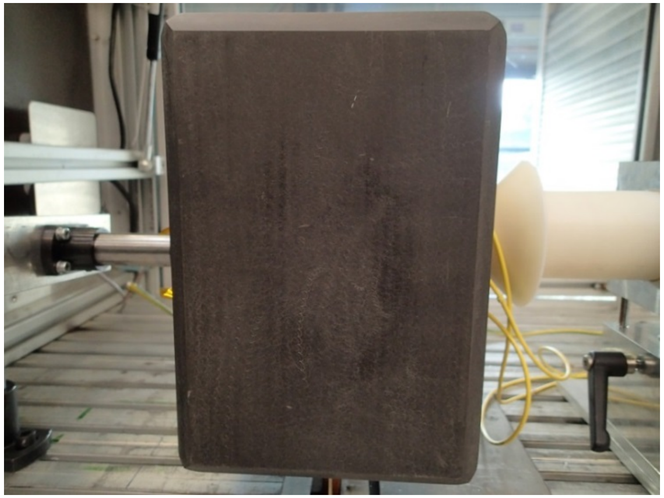
INFLUENCE OF AXIAL WORKPIECE POSITION IN THE COIL FOR ELECTROMAGNETIC PULSE JOINING

Shed some light on the black box



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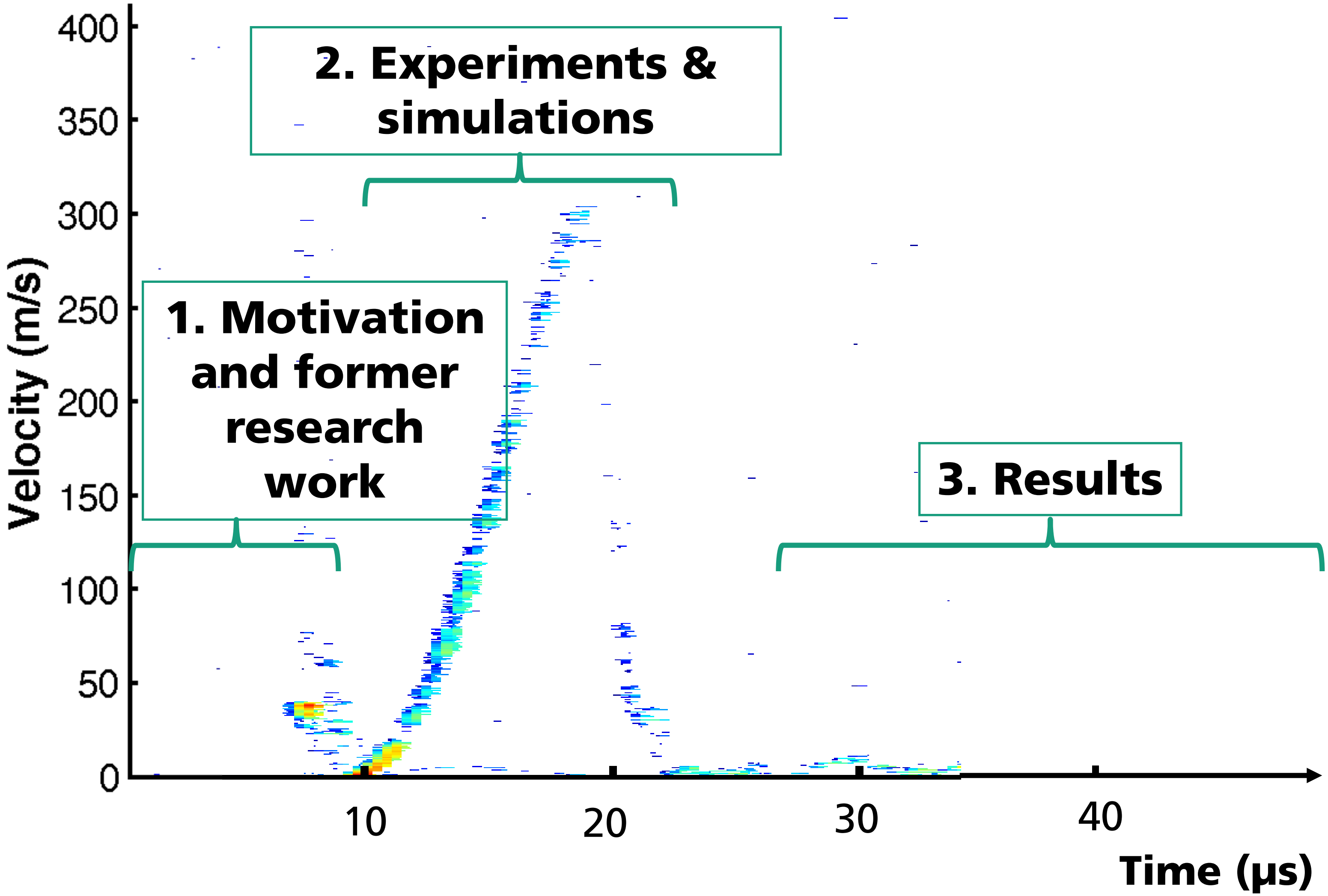
Content


2. Experiments & simulations
1. Motivation and former research work
3. Results
Velocity (m/s)
400
350
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250
200
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100
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0
10
20
30
40
Time (µs)

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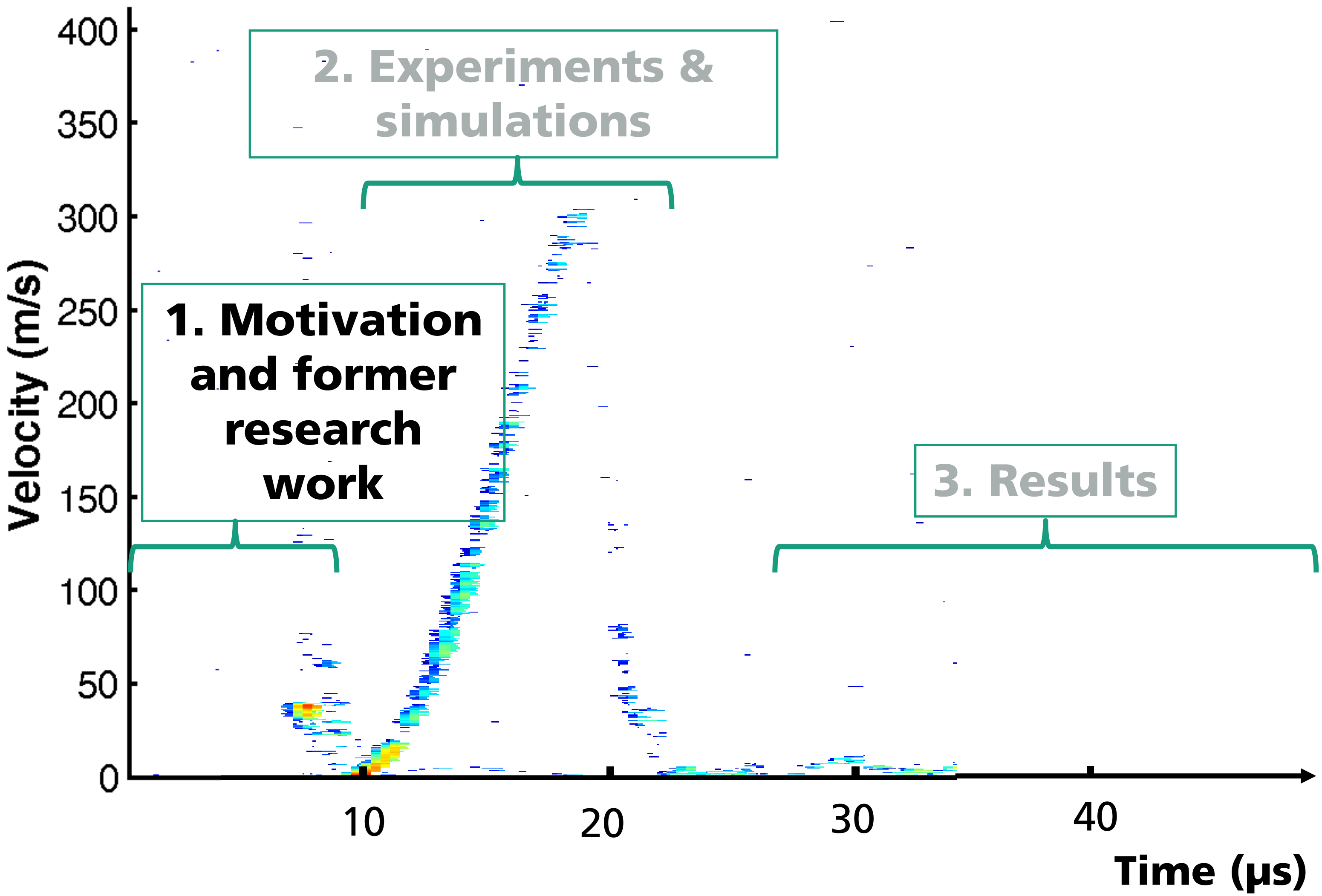

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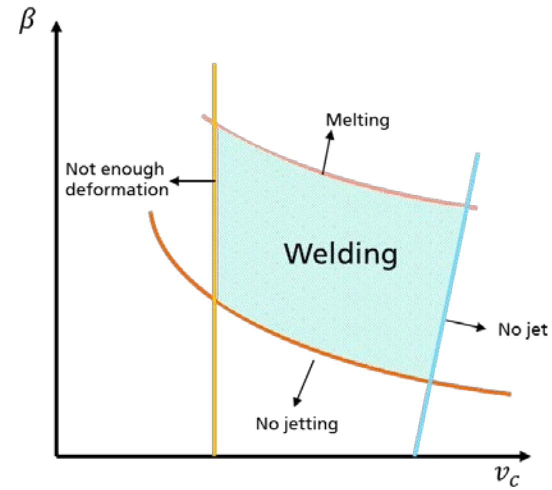
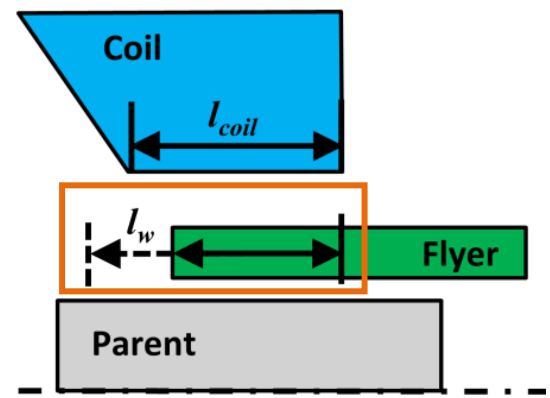
1. Motivation and former research work
Welding parameters

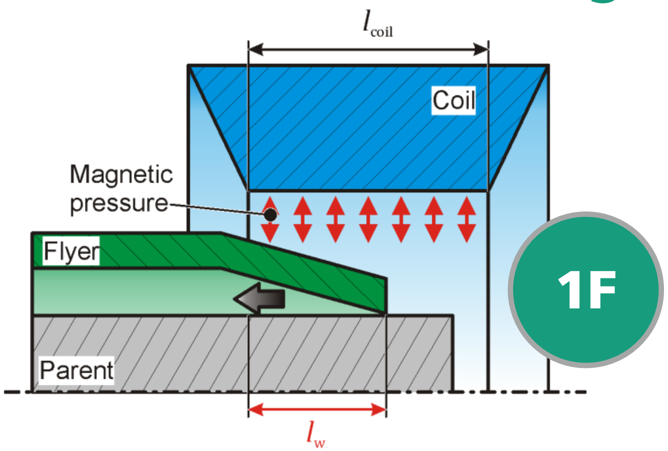
- Front conditions estimated using welding windows
- Conditions have to be applied to part design and setup
- Geometric factors:
  - Coil-flyer standoff
  - Parent-flyer standoff
  - Parent-flyer contouring
  - **Working length**

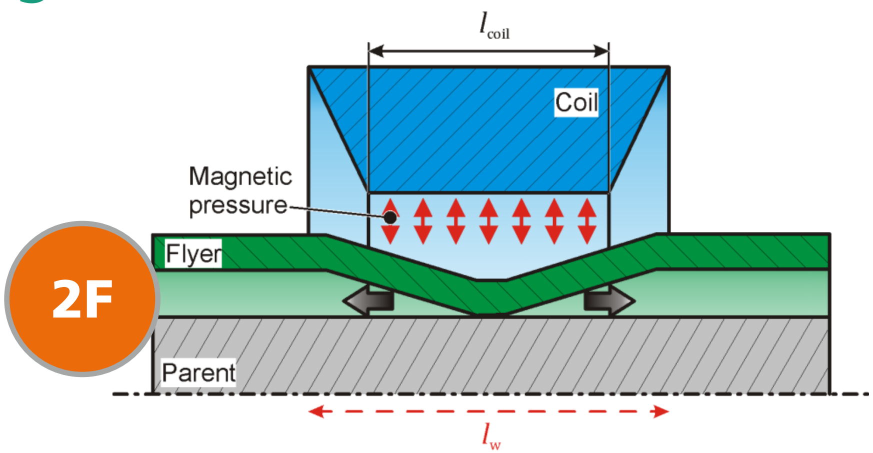




1. Motivation and former research work

"Traditional" welding front regimes





One sided Front:

\+ Longer path for jet development
\+ Lower deformation energy
– Higher shear in flyer

Two front process:

\+ Less shear in flyer
– Higher deformation energy
– Reduced weld length

Questions:

- How does the working length affect the front development in MPW?
- What is the optimal working length?

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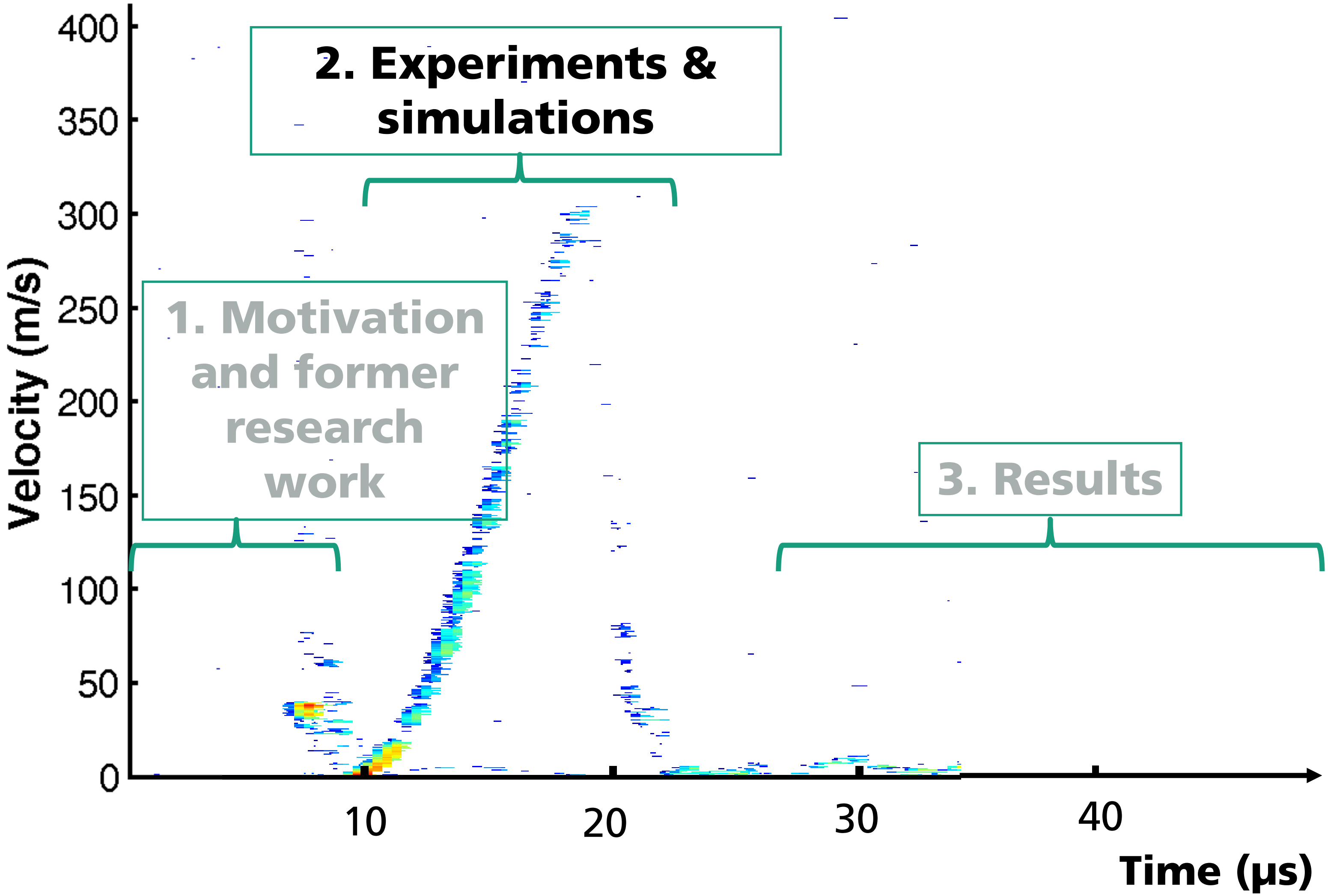
Content



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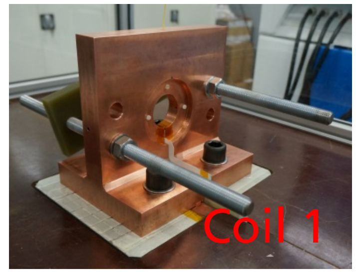
2. Experiments and simulations

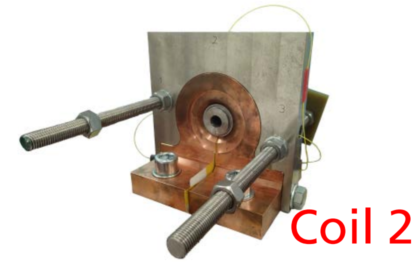
Experimental setup

MP 50 kJ/ 25 kV (Bmax)

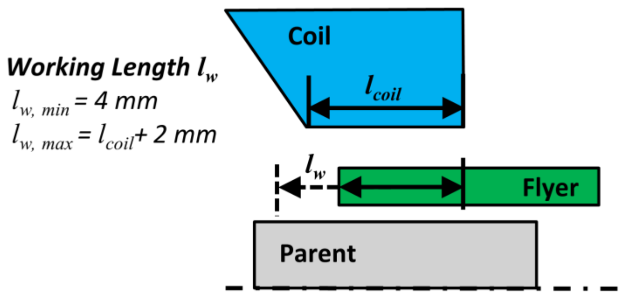
$f_{circuit}$~23 kHz

Coils (CuZnZr1, $Ø_{inner}$ = 42 mm)





Parent:
C45 Steel
$Ø_{outer}$ = 33 mm

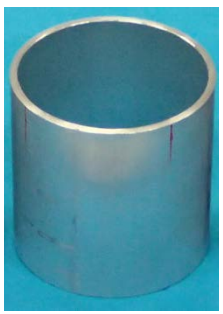


Flyer:
EN AW-6060 T66 (AlMgSi0.5)
1.0 mm thickness
$Ø_{outer}$ = 40 mm

	l_{coil} [mm]	Charging energy [kJ]	Working lengths [mm]										
			4	5	6	7	8	9	10	11	12	15	17
Coil 1	15	11.5	x			x	x	x	x	x	x	x	x
Coil 2	10	7.7	x	x	x	x	x	x	x		x		

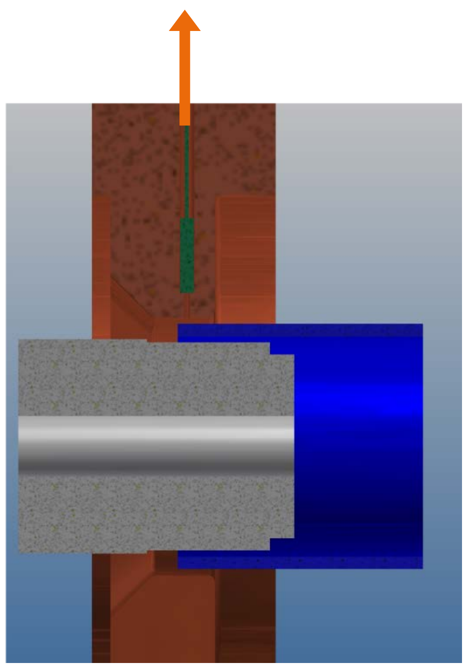
2. Experiments and simulations
Experimental sequence

Preparation



Joining

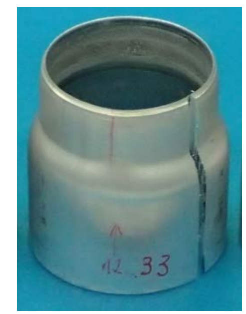
- Flyer velocity (time): PDV
- Current (time): Rogowski Current Probe

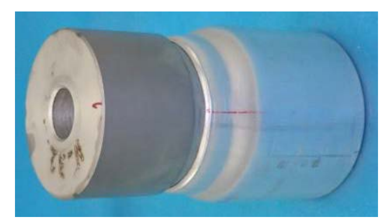


Analysis

Surface observation

Flyer elongation

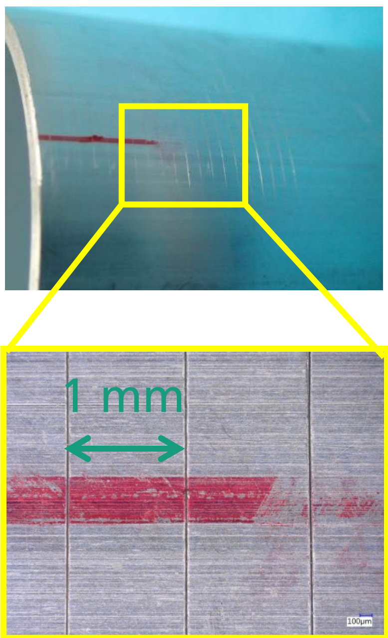




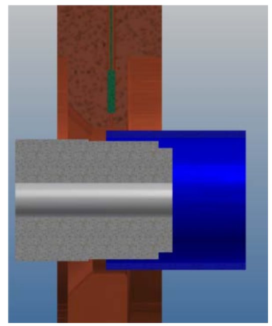
2. Experiments and simulations

Measuring the flyer elongation

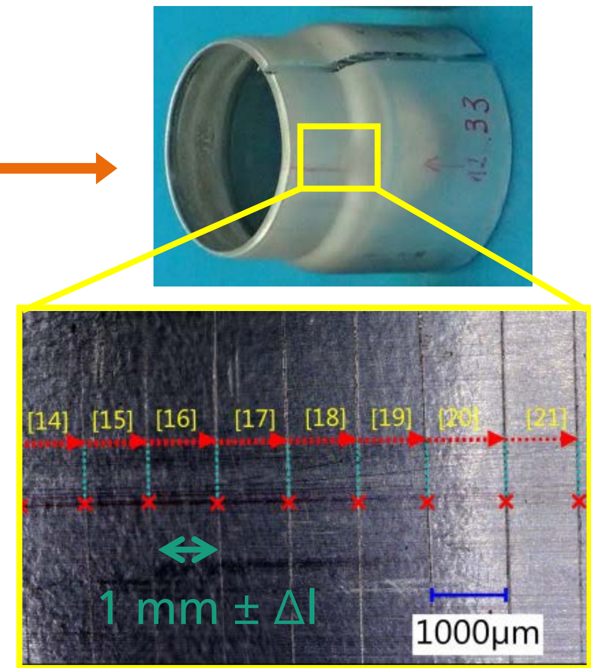
Application of marks on the flyer outside



Joining

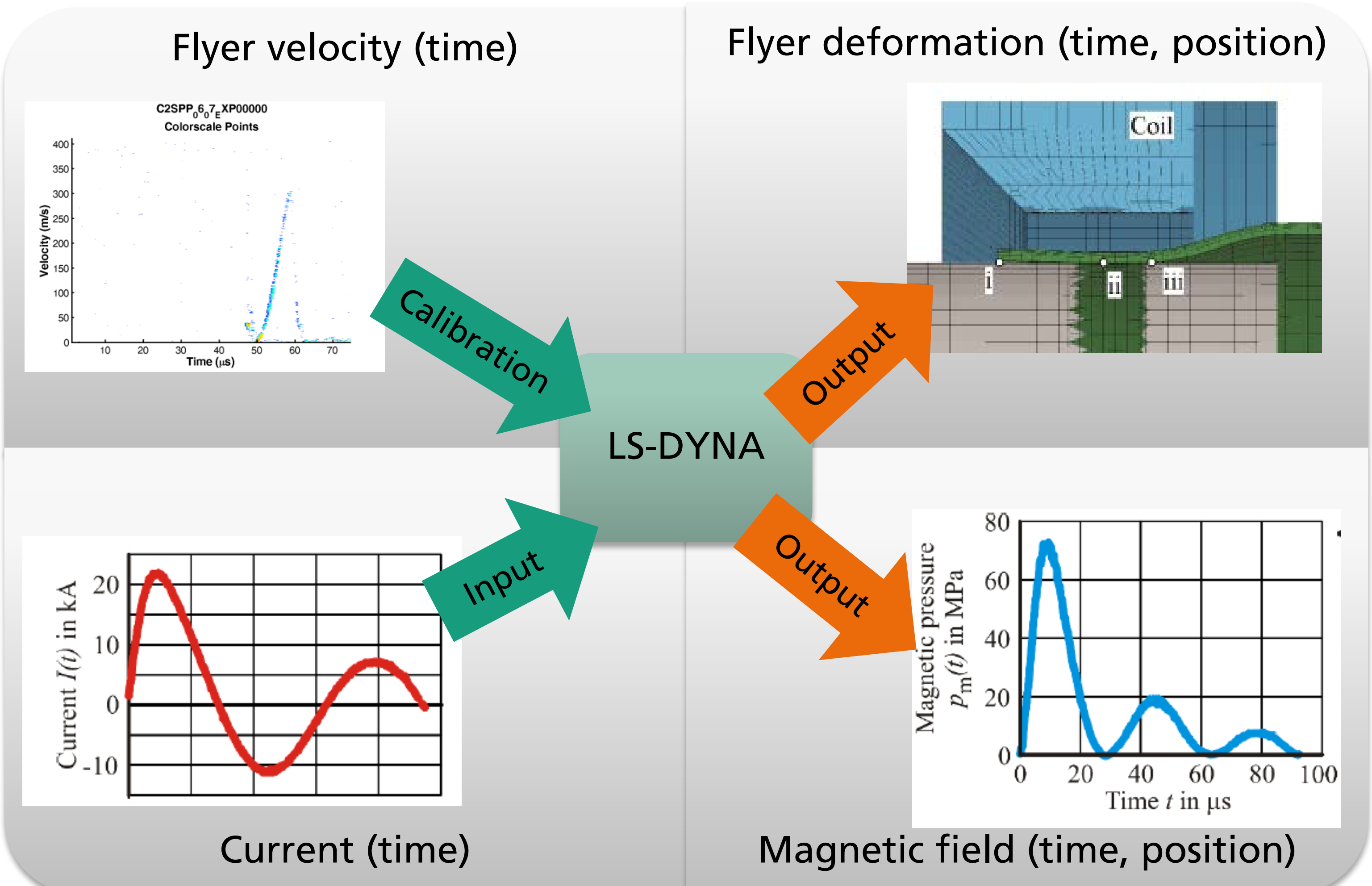


Analysis of the elongation



Calculation of the elongation for each flyer segment

2. Experiments and simulations
Simulation



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2. Experiments and simulations

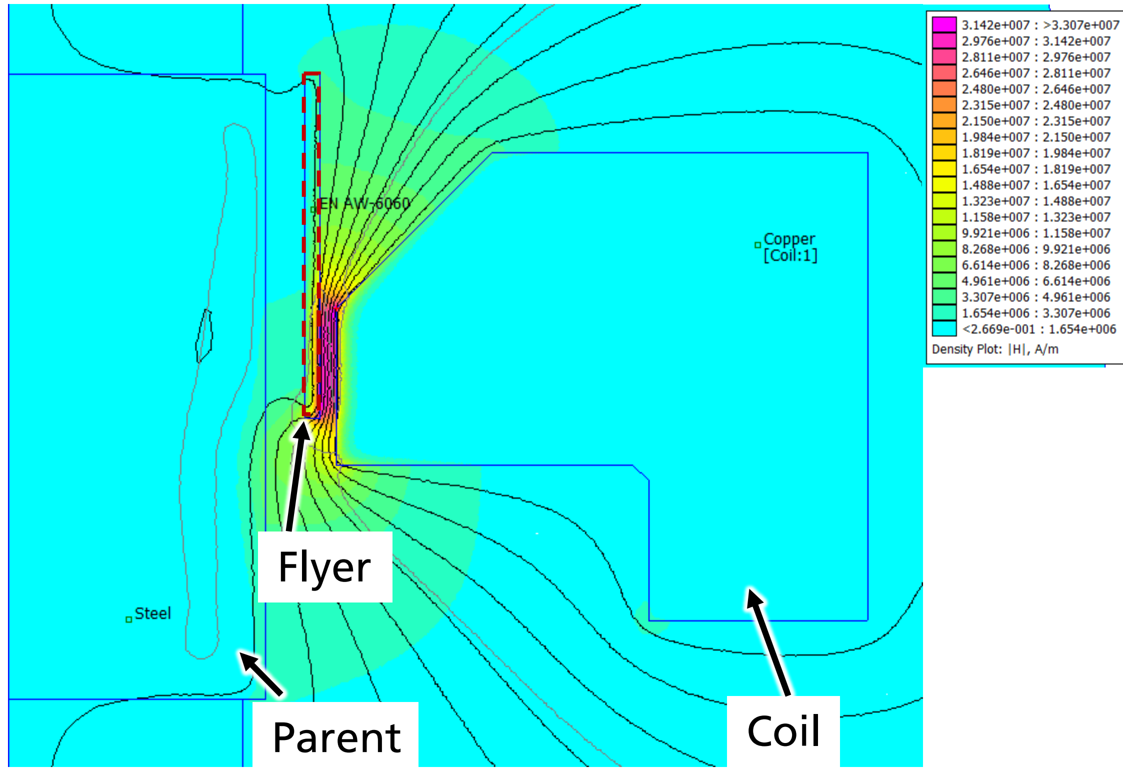
Simulation with Finite Element Method Magnetics (FEMM)

Input:

- Setup data
- Current amplitude
- Current frequency

Output:

- Field formation



www.femm.info

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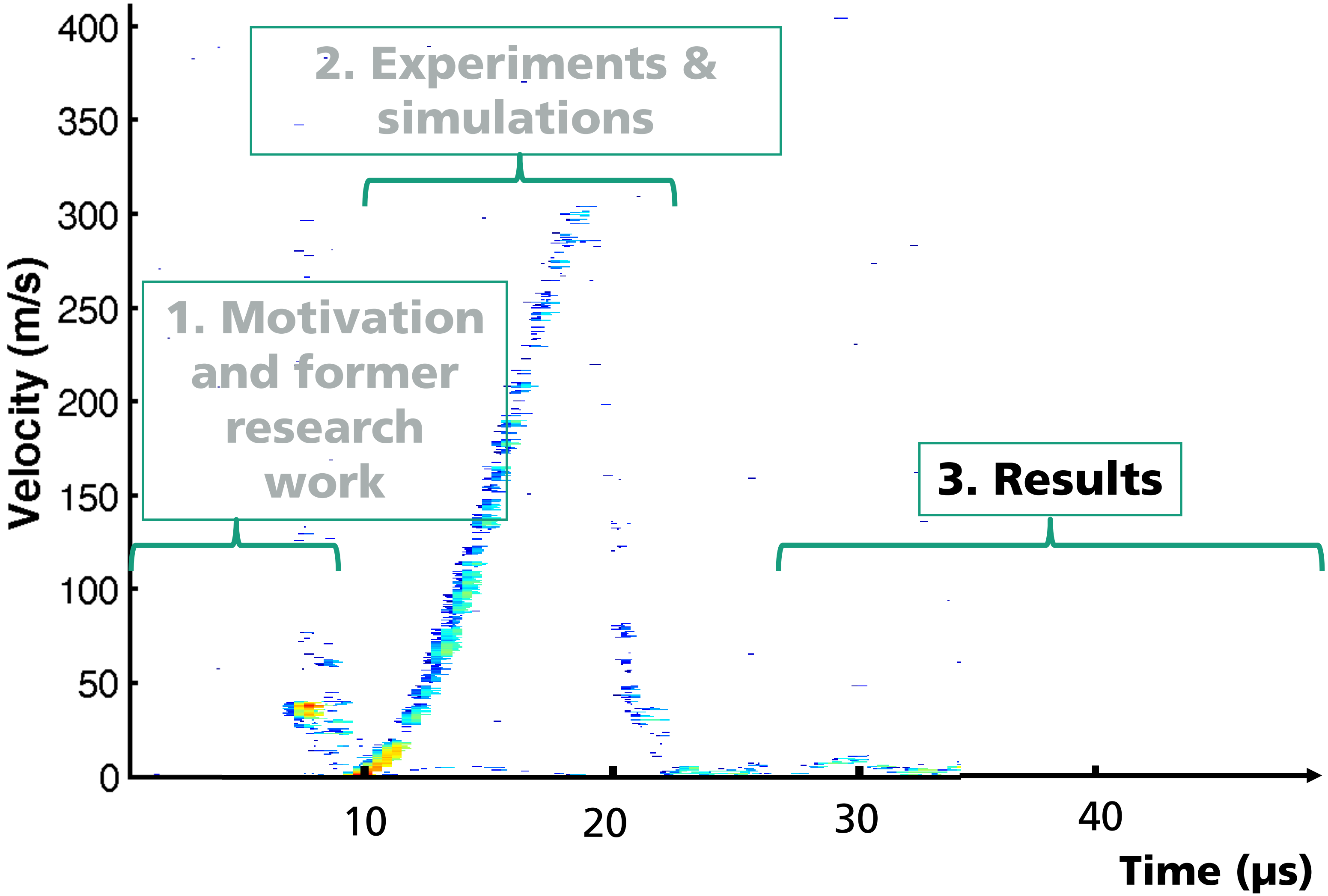

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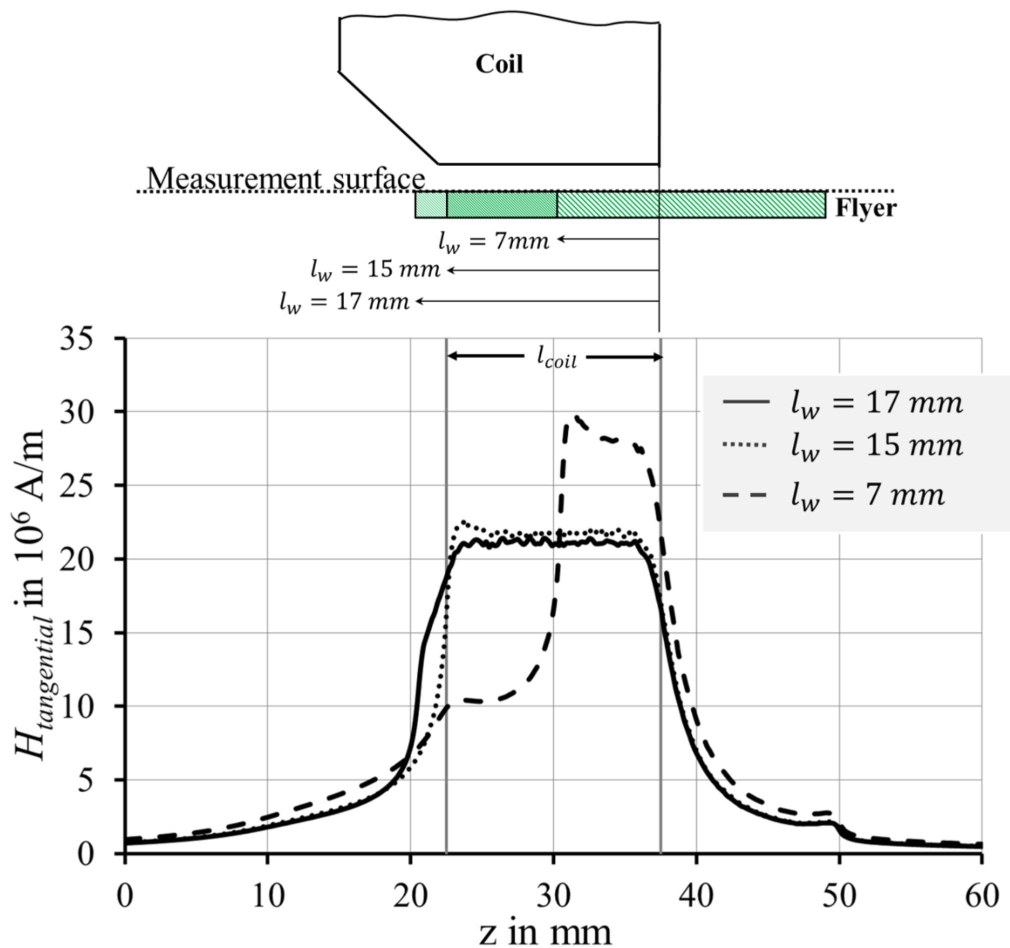
3. Results
Simulation of the magnetic field for different l_w

- Magnetic field at workpiece surface larger for smaller working length, but not directly proportional
- Increase in magnetic field at the workpiece edge, decreases with increasing working length



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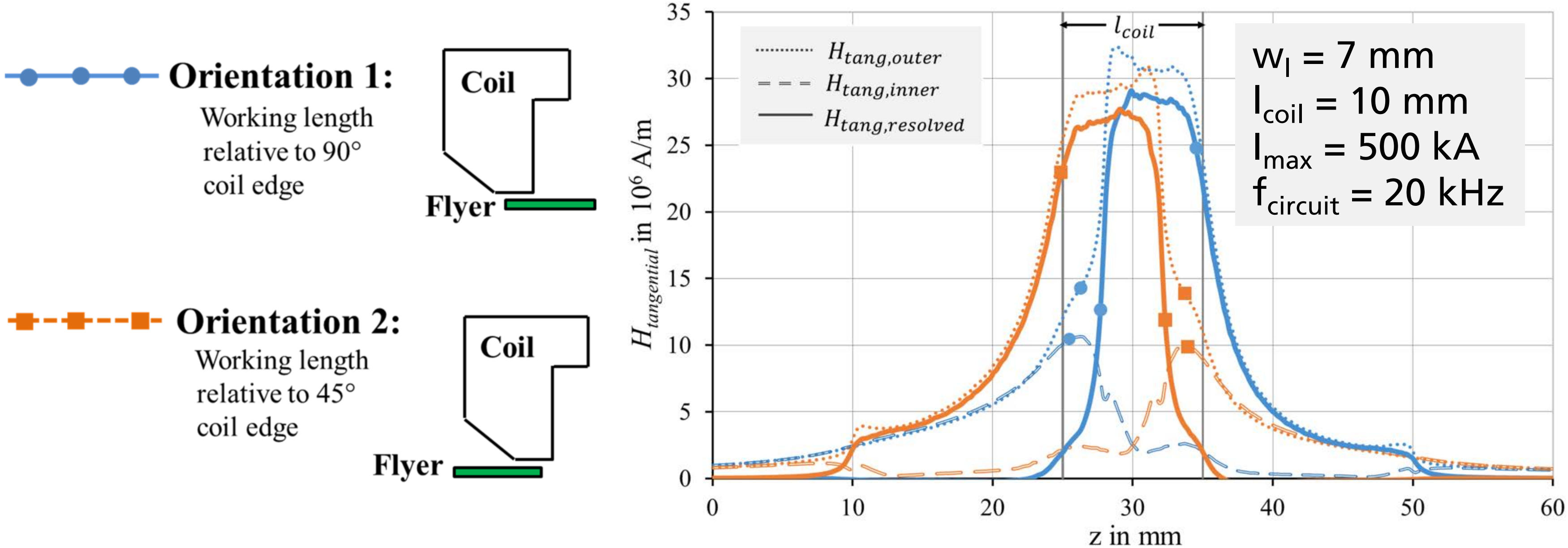
3. Results

Simulation of the magnetic field for two flyer orientations



Magnetic field at workpiece surface larger for flyer direction to the 90° coil edge

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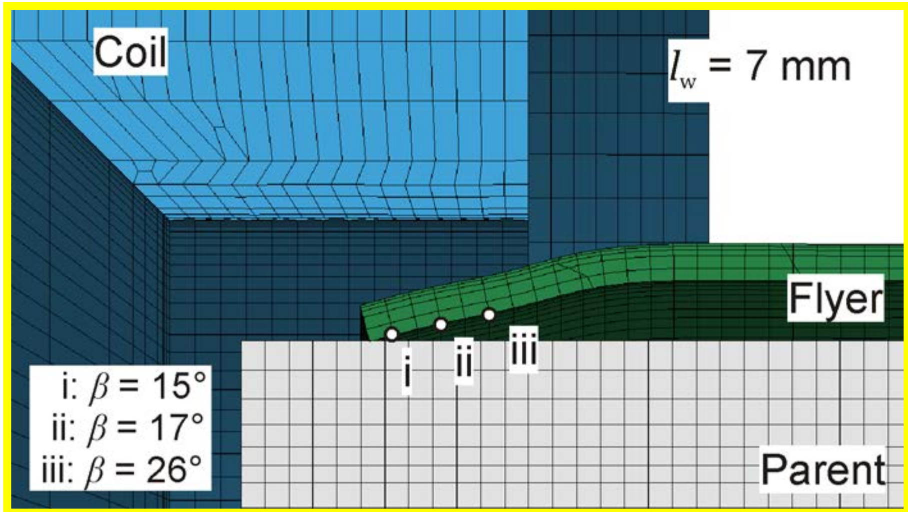
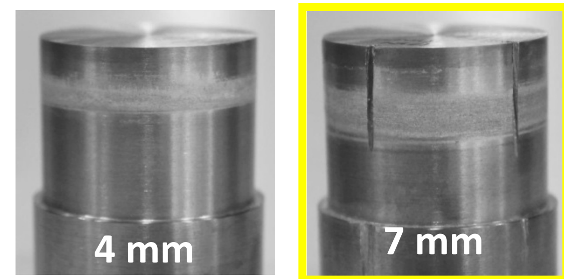
3. Results

Experiments & simulation of the one-front process

1F





- $l_w \leq 0.5\ l_{coil}$
- Deformation begins at flyer edge
- Continuous deformation along one front
- Easy ejection of jet away from joining front

➡ **Optimal for welding**

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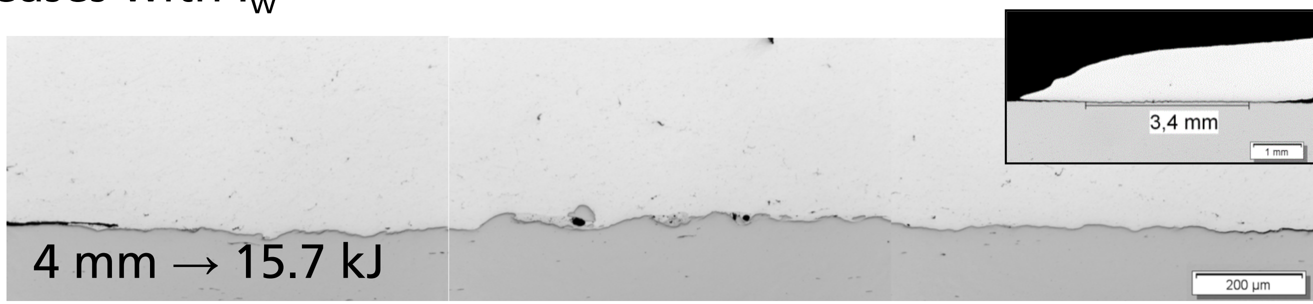
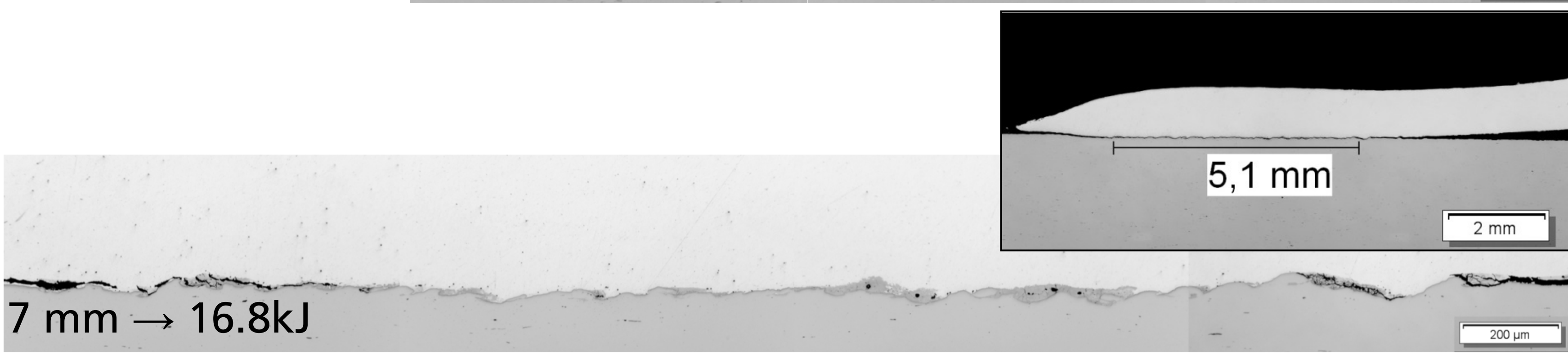
3. Results
Welding experiments using the one-front process

Welding in samples with $l_w \leq 0.5\ l_{coil}$

1F

- Non-uniform wavy interfacial structure
- Thin intermetallic layer
- Weld length increases with l_w





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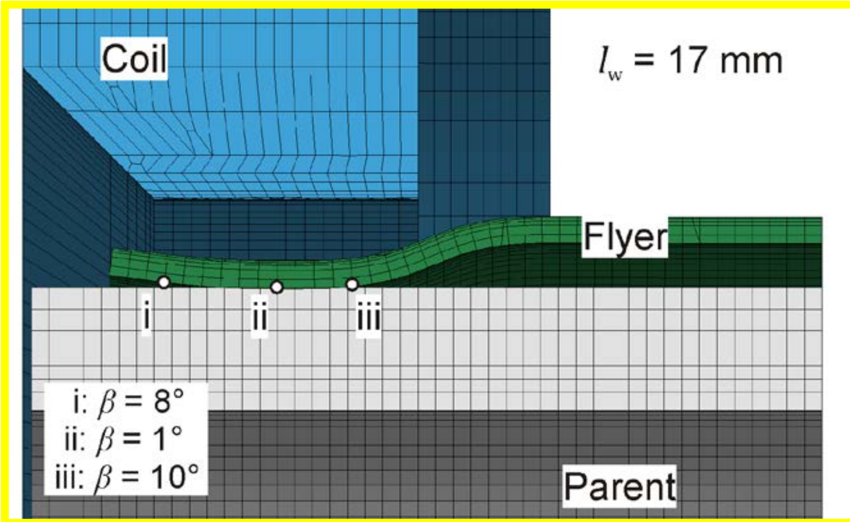
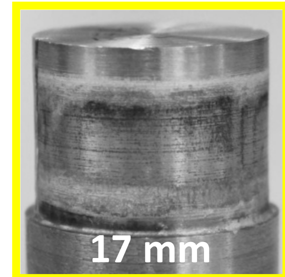
3. Results

Experiments & simulation of the two-front process

2F





- $l_{coil} < l_w$
- First contact near coil center
- Front propagation outwards in two directions
- Smaller deformation angles than single-front

Coil width suboptimal for two-sided welding front

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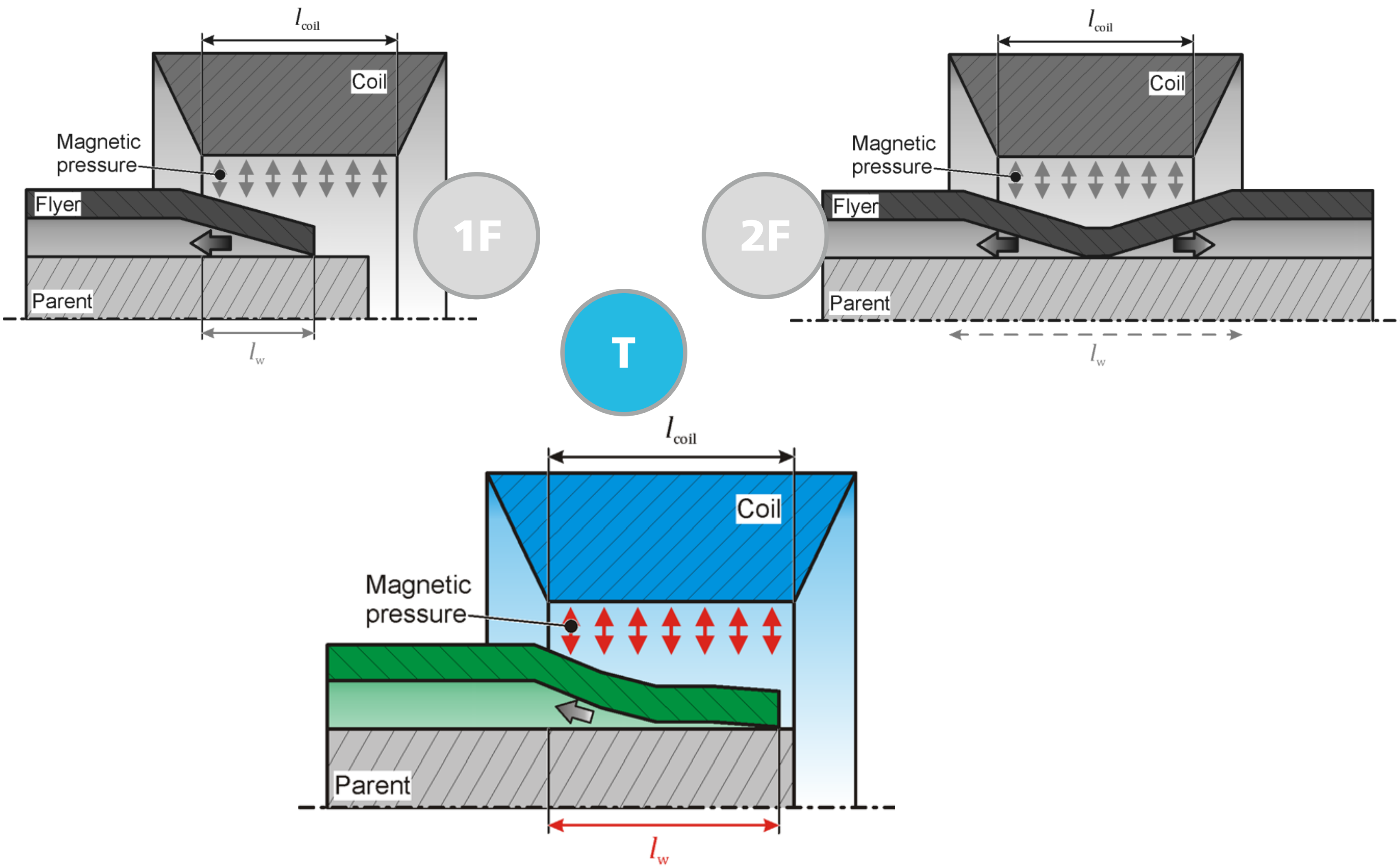
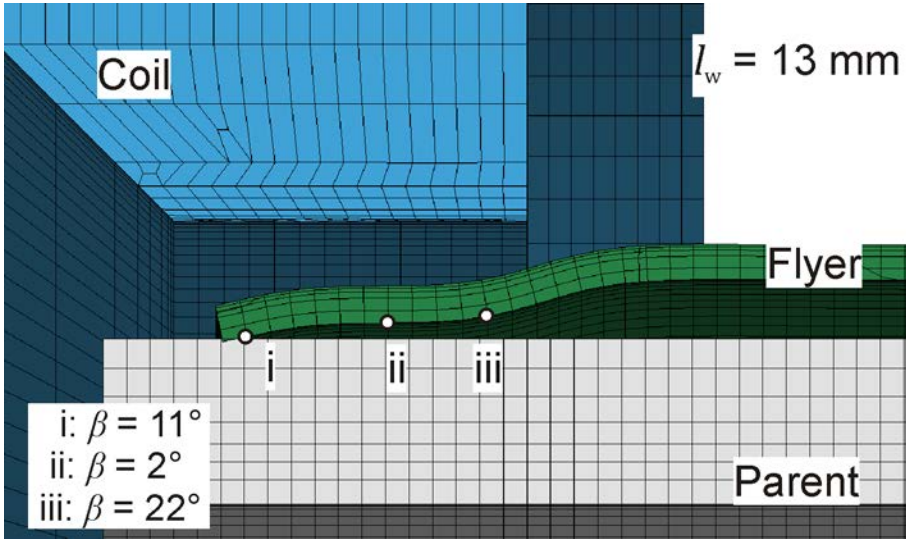
3. Results

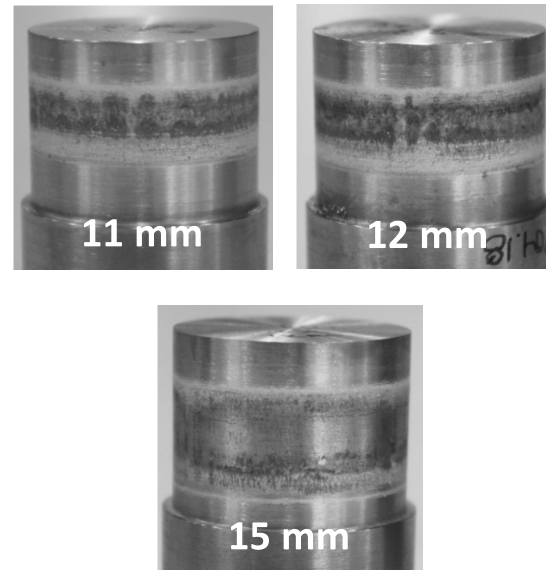


3. Results

Experiments & simulation of the transition-front process

T





- $0.5\ l_{coil} < l_w < l_{coil}$
- Flyer deformation in flat manner → Reduced deformation angles
- Jet hindered or trapped between joining partners

→ **Suboptimal for welding**

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3. Results

Experiments & simulation of the transition-front process

- Samples pulsed at various energies to compare front characteristics
- l_w = 10 mm

7.2 kJ

11.5 kJ

15.7 kJ

T

Front propagation direction

Same basic features for all samples

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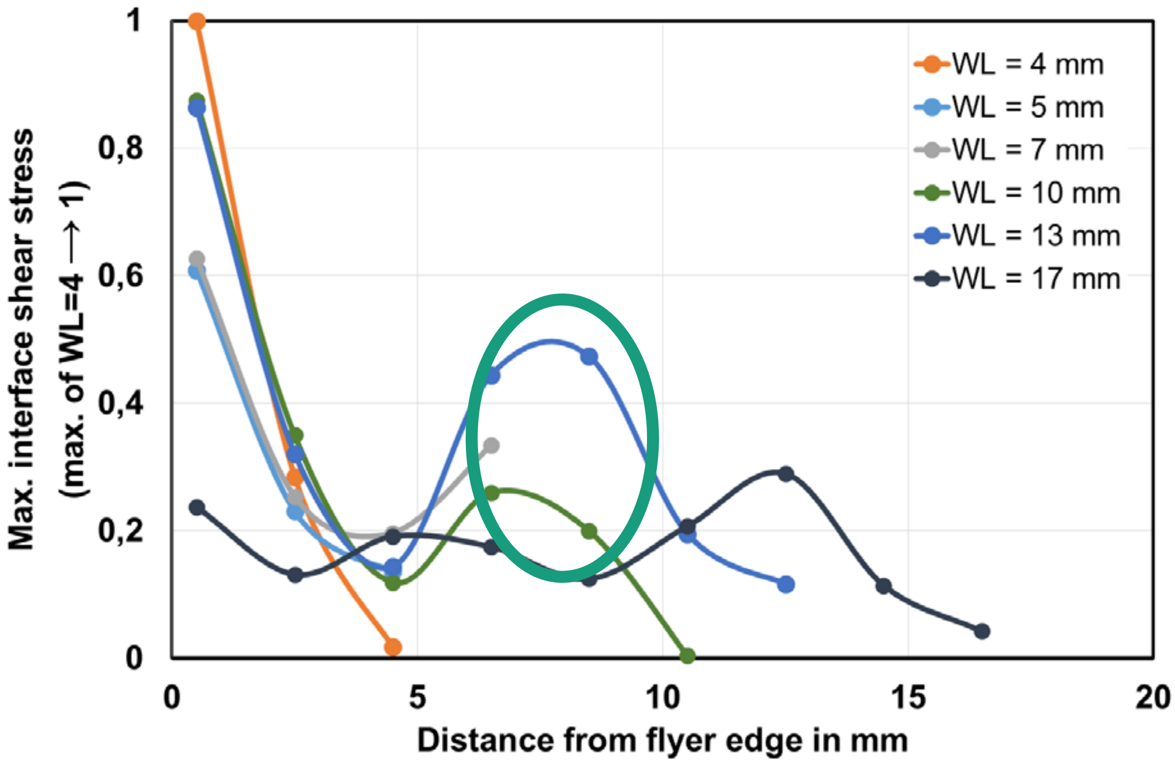
3. Results

Shear stress simulation at the contact zone



- Shear stress at flyer edge increases with decreasing working length
- Increase in shear stress for transition regimes (7…13 mm) at 7 mm distance from flyer edge

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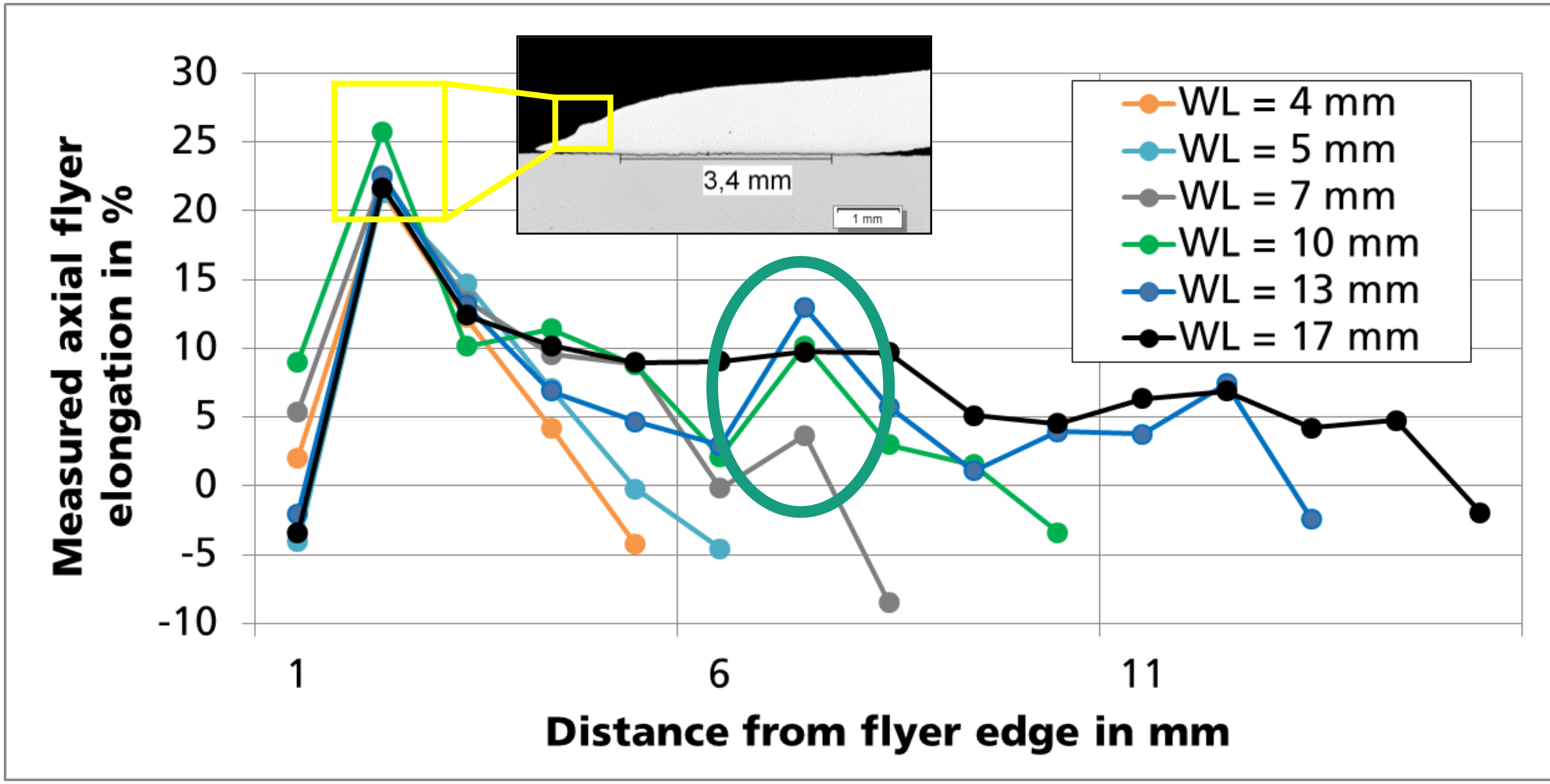
3. Results

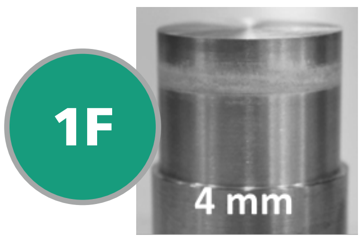
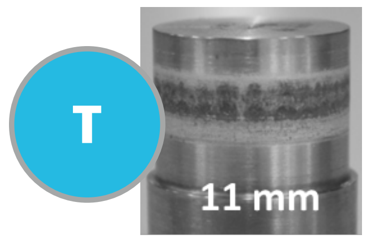
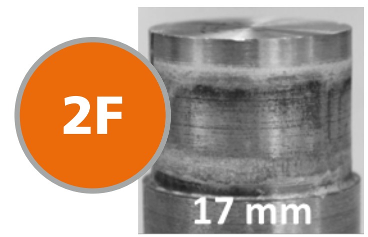
Visioplastic measuring of the flyer elongation



- Highest elongation at the flyer edge
- Increase in elongation for transition regimes (7…13 mm) at 7 mm distance from flyer edge

Conclusion

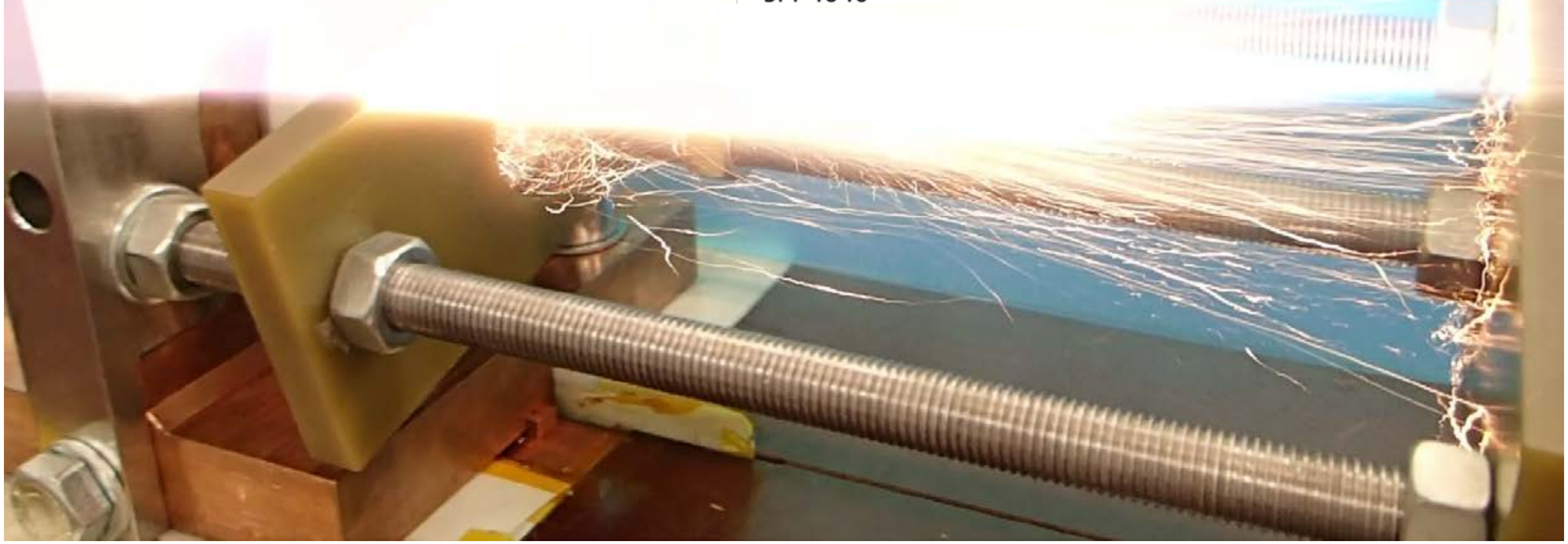
- Three front regimes related to the working length were identified:

	One-sided Front	Transition Front	Two-sided Front
Geometric relation	$l_w < 0{,}5\ l_{coil}$	$0{,}5\ l_{coil} < l_w < l_{coil}$	$l_{coil} < l_w$
			
Jet escape	easy	trapped	easy
Weld formation	optimal	no	suitable

- Pulse energy does not have large effect on deformation flyer shape
- Good correlation between calc. shear stress and measured elongations

Thank you for your attention.

This work is based on the results of the subproject A1 within the priority program SPP 1640 of the Deutsche Forschungsgemeinschaft (DFG). This project is executed together with the IUL at Technische Universität Dortmund. The authors would like to thank the DFG for the financial support.



Lorenz, Amanda; Lueg-Althoff, J.; Göbel, Gunther; Weddeling, C.; Beyer, Eckard; Tekkaya, A. E. (2014): Influence of Axial Workpiece Positioning during Magnetic Pulse Welding of Aluminum-Steel Joints. In: Proceedings of the 6th International Conference on High Speed Forming. 6th International Conference on High Speed Forming. Daejeon, Korea, May 26-29, 2014.