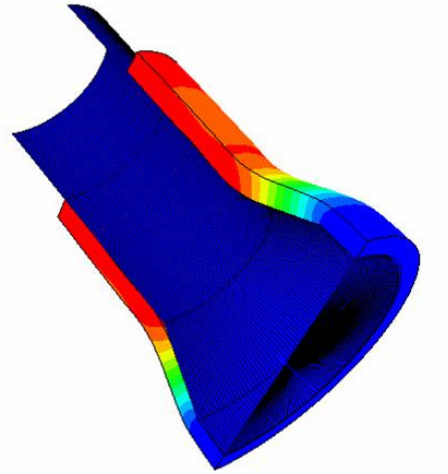
Fundamentals of EMPT-Welding

TECHNISCHE UNIVERSITÄT DARMSTADT

4th International Conference on High Speed Forming
March 9-10 2010
Columbus, Ohio



Prof. Dr.-Ing. Dipl.-Wirtsch.-Ing. P. Groche
Dipl.-Ing. A. Elsen

Institute for Production Engineering and Forming Machines
Technische Universität Darmstadt
Germany

ZIM impulse für wachstum Zentrales Innovationsprogramm Mittelstand

PST products Wir geben Impulse!

Outline

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- Introduction and Motivation
  - Basic Principles of the EMP–Technology
  - The EMP-Welding Process
- Objective and Approach
- Results
  - Simulation of EMP–Welding Zone
  - Welding Experiments
  - Metallographic Examination
  - Concept for Test Stand
- Summary and Outlook

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Electromagnetic Pulse Technology (EMPT)

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- The EMPT (Electromagnetic Pulse Technology) utilizes the force effect of an impulse-type magnetic field for the acceleration of planar (e.g. sheets) or cylindrical structures (e.g. tubes, profiles, etc) of conductive materials.

- Depending on the conceptual design of the tools, the selection of materials and the adjustment of parameters, the EMPT can be subdivided in:

> Electromagnetic Pulse **Joining**,

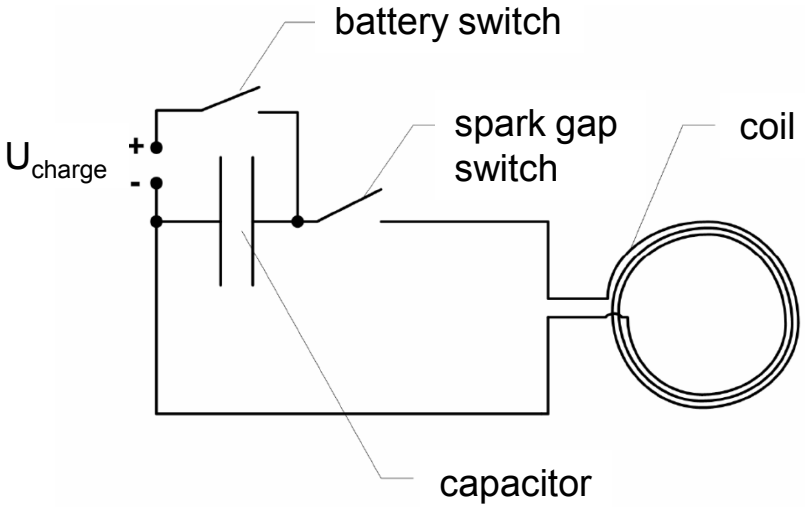
> Electromagnetic Pulse **Forming**,

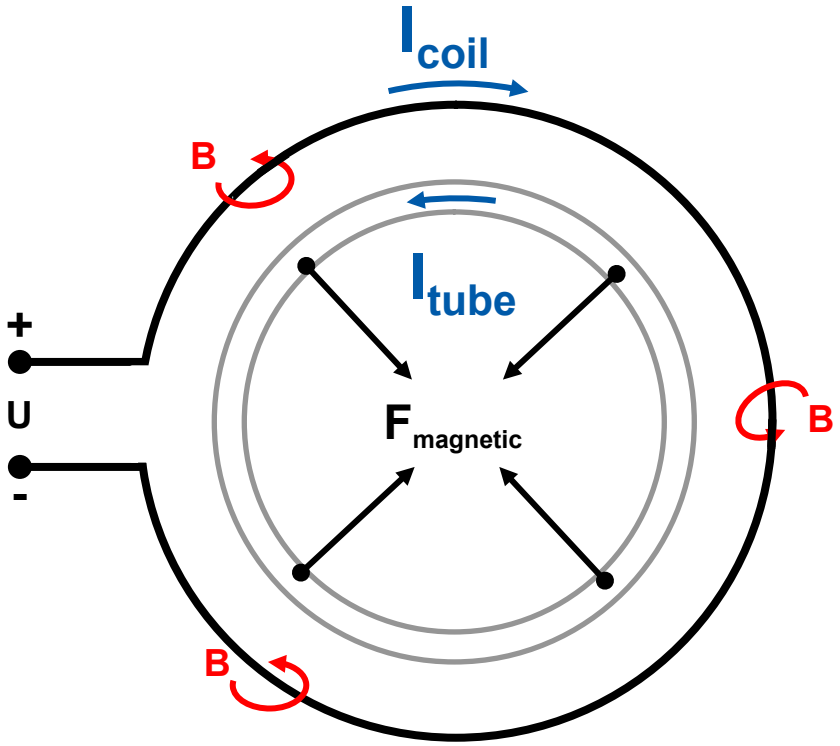
> Electromagnetic Pulse **Cutting**

> Electromagnetic Pulse **Powder Compaction** and

> Electromagnetic Pulse **Welding**

Process Sequence





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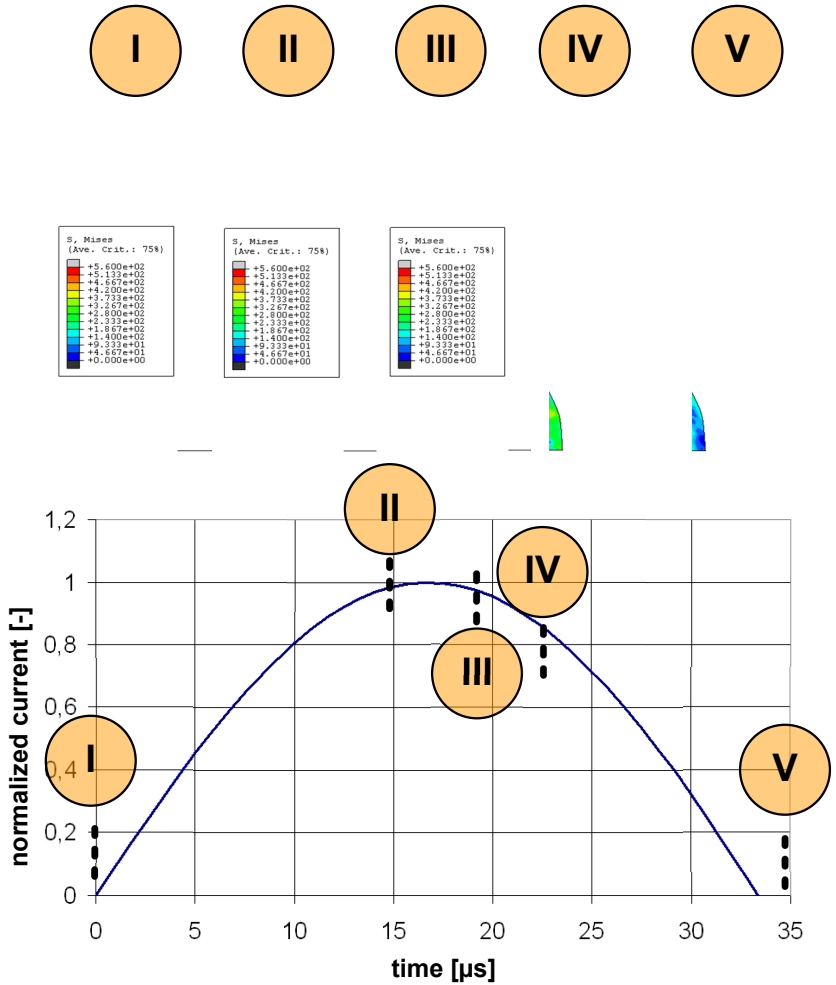

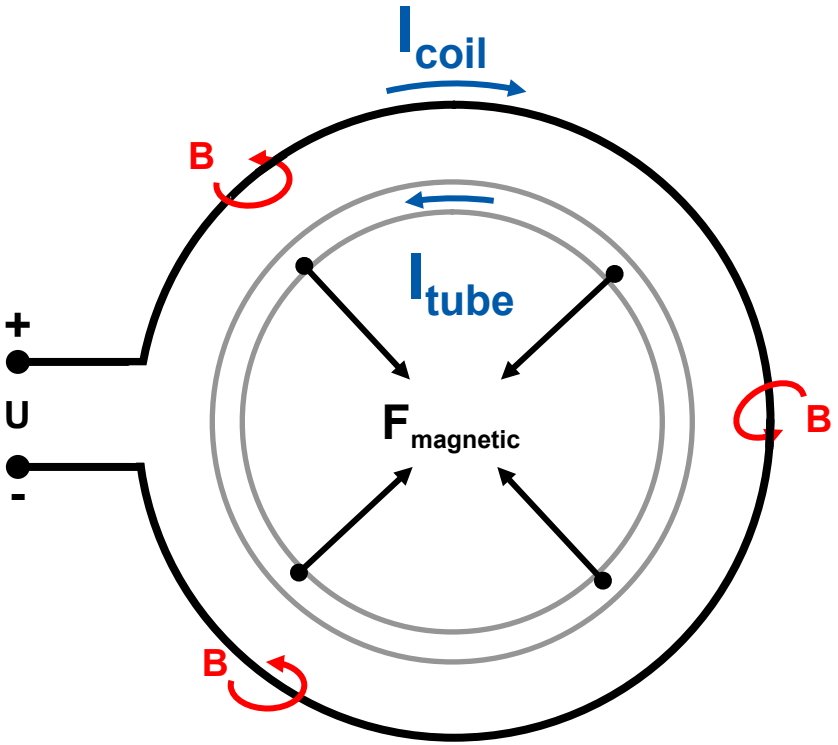

Variety of Parts

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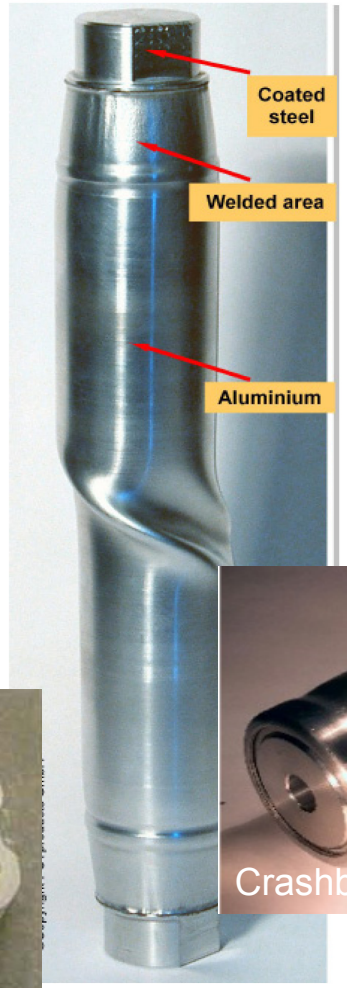
Typical Products are:

- Hybrid and Lightweight Structural Parts
- Automotive Crash Management Structures
- Filter Bodies and Cases
- Hybrid-Driveshafts
- other Hybrid Metal Assemblies



Driveshaft

PST products
Wir geben Impulse!

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The EMP-Welding Process

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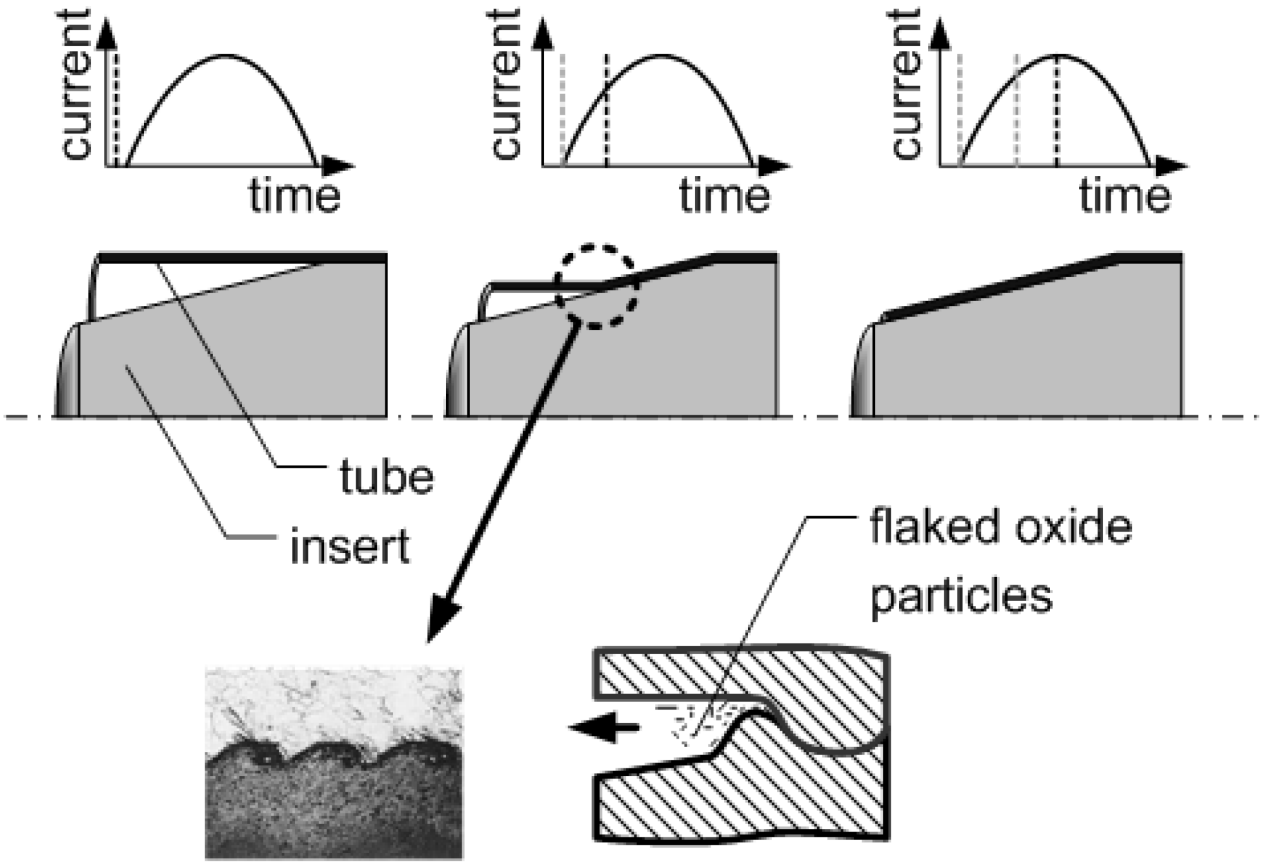
Integral joining of metallic parts without addition of thermal energy



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Characterstics of EMP-Welding

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Advantages

- **no thermal loads** on the parts as in conventional welding processes
- **no extensive preparations** as in adhesive joining
- **non-contacting** forming forces
- feasibility joining of **joining dissimilar materials**
- **high repeat accuracy** at an actual production time of <0.1 s
- high potential of **automation** as well as manual handling without particular technical skills
- **no additives** or auxiliary materials required

Disadvantages

- several **unknown process parameters**
- procedure of **“trial and error”** in prototyping

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Collaborative Research Project

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Overall Objective

Programming of an „Expert System EMP-Welding“

for the numerical dimensioning of relevant process parameters prior to prototyping

Development of a conventionally driven test stand with reduced complexity for the investigation of high-speed impacts

- identification of process windows for welding of Al-Al, Al-steel and steel-steel combinations
- study of the joining mechanism
- numerical modeling of the forming process and validation by experimental data
- conduction of experiments on joint strength
- coding of scripts and subroutines; implementation into FEA-software

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Numerical Simulation of EMPW-Process

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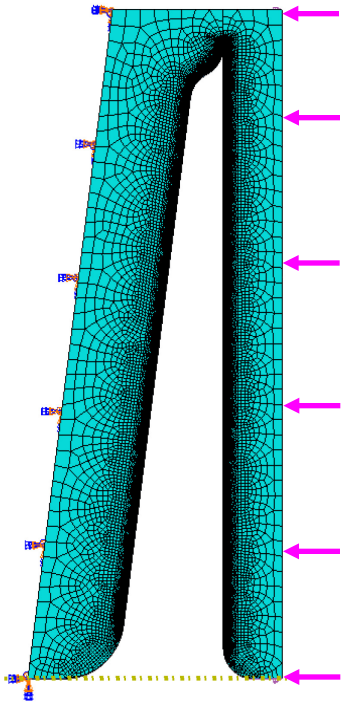
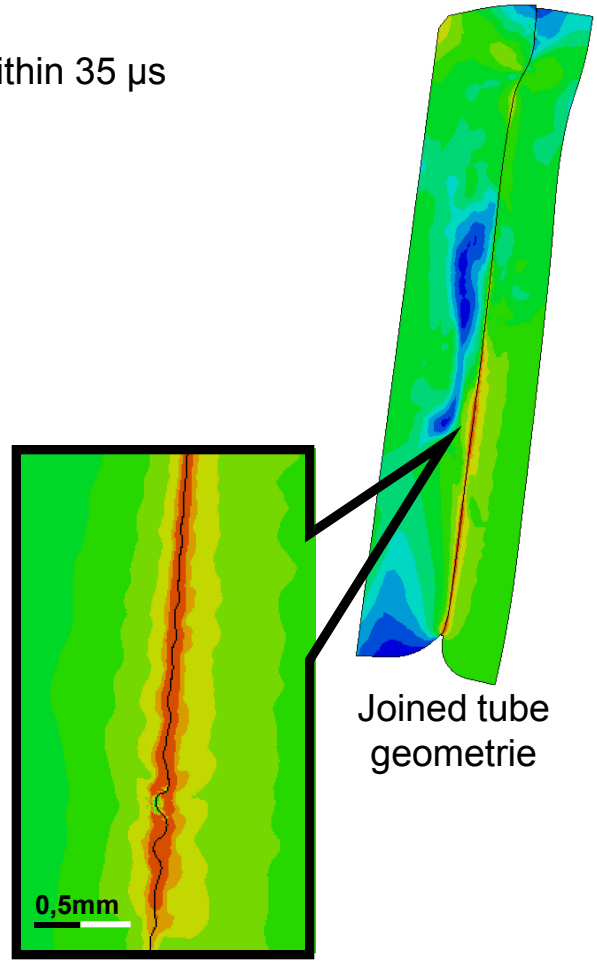
- rotationally-symmetric model consisting of two tubular parts
- Application of the magnectic pressure with a sinusodial amplitude within 35 µs



fixed part

sinusodial load



Joined tube geometrie

Wave formation

Identification of relevant parameters for the simulations:

- Element size of 5 µm in the forming zone
- Adaptive remeshing with 20 sweeps per increment

Numerical Simulation of EMPW-Process

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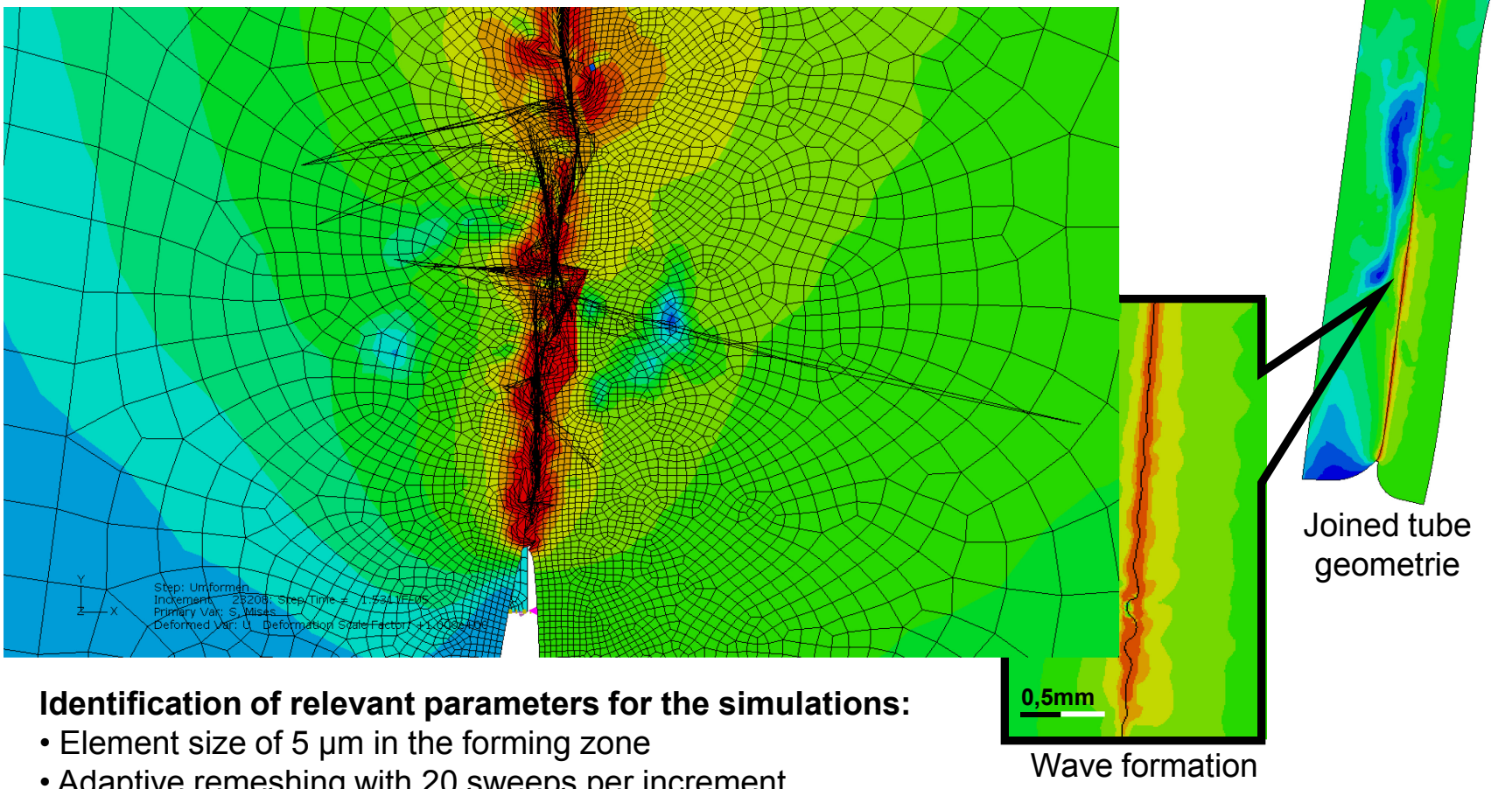

Identification of relevant parameters for the simulations:

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Numerical Simulation of EMPW-Process

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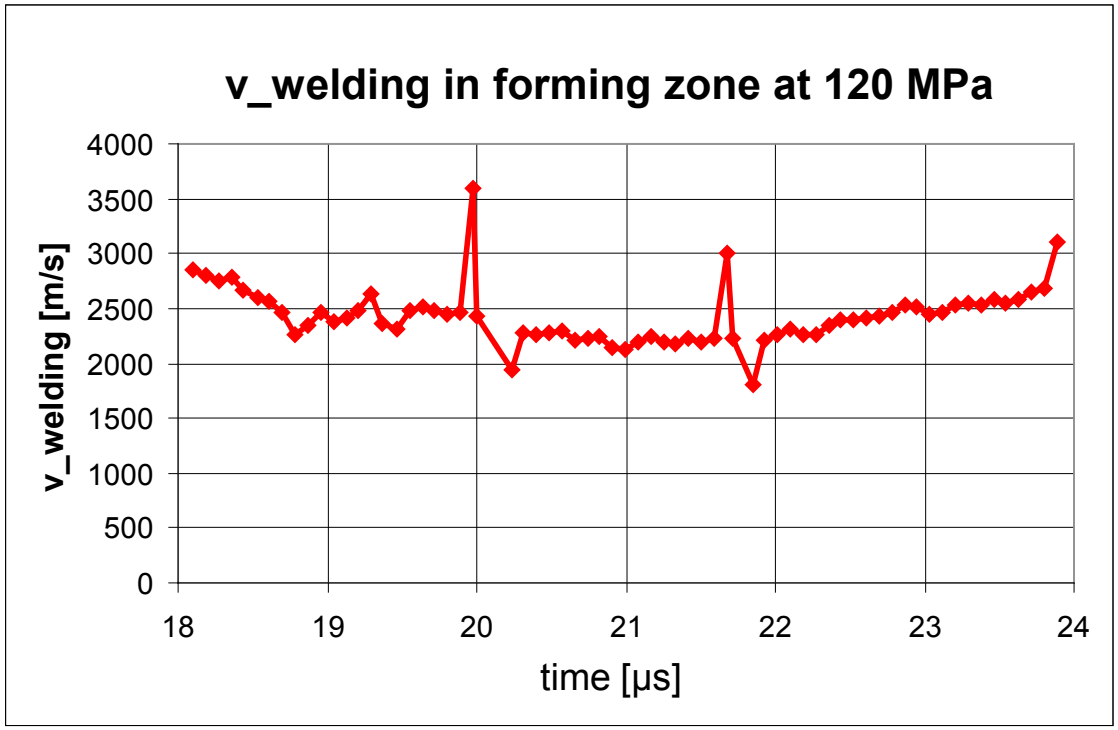
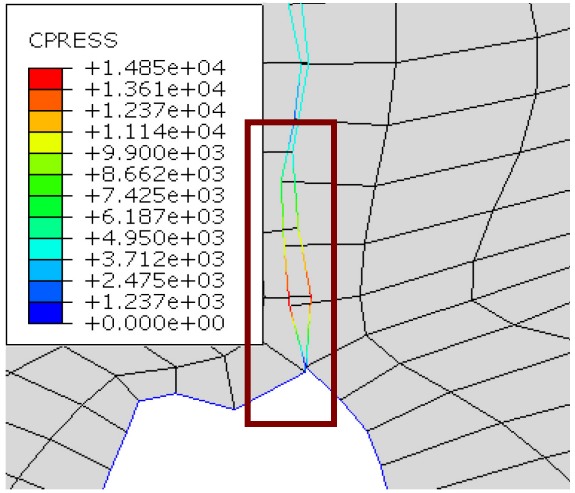
- local welding velocity v_welding: 300 - 4000 m/s
- formation of a wavy interface
- normal contact forces 2 – 8 GPa





limited significance of contact normal force values due to element penetration

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Numerical Simulation of EMPW-Process

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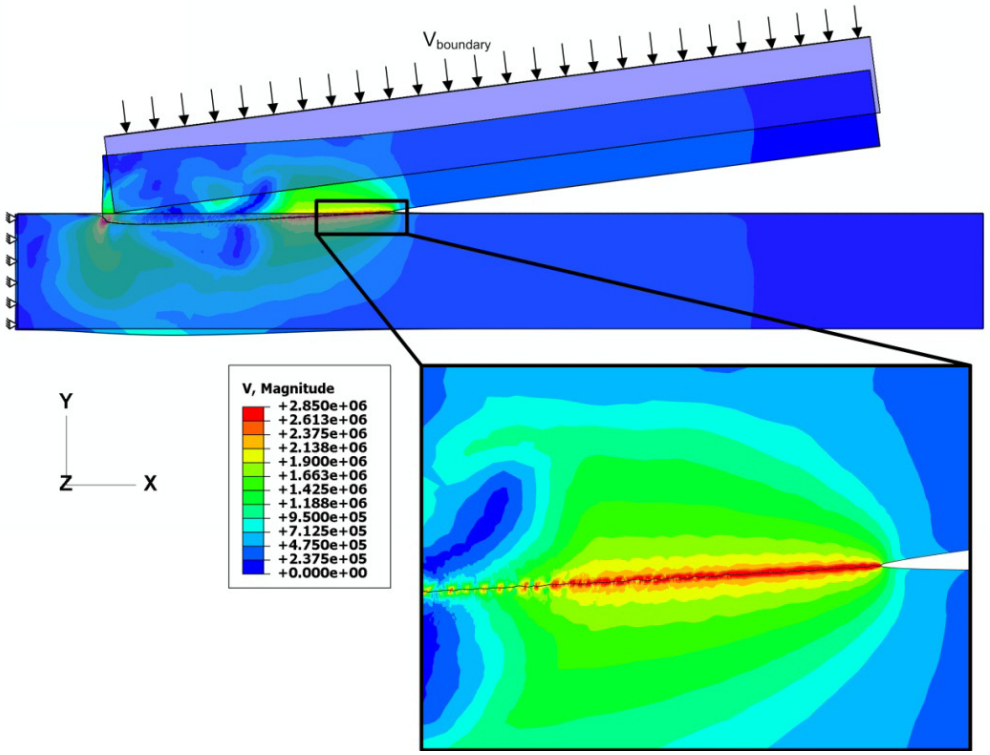
Abstraction of the process to reduce computing times:

- no sinusodial pressure but presetting of impact velocity
- utilization of mass inertia
- planar sheet metal in place of tubular parts



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Numerical Simulation of EMPW-Process

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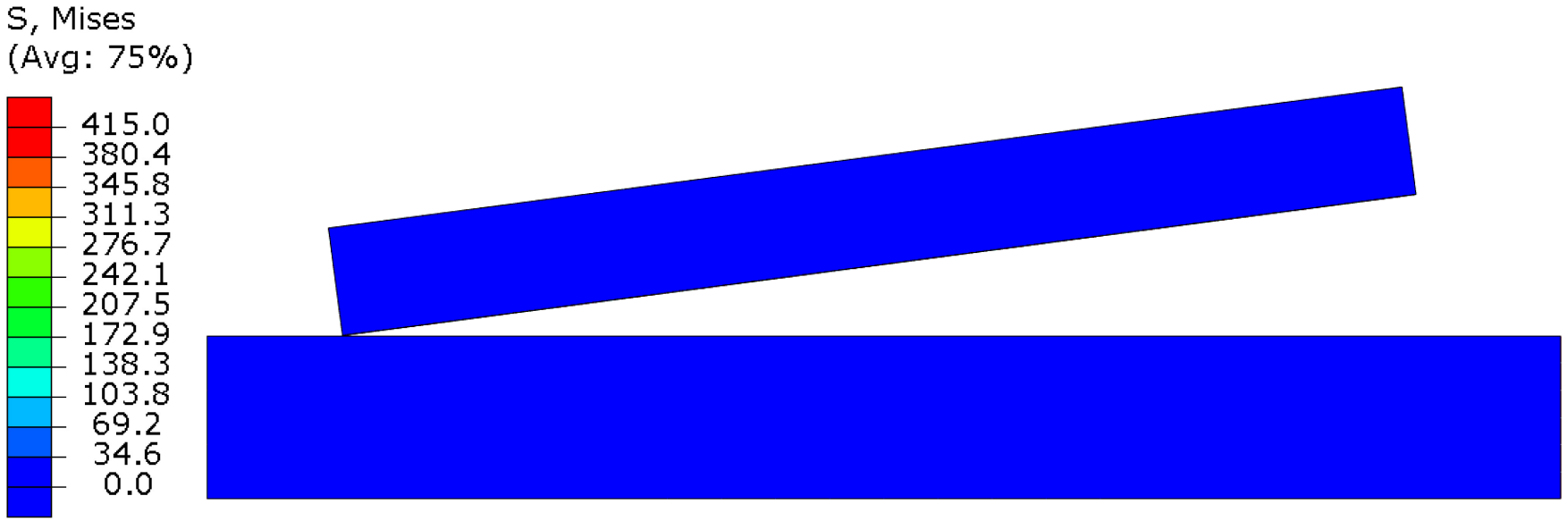

Results: normal contact forces

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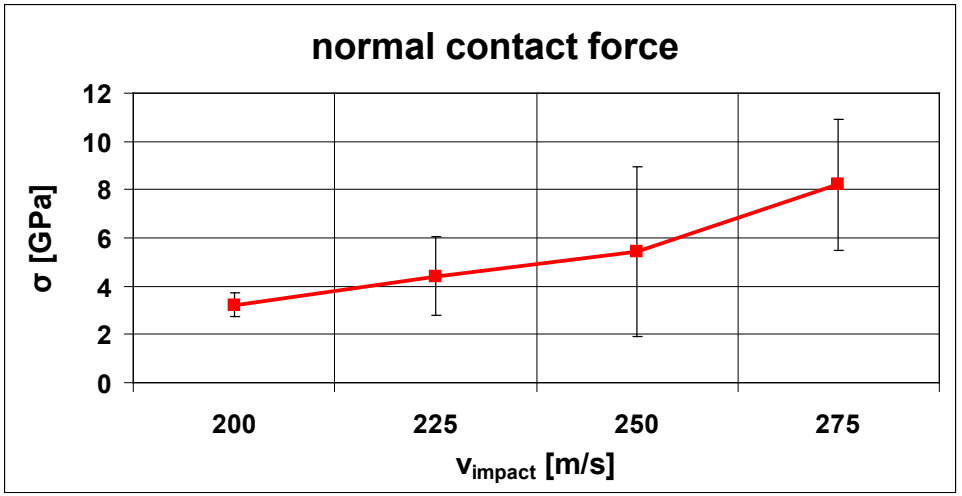
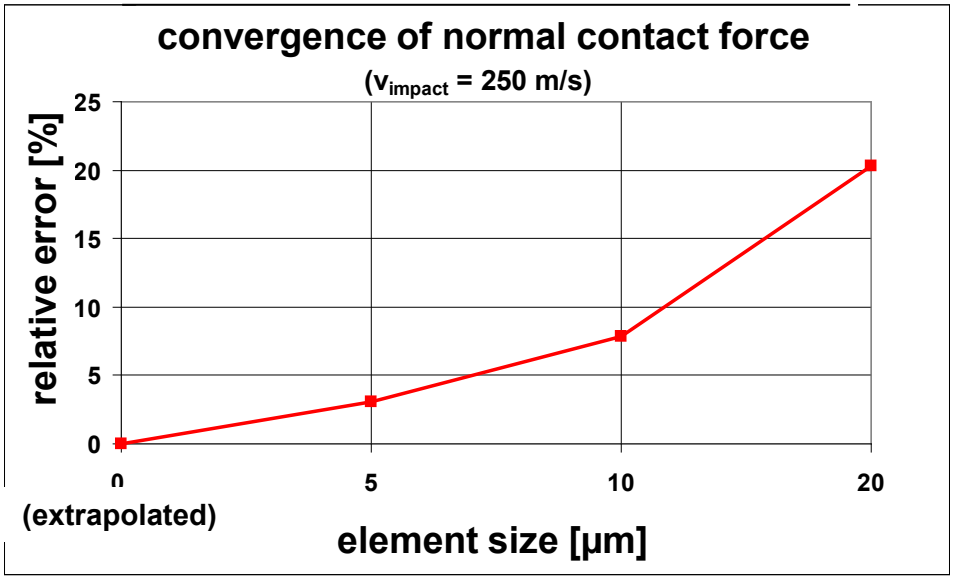
- normal contact forces in the joining zone are subject to wide variations and inaccuracies
- analyses can only be carried out with the aid of average values



- Average value can be utilized for convergence examination purposes



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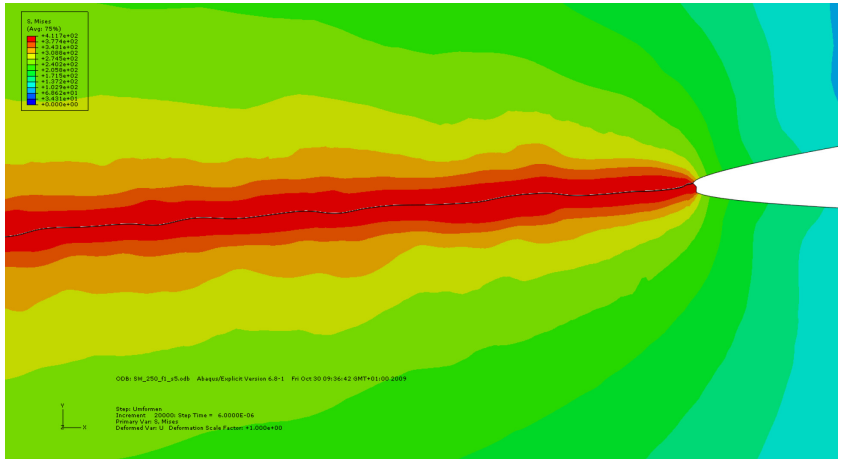
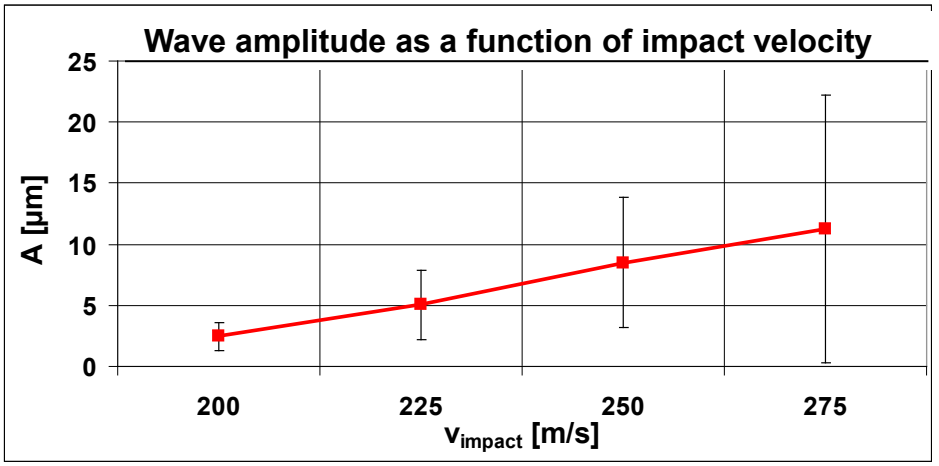
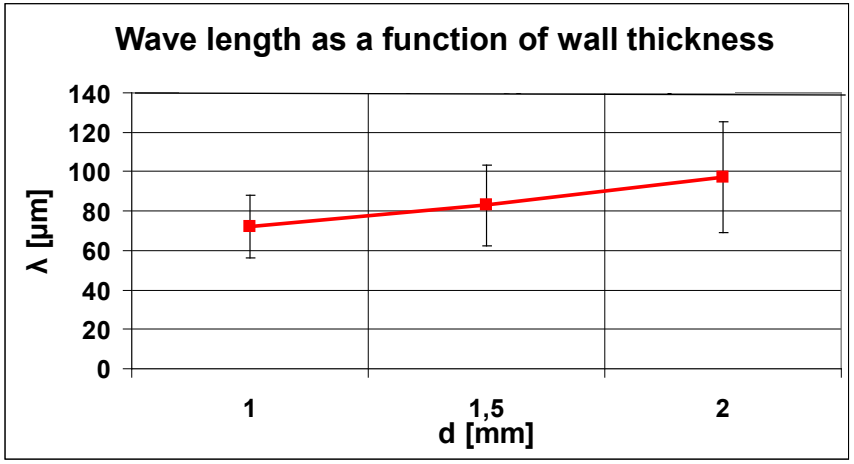
Results: wave formation

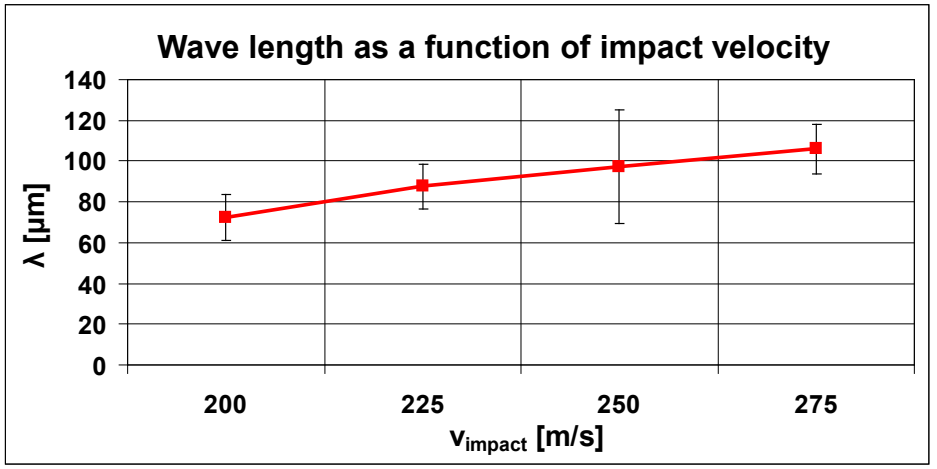
- Formation of waves in the welding interface



- Specific values are dependend on load and geometry



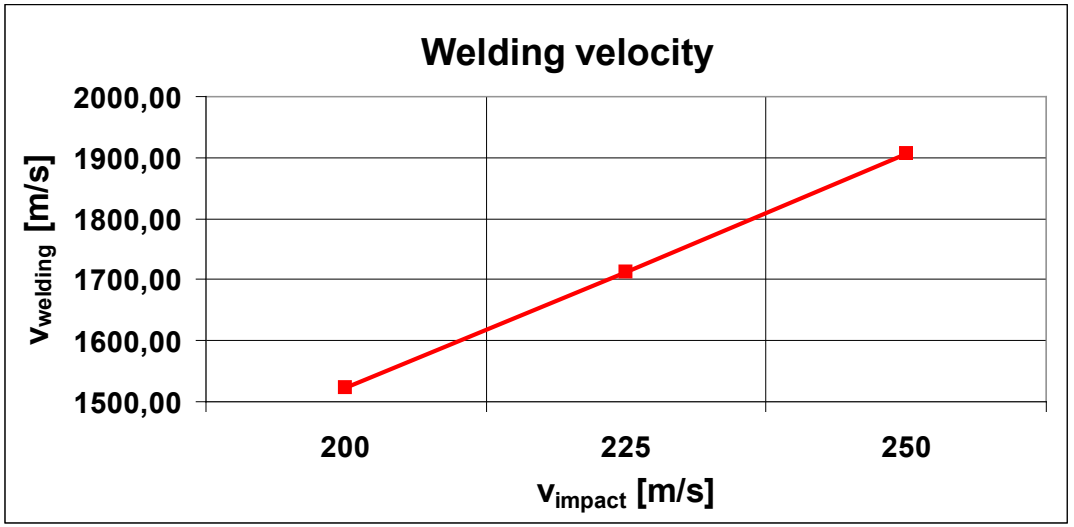




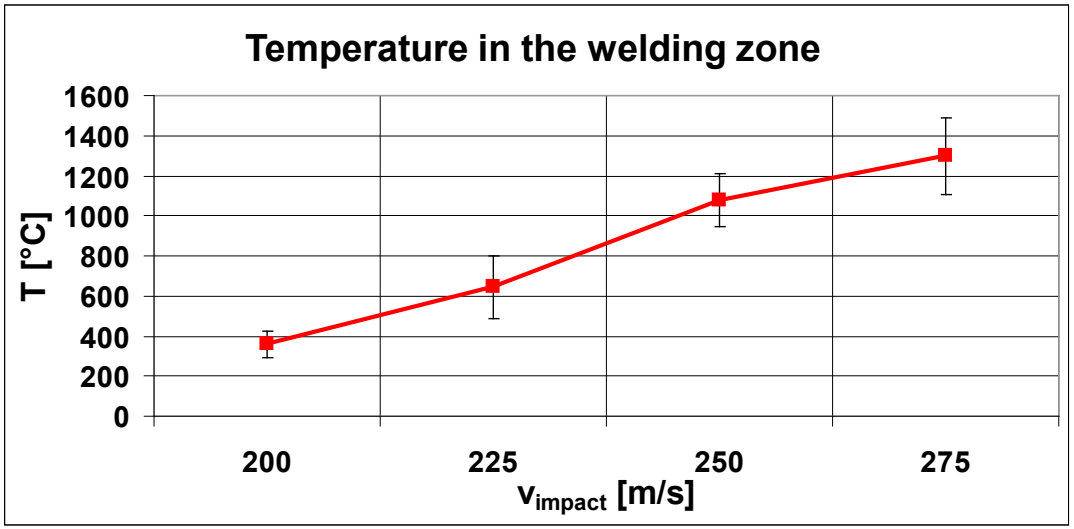
Results: other values

- Welding velocity is in good accordance with the geometrical relation (0,3%)

  $v_{welding} = v_{impact} / \tan(\alpha)$



- Temperature exceeds the melting temperature in individual elements
- no overall temperature increase of the components



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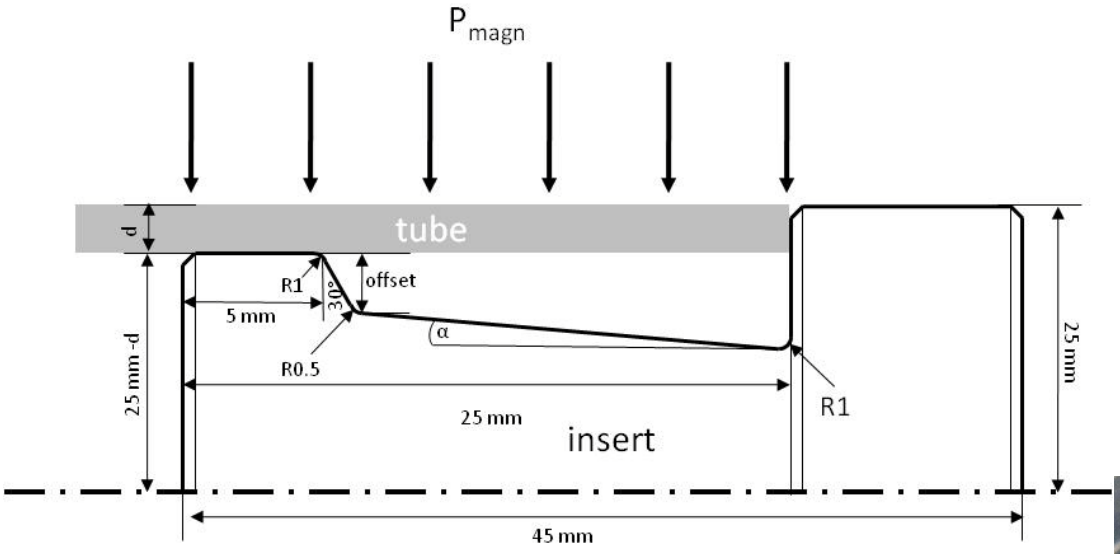
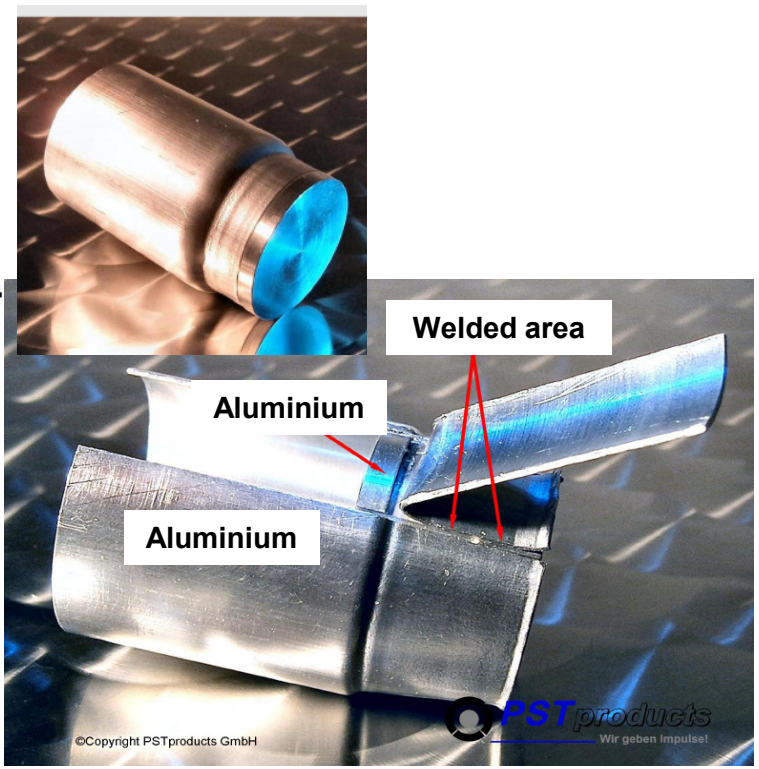
Welding Experiments



discharge current:
930 kA @ 14 KHz → 400 MPa

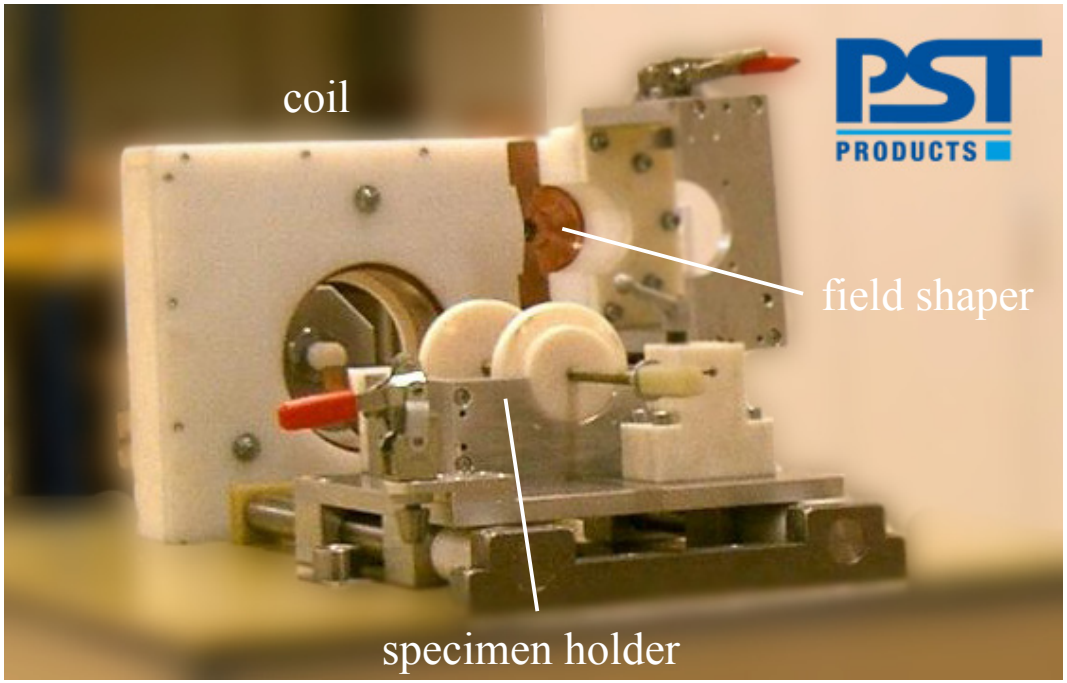
Material: EN AW-6061-T6



Variation of

- step size („offset“): 1 mm, 3 mm
- angle α: 5°, 7.5°, 10°
- wall thickness of flyer: 1.5 mm, 2 mm, 3 mm

Welding Experiments



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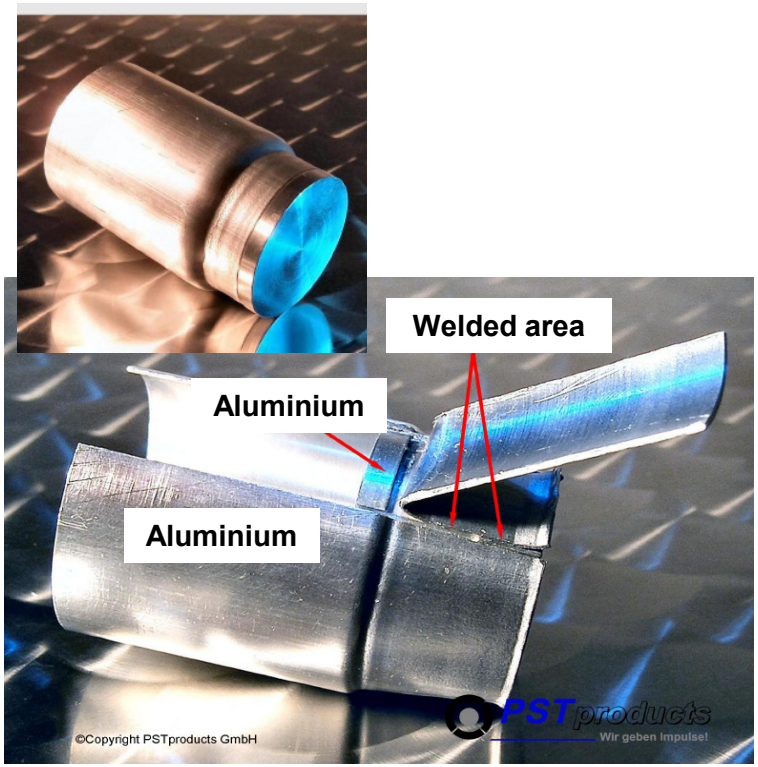

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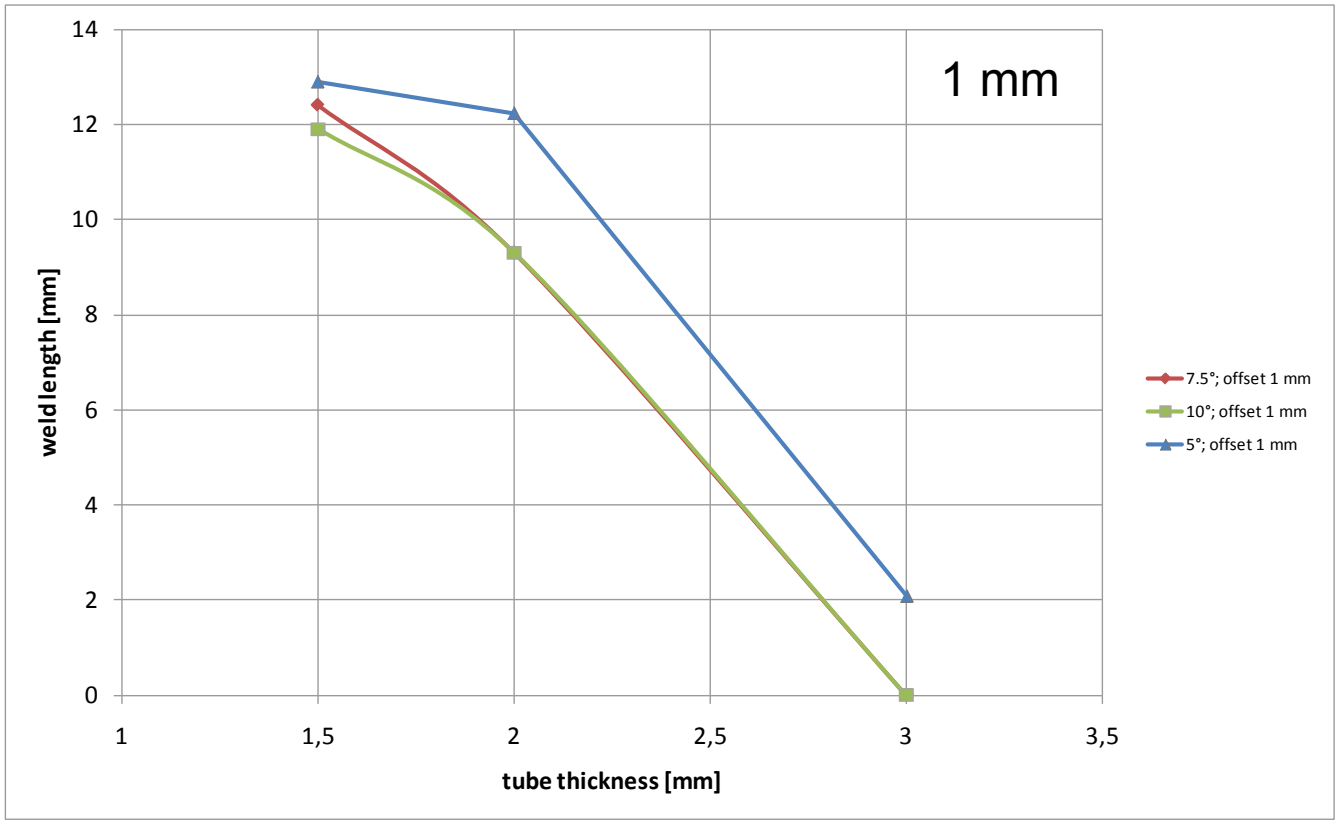
Welding length as a function of tube thickness



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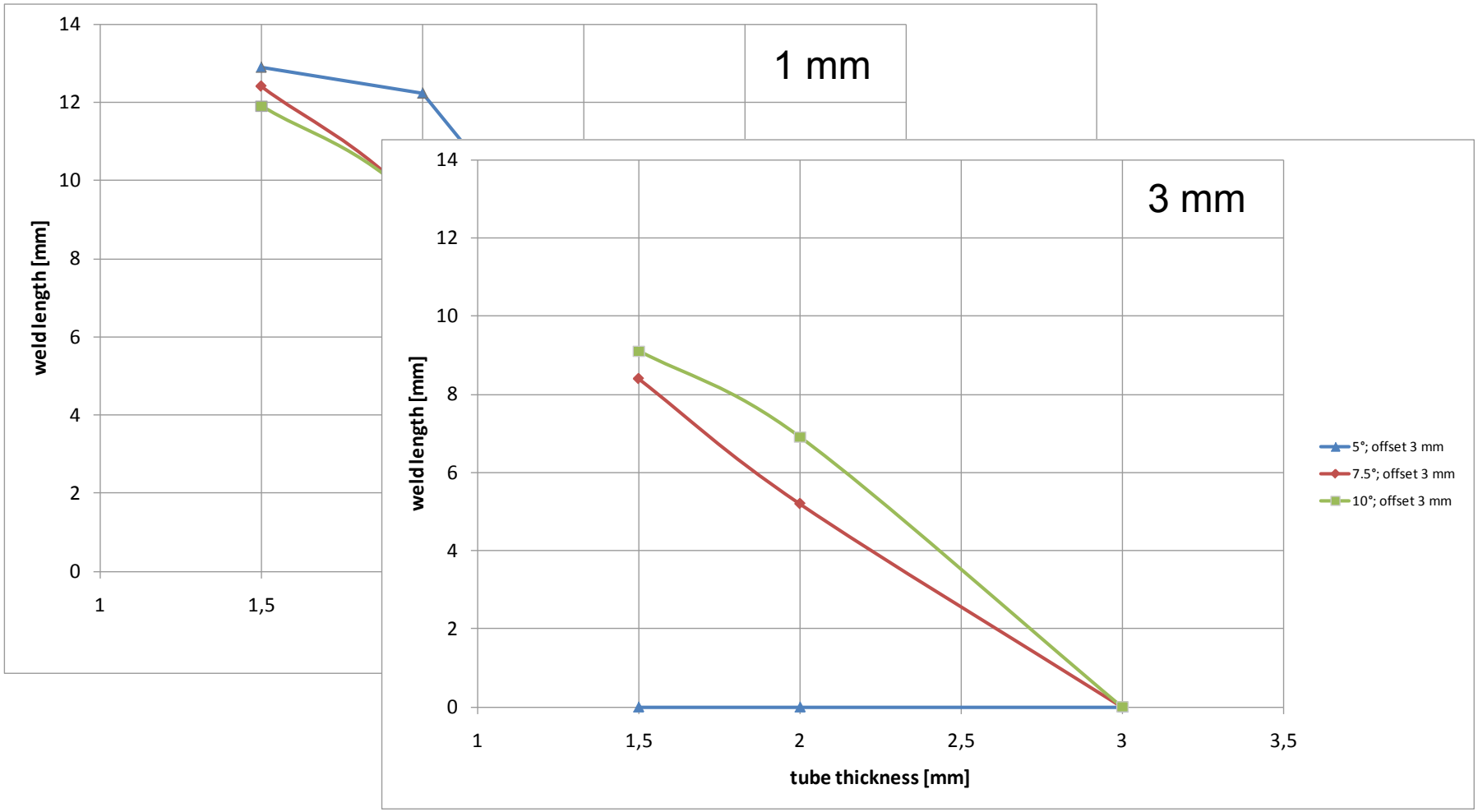

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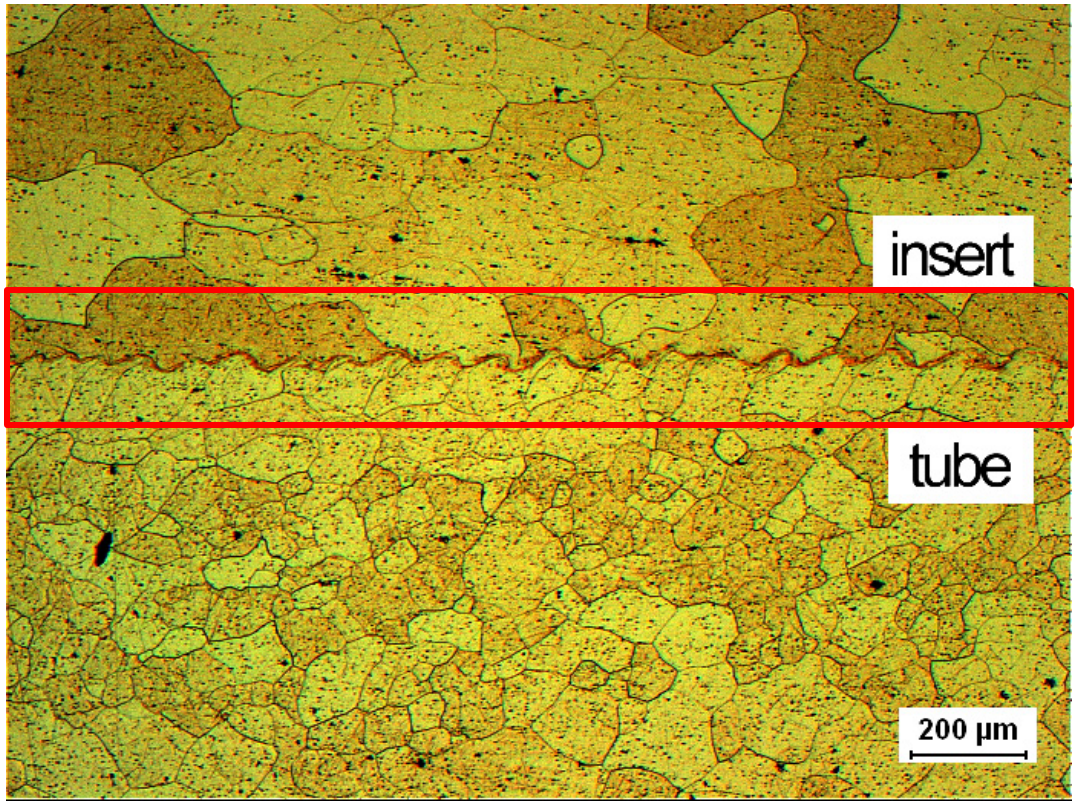
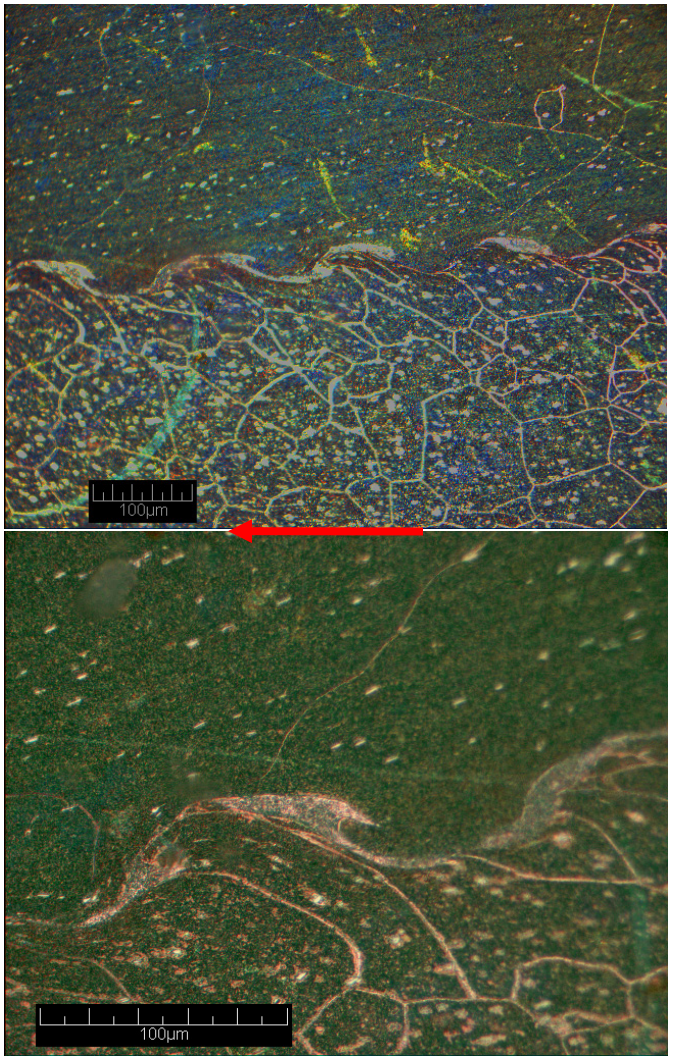
Metallographic Examination





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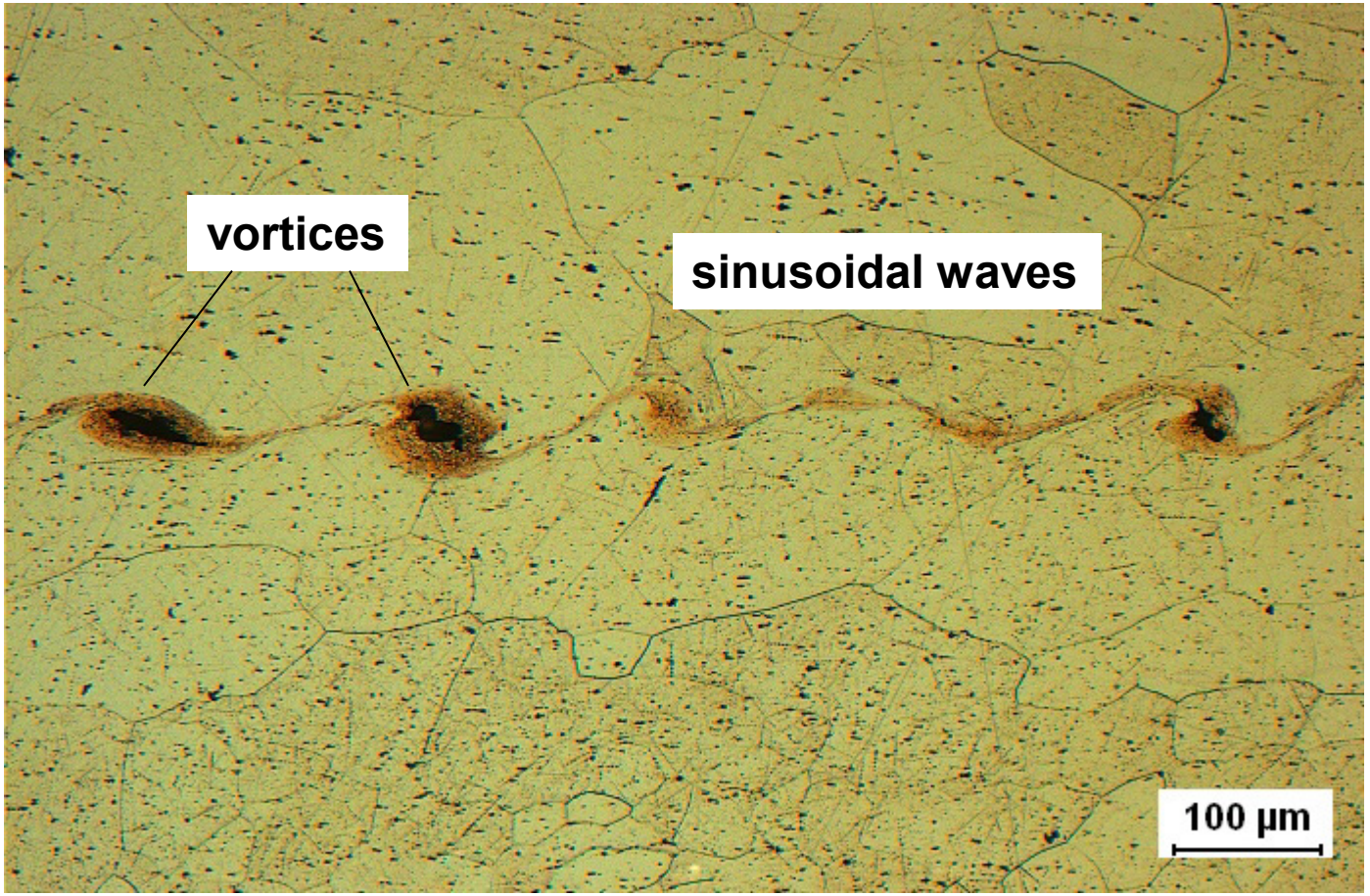

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Principles for Acceleration of impacting Specimen

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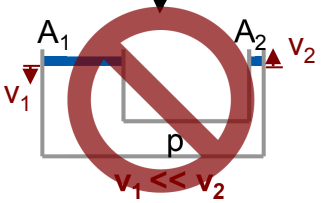
Partial Solutions

Magnetic

knock-out criterion

- opposite tendencies of magnetic circuit attributes and demands on mass interia

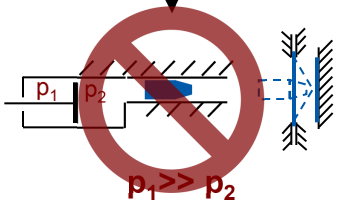
Hydraulic



knock-out criterion

- turbulent flows
- high mass interia
- compressibility

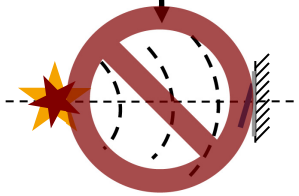
Pneumatic



knock-out criterion

- insufficient impulse transmission
- reproducibility
- influence of projectile

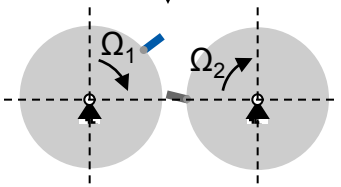
Explosive



knock-out criterion

- safety in handling explosives
- reproducibility
- parameter adjustment

Mechanical



feasible

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Systematic Variation of Mechanical Principles

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principle

motion

1

2

solution

Mechanical

Translational

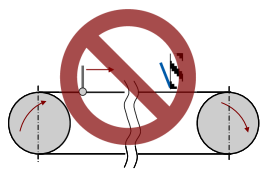
Rotatory

Translational/ Fixed

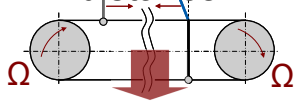
Translational

Rotatory

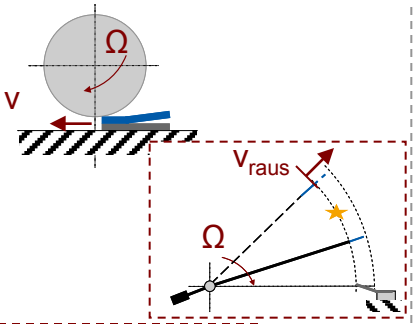
Fixed

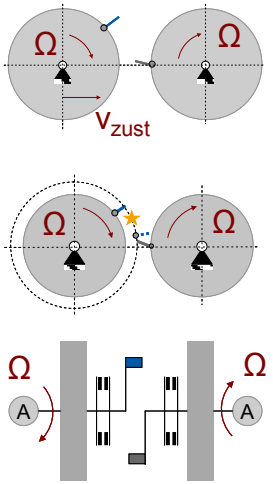


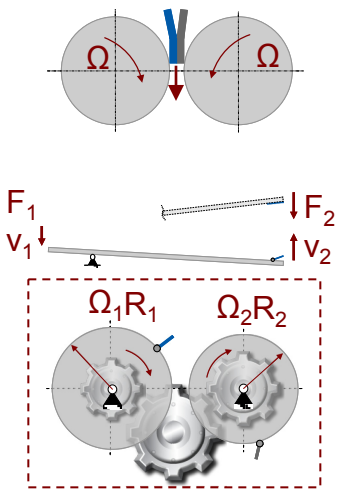
long start-up distance

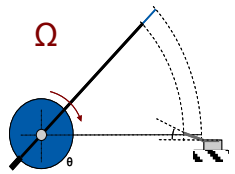


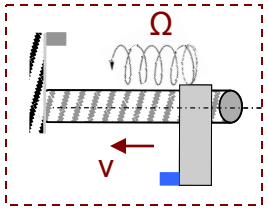
Enormous size











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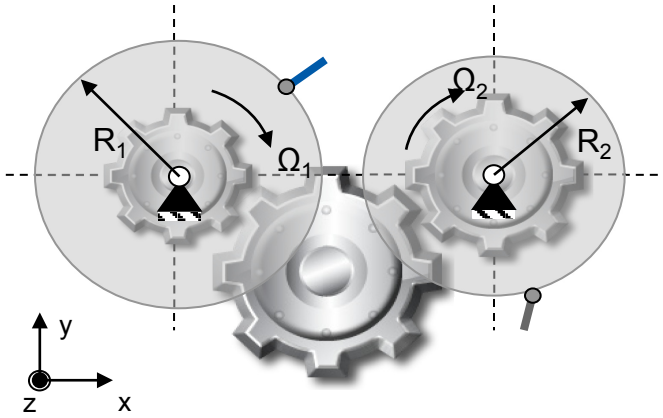
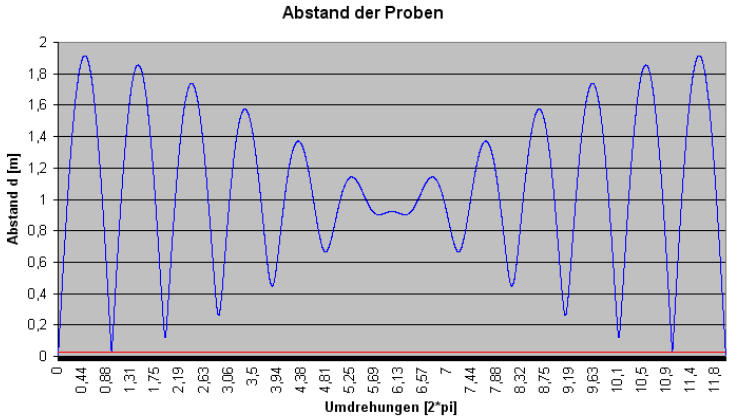
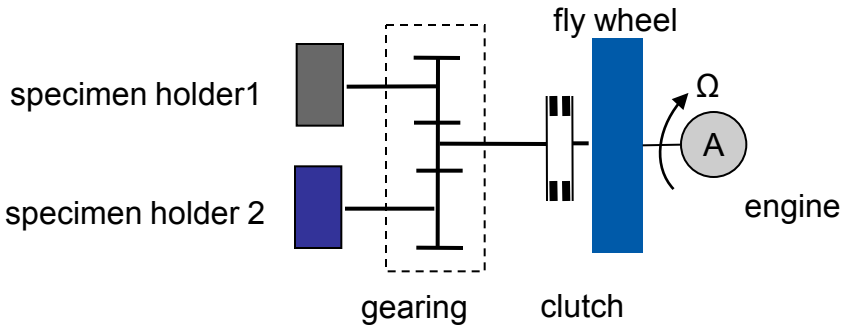
Final Conception



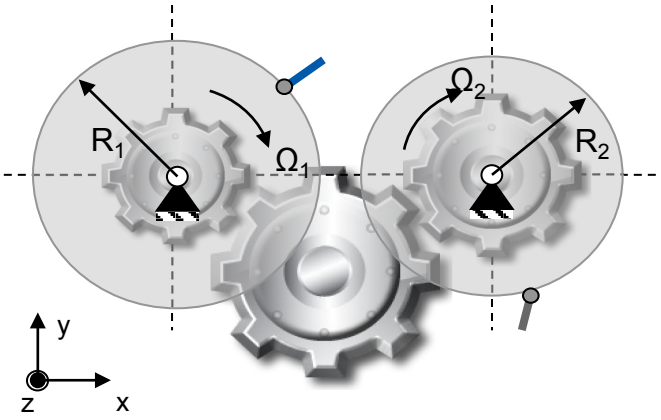


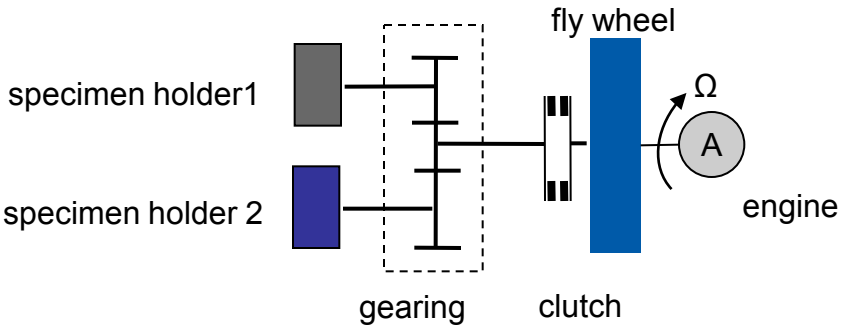


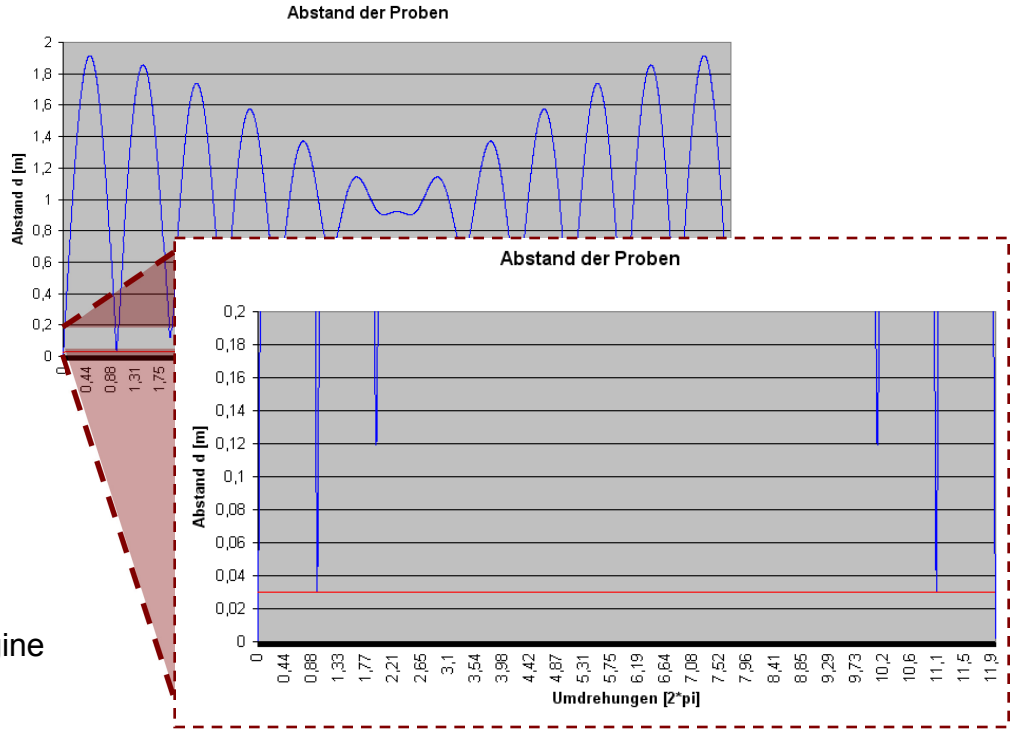
Characteristics:

- free-wheeling run-up of the fly wheel
- coupling of the clutch
- transmission of the energy of the fly wheel onto the synchronous gear
- run-up of both specimen within several rotations
- only half the speed per specimen required

Final Conception







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Summary

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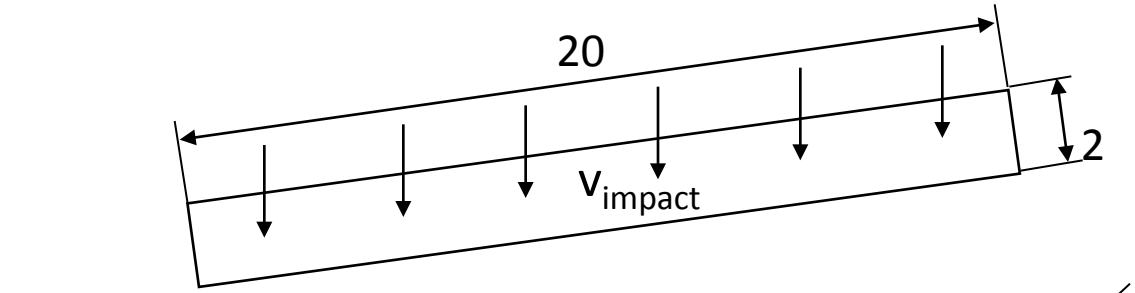
- Objective: Programming of an „Expert System EMP-Welding“ for the numerical dimensioning of relevant process parameters prior to prototyping
- Development of a conventionally driven test stand with reduced complexity for the investigation of high-speed impacts
- Numerical Simulations show similar characteristics as the actual welding process
- Welding experiments are conducted to indentify the process window

Outlook

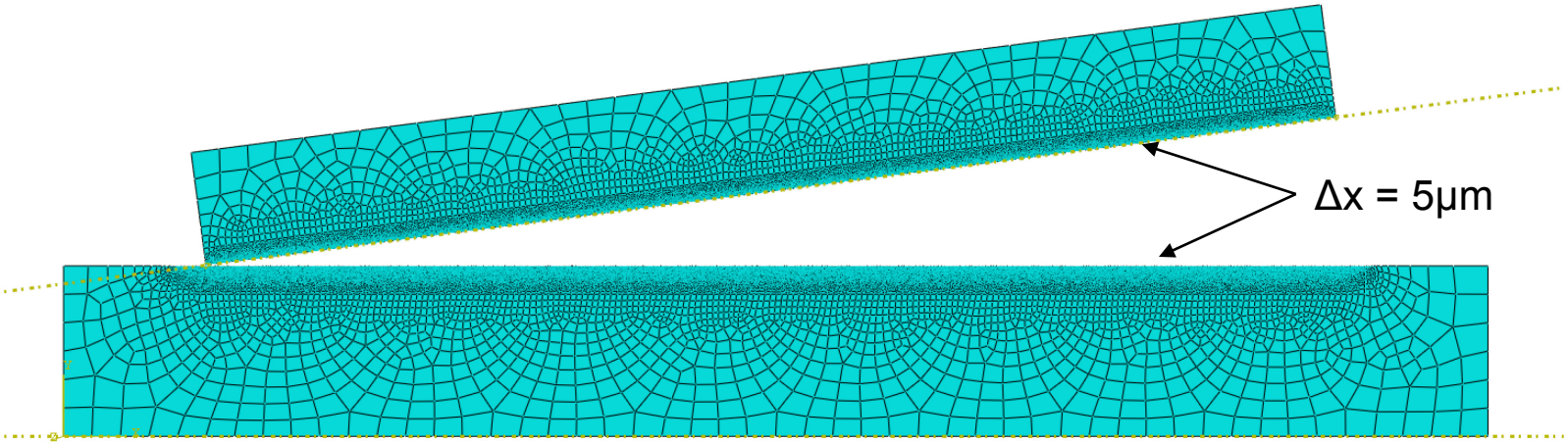
- Manufacturing of test stand starting in april
- Numerical simulations are adapted with contact algorithms that prevent the materials from separating, once threshold values for contact force and strain are exceeded
- SEM-imaging and electron microprobe analysis of the interface

Thank you for your attention

Numerical Simulation: Geometry and Boundary Conditions



proportions in mm



Influence of Rezoning

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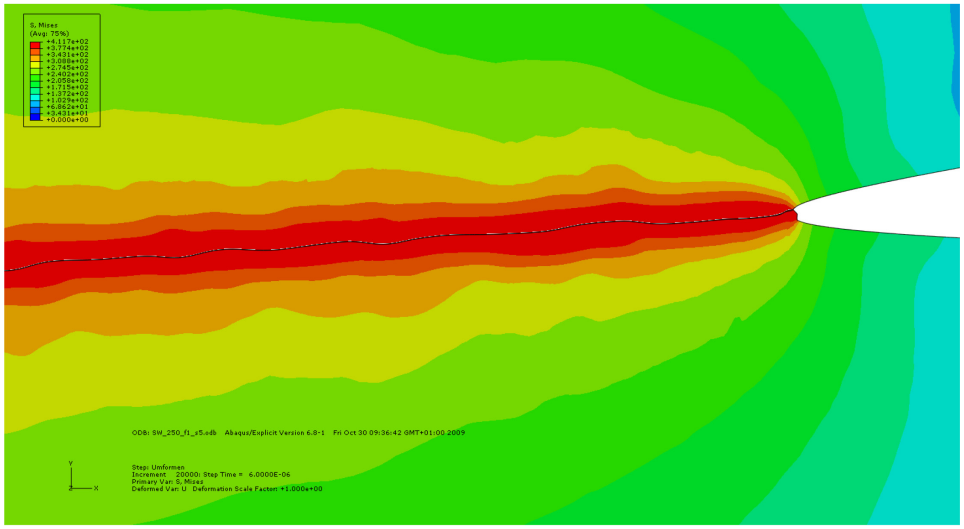
- Rezoning with ideal settings



- no Rezoning