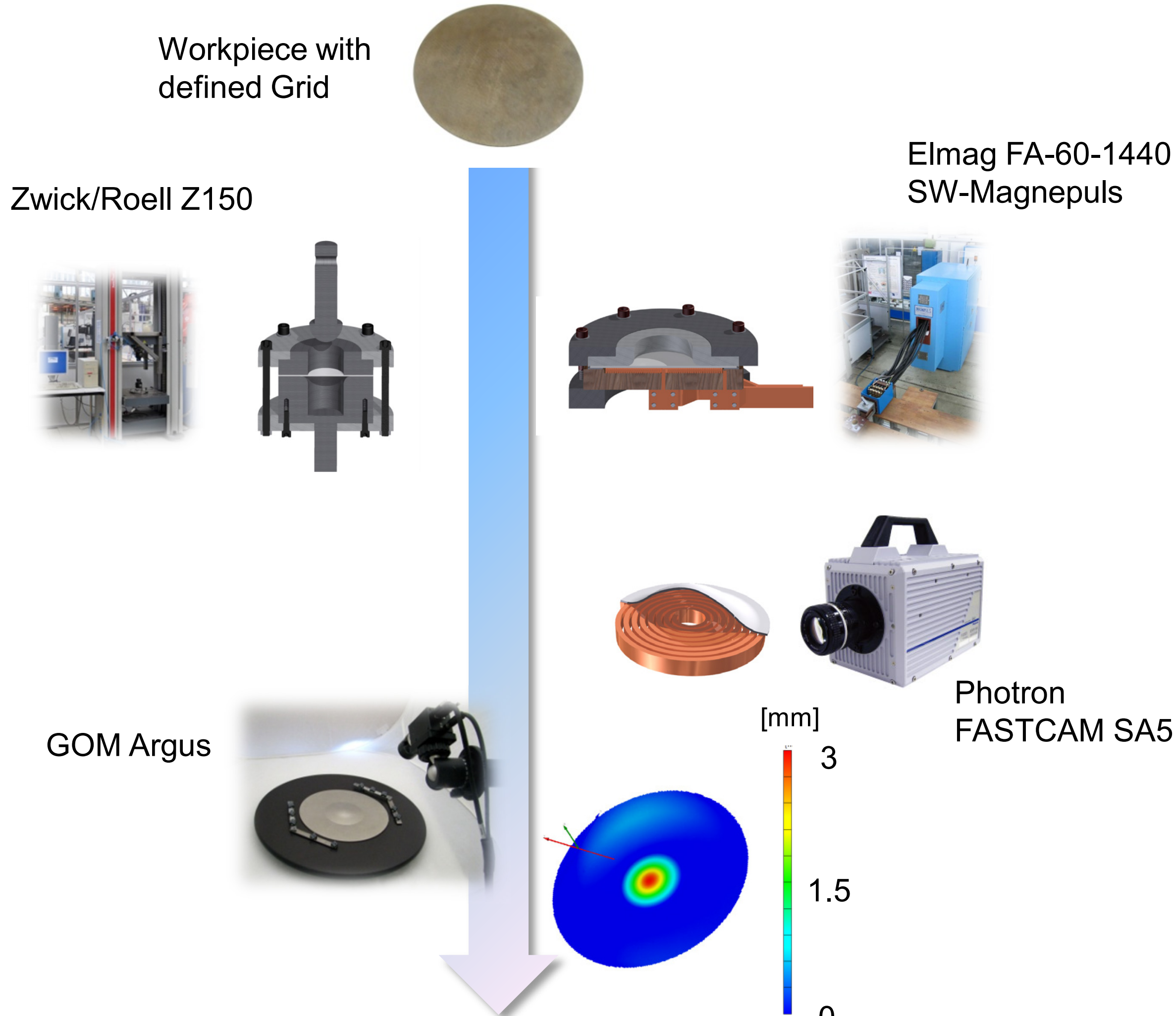


Experimental Setup

Process chain

- Sample preparation
  - Sample generation
  - Grid generation
- Preparation of experimental setup
- Experimental procedure
  - High-speed photography
- Data evaluation
  - Optical measurement (GOM)
  - Hardness
  - Texture

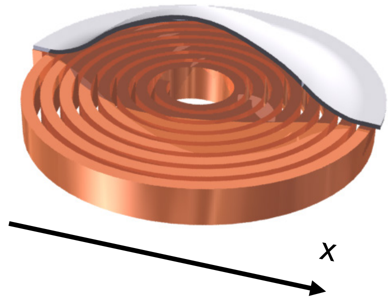
Quasi-static forming **High-speed forming**

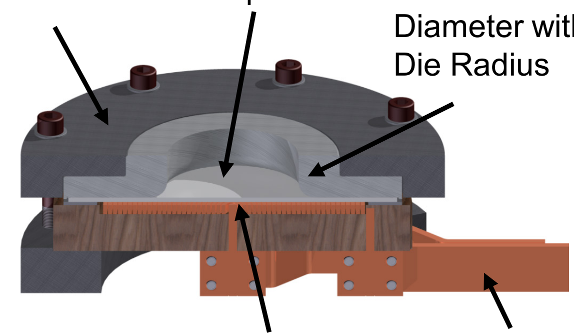


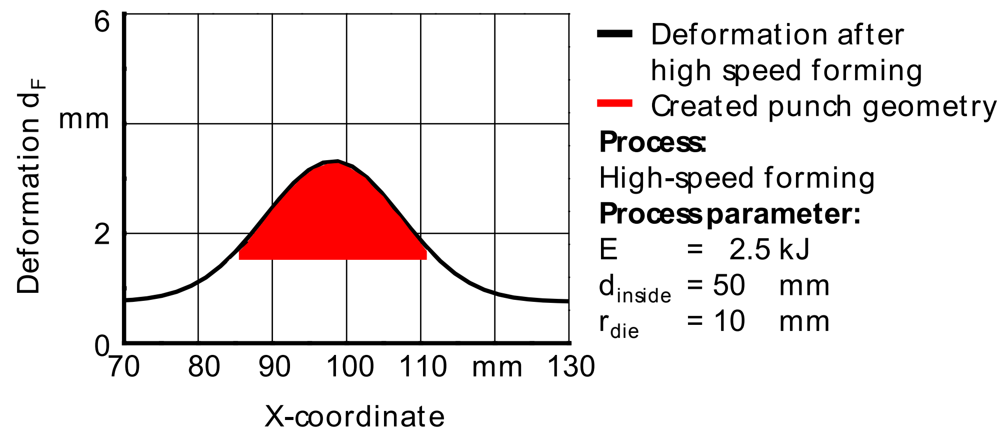
Experimental Setup

Definition of punch geometry

- Experimental setup for high-speed formi
- Defined boundary conditions
- Creation of defined forming geometry
- Production of a defined punch
  - Hardness of 750 HV 30 in according to Erichsen-Test



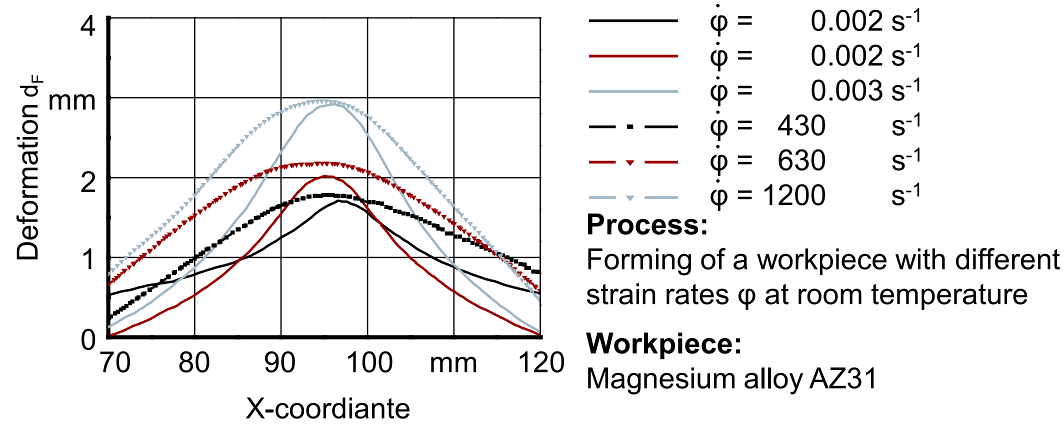


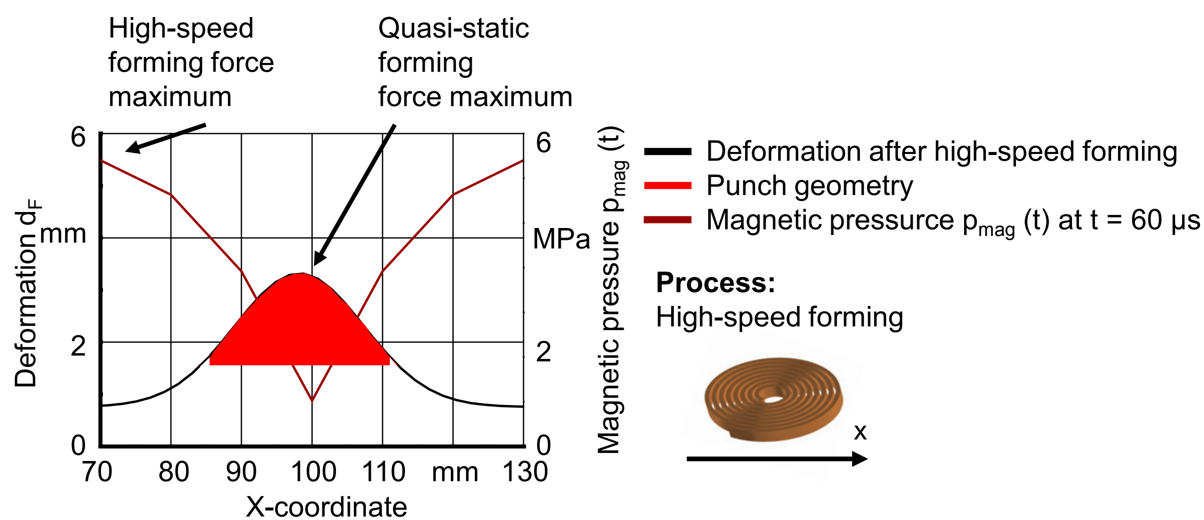


Experimental Results

Deformation

- Maximum deformation d_F at different strain rates at room temperature
- No occurance of cracks in the deformation area
- Different forming geometries
  - Quasi-static forming
    - Maximum force in the center of the punch
    - Friction between punch and workpiece
  - High-speed forming
    - Maximum force outside of coil center





Experimental Results

Plastic strain

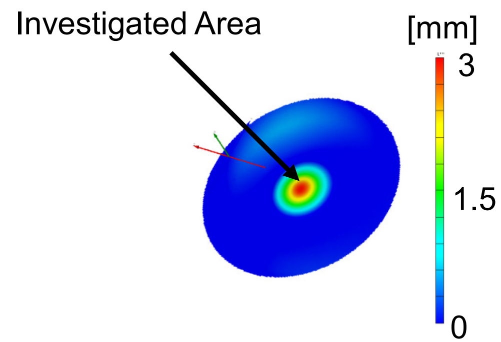
- Differences in plastic strain at same deformation in dependence of strain rates in investigated area
- Significantly larger maximum strains for quasi-statically deformed workpieces
- No occurance of cracks in the deformation area at reached deformation d_F
    - Deformation $d_F > 3$ mm leads to failure of workpiece at quasi-static forming
    - At high-speed forming deformation d_F up to 6 mm were realized

Quasi-static forming

Deformation d_F	Maximum plastic strain ε_{pl}
1.7 mm	8.0 %
2.0 mm	11.5 %
2.9 mm	13 %

High-speed forming

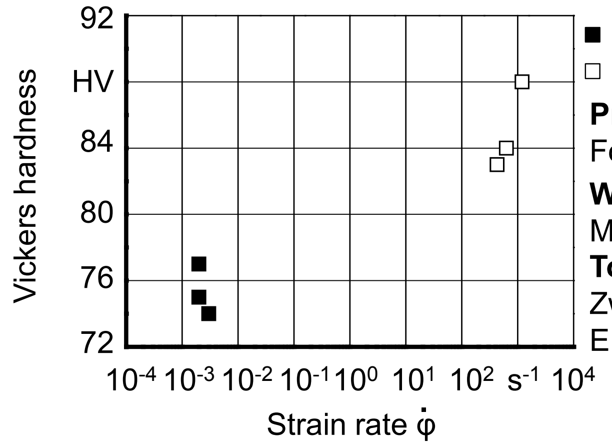
Deformation d_F	Maximum plastic strain ε_{pl}
1.8 mm	3.8 %
2.2 mm	4.8 %
3.0 mm	6.0 %



Experimental Results

Hardness

- Significant differences in Vickers hardness (HV) in dependence of strain rate
- Average difference of 11 HV between both processes
- Initial hardness of AZ31 63 HV
  - Increase of average hardness HV of 19 % at quasi-static forming
  - Increase of average hardness HV of 37 % at high-speed forming

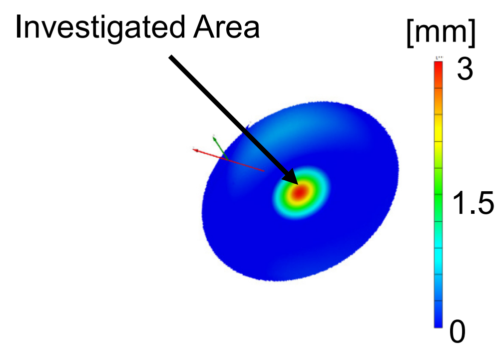


■ Quasi-static forming
□ High-speed forming

Process:
Forming at room temperature

Workpiece:
Magnesium alloy AZ31

Tool:
Zwick/Roell Z150 testing machine
Elmag FA-60-1440-SW-Magnepuls

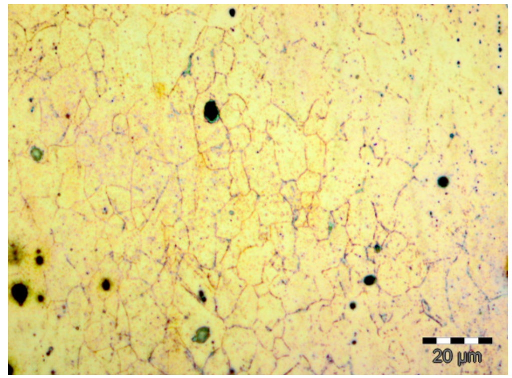


Experimental Results

Texture

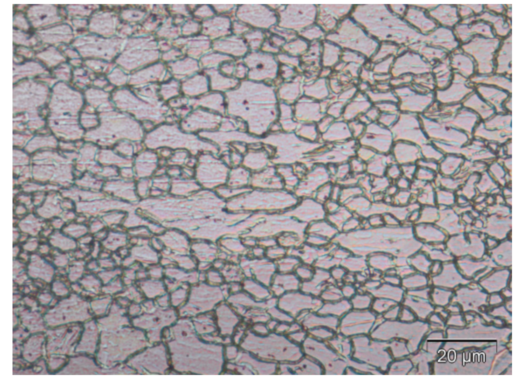
- Formation of different grain structures in dependence of strain rates can be suggested
- High-speed forming
  - Quasi-adiabatic process
- Quasi-static forming
  - Hardening process

Quasi-static forming



Parameter:
ε_{pl} = 11.5 %
$\dot{\varphi}$ = 0.002 s^{-1}

High-speed forming



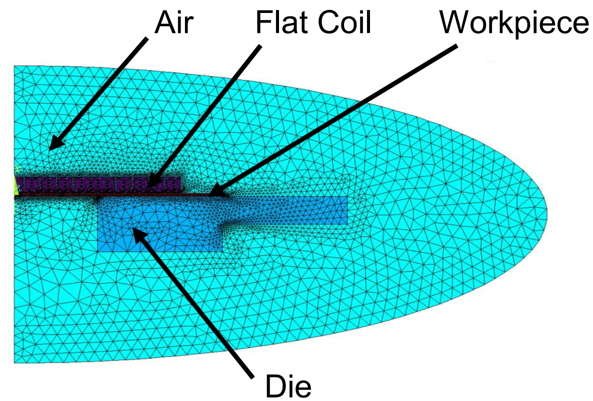
Parameter:
ε_{pl} = 4.8 %
$\dot{\varphi}$ = 630 s^{-1}

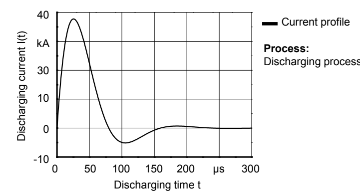
Conclusion

- Realization of different deformations at different strain rates with comparable boundary conditions
- Forming geometries were generated by different methods
- Generated forming geometries exhibit different characteristics due to different local maxima in forces
- Realized strains in deformation area at the same forming geometries vary depending on the strain rates
- Due to different strain rates the Vickers hardness in the deformation area varies

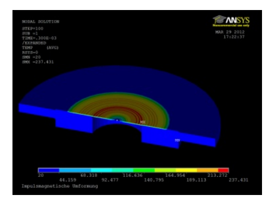
Outlook

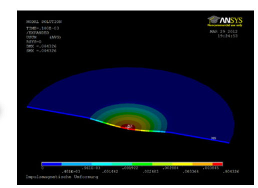
- Simulation of the whole forming process
  - Circuit
  - Electomagnetic simulation
  - Thermal simulation
  - Structural simulation
- High-speed adjusted material model
- Investigation of influence on maximum forming geometry in dependence of different coil geometries





Electromagnetic Simulation





Thermal Simulation

Structural Simulation

Thank you very much for your attention!

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