IMPROVING AND MONITORING THE MAGNETIC PULSE WELDING PROCESS BETWEEN DISSIMILAR METALS

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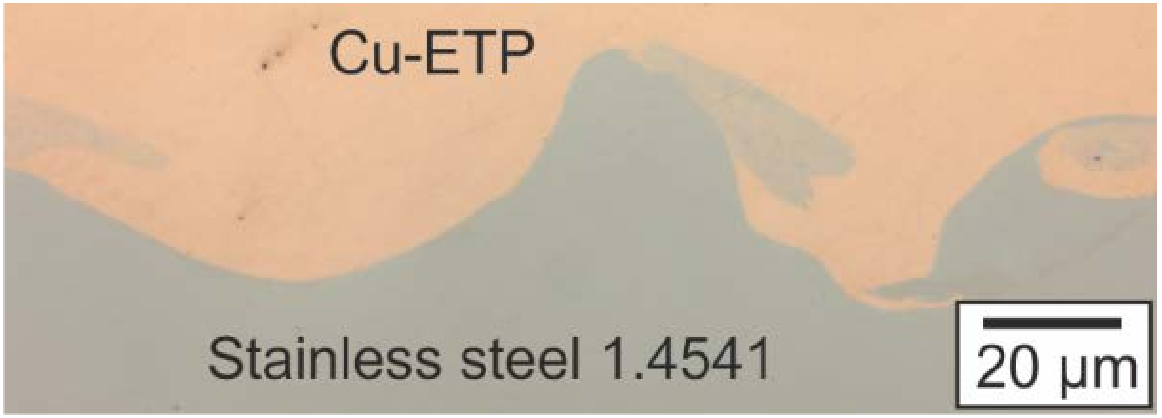
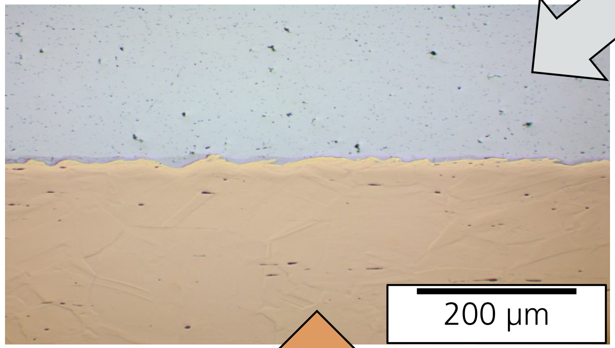
AGENDA

- Taking advantage of magnetic pulse welding (MPW)
- Facing the challenges of MPW
- Characterizing the high-speed impact
- Reducing the impact energy during MPW
- Testing of magnetic pulse welded joints
- Concluding remarks
- Competences at IWS



Advantages of MPW
Dissimilar metal welding

Aluminum
Melting point ≈ 660°C
Density ≈ 2.7 g/cm^3
Electrical conductivity ≈ 37 MS/m

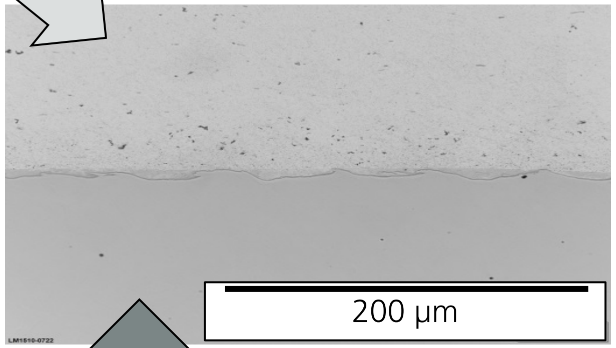


Exemplary motivations:

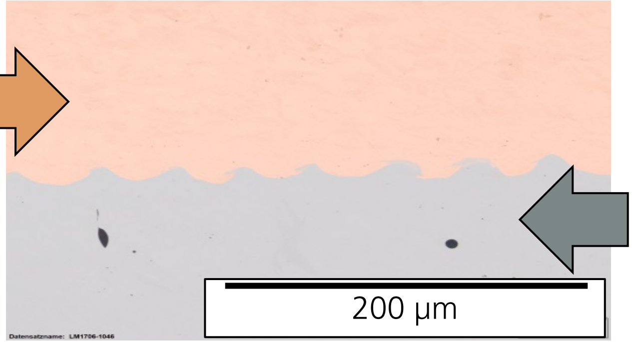
Realizing lightweight design

Substituting expensive or rare materials

Combining distinct different material properties within one part



Copper
Melting point ≈ 1085°C
Density ≈ 8.9 g/cm^3
Electrical conductivity ≈ 58 MS/m



Steel (S235)
Melting point ≈ 1250-1460°C
Density ≈ 7.8 g/cm^3
Electrical conductivity ≈ 10 MS/m

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Advantages of MPW
Possible joining configurations

Examples

Welding geometries

- Sheet-to-sheet or sheet-to-profile welding with flat coils
- Tube-to-tube or tube-to-cylinder welding with one turn coils or multi-turn coils with fieldshapers (compression or expansion)

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Advantages of MPW
Applications for tubular welding

Case studies

Material combinations

Hybrid drive shaft (left)

- Steel and aluminum

Multi-material part (right)

- Aluminum and stainless steel
- Copper and stainless steel

C45 (1.0503)
t = 11.5 mm

EN AW-6060 T66
t = 2 mm

Drive shaft:

torque transmission

EN AW-1050
t = 1 mm

X6CrNiTi18-10
(1.4541)
t = 2 mm

Cu-ETP
(CW004A)
t = 1 mm

Multi-material part:

thermal isolation and tightness at low temperatures

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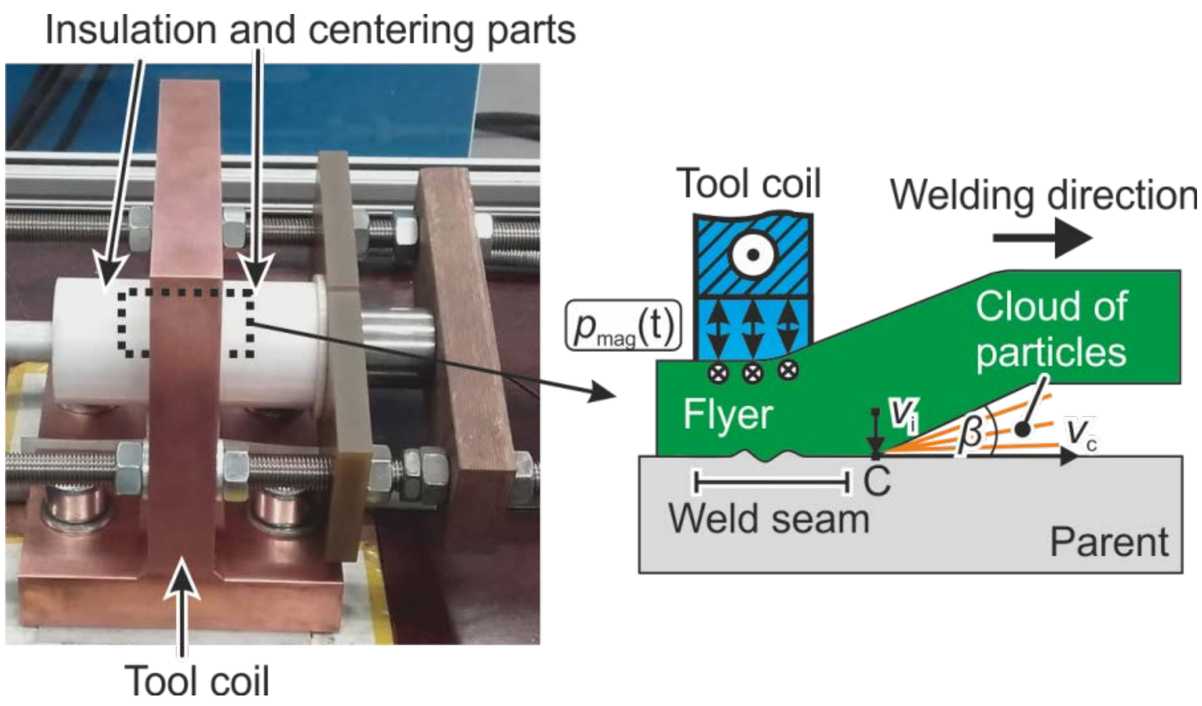
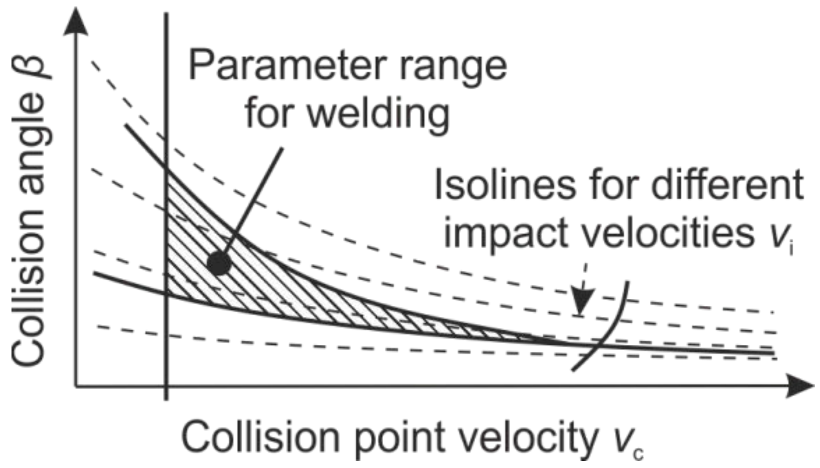
Challenges of MPW
Physical background



Schematic of a welding window



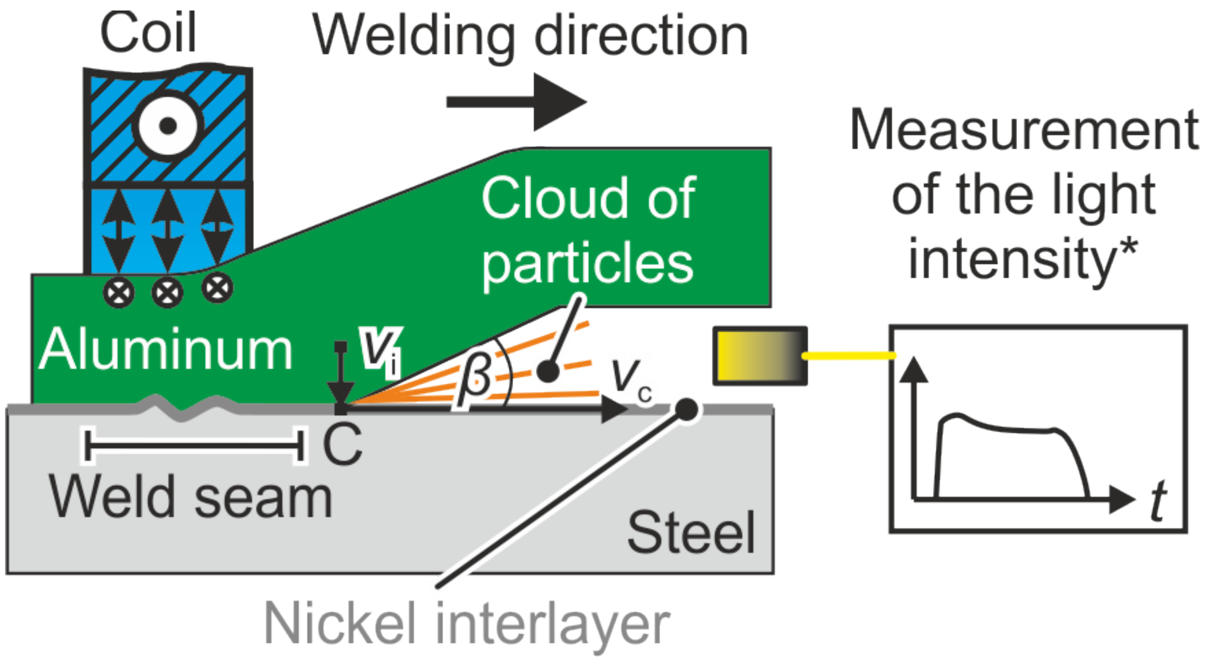
- Collision kinetics and welding results depend on multiple factors (geometrical, material and machine related)
- Welding at the lower boundary is aspired to increase the lifetime of the tool coils, but difficult to achieve and to monitor with conventional measurement techniques

Challenges of MPW
Strategies for process monitoring and improvement

Solutions

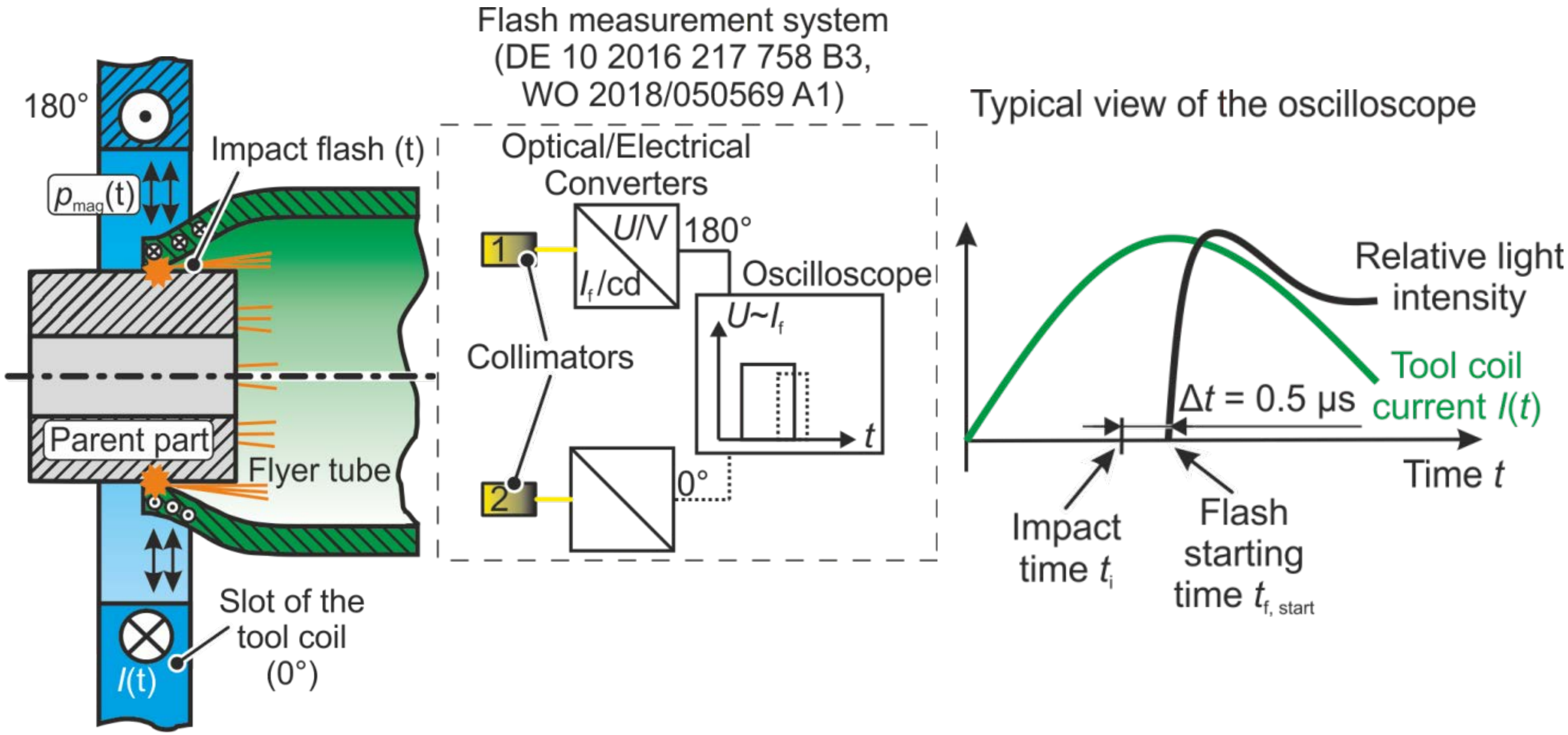
Measurement & Improvement

- Characteristic light emission enables determination of v_i, v_c & β
- Light intensity serves as a necessary welding criterion
- Interlayer of nickel is applied prior MPW on the steel parent



*DE 10 2016 217 758 B3, WO 2018/050569 A1

Characterization of the high-speed impact
Flash measurement system



- Reproducible delay of the flash starting time enables the calculation of the impact time t_i
- Impact velocity v_i, axial collision point velocity v_c and collision angle β can be estimated

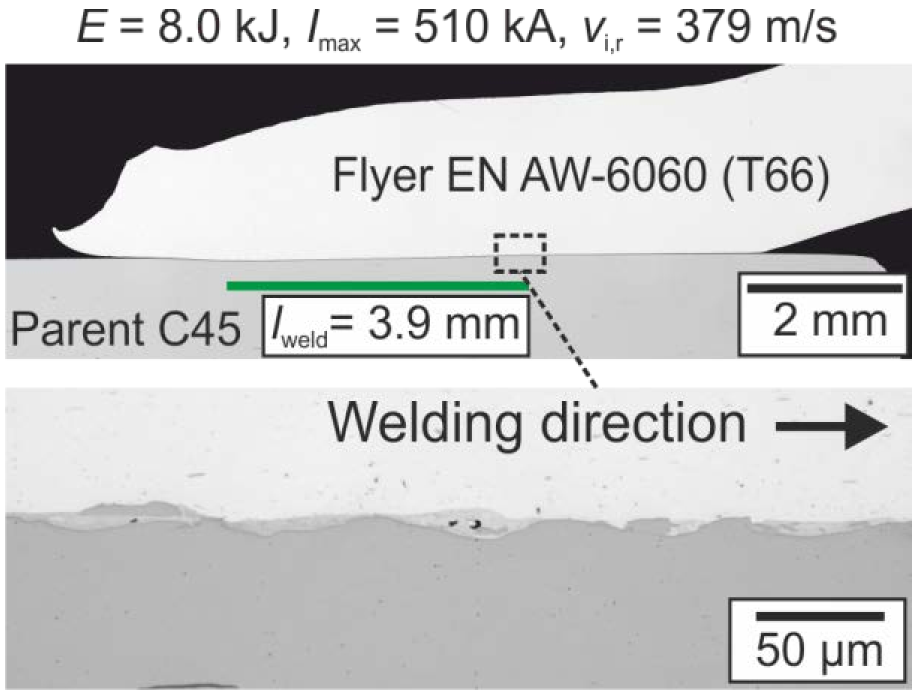
[Bellmann J. et al. (2017) Measurement of Collision Conditions in Magnetic Pulse Welding Processes.
Journal of Physical Science and Application 7(4):1–10. doi:10.17265/2159-5348/2017.04.001]

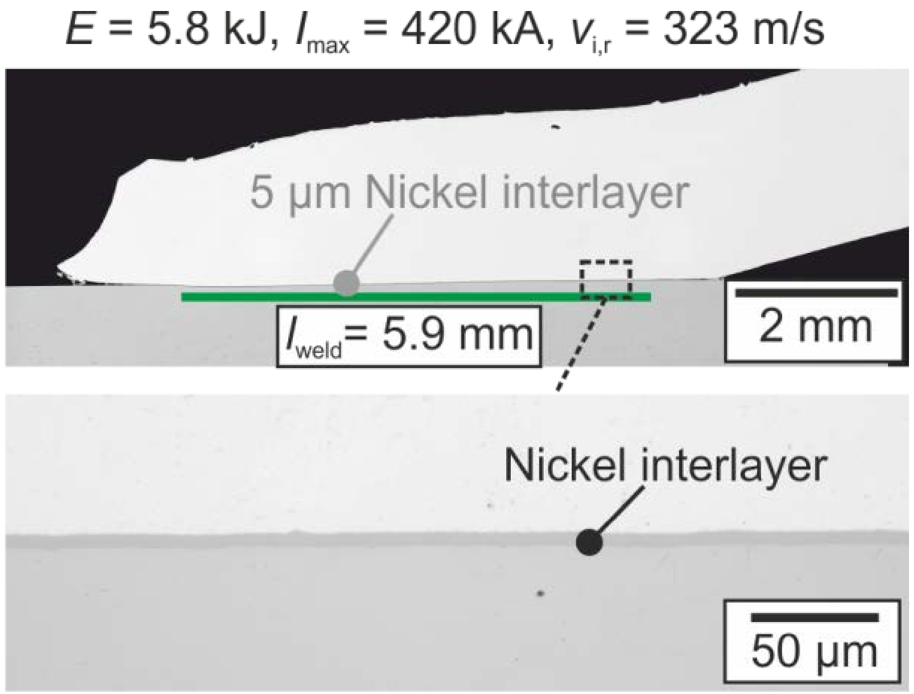
Characterization of the high-speed impact
Application of the flash measurement system

Material combination	Charging energy E	Maximum tool coil current *I*(t)	Starting time of the flash $t_{f,start}$	Calculated radial impact velocity $v_{i,r}$	Circumferential weld
	kJ	kA	µs	m/s	
Aluminum - steel	2.0	251	19.0	108	Yes
	2.9	312	17.2	120	Yes
	3.9	360	14.9	139	Yes
Copper - steel	8.0	504	14.6	142	No
	11.5	630	9.3	227	Yes

- Measurement system enables the identification of the lowest possible impact velocity for weld formation (welding window)
- Influence of machine and part related parameters on the forming behavior can be studied

Energy reduction during MPW
Influence of reactive interlayers





- Nickel interlayer on steel surface enables an energy reduction and extension of the weld seams
- Underlying mechanism is the reaction enthalpy of Al-Ni, which is higher compared to Al-Fe

[Bellmann J. et al. (2018) Effects of Reactive Interlayers in Magnetic Pulse Welding. Proceedings of the 8th International Conference on High Speed Forming]

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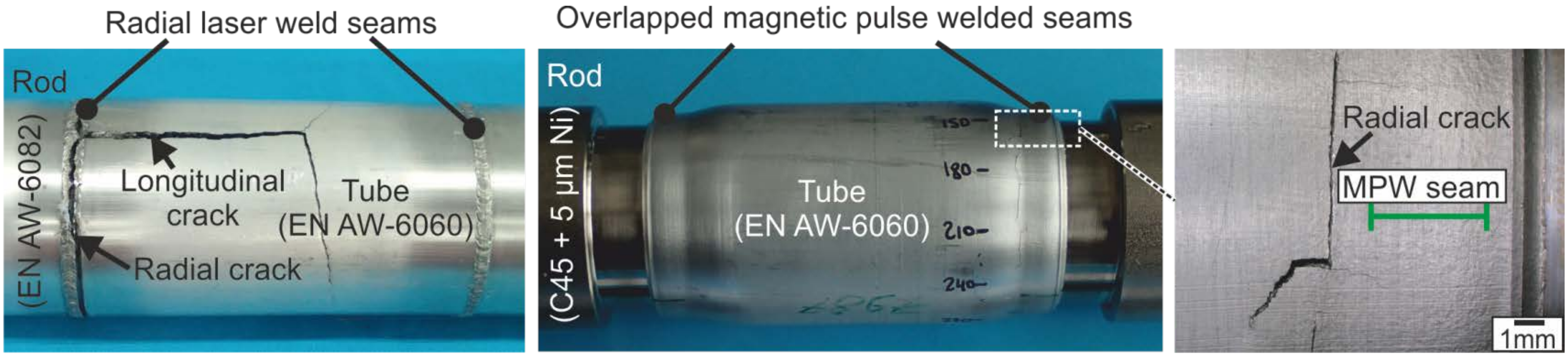
Testing of MPW parts with nickel interlayer
Comparison with laser welded specimens (LBW) under torsional loading

- Same dimensions of the middle section: Ø40 x 2 mm EN AW-6060 T66
- Increase of the overall static load bearing capability from 558 Nm (LBW) to 737 Nm (MPW)
- Slight increase of the alternating torsional load for a failure probability of 50 % from 113 Nm (LBW) to 127 Nm (MPW)



[Bellmann J. et al. (2016) Magnetic Pulse Welding: Joining within Microseconds – High Strength Forever. Proceedings of the 10th International Conference on Trends in Welding Research and 9th International Welding Symposium of Japan Welding Society, pp. 91–94 and Bellmann J. et al. (2017) Targeted Weld Seam Formation and Energy Reduction at Magnetic Pulse Welding (MPW). Biuletyn Instytutu Spawalnictwa 2017(5):91–102. doi:10.17729/ebis.2017.5/10

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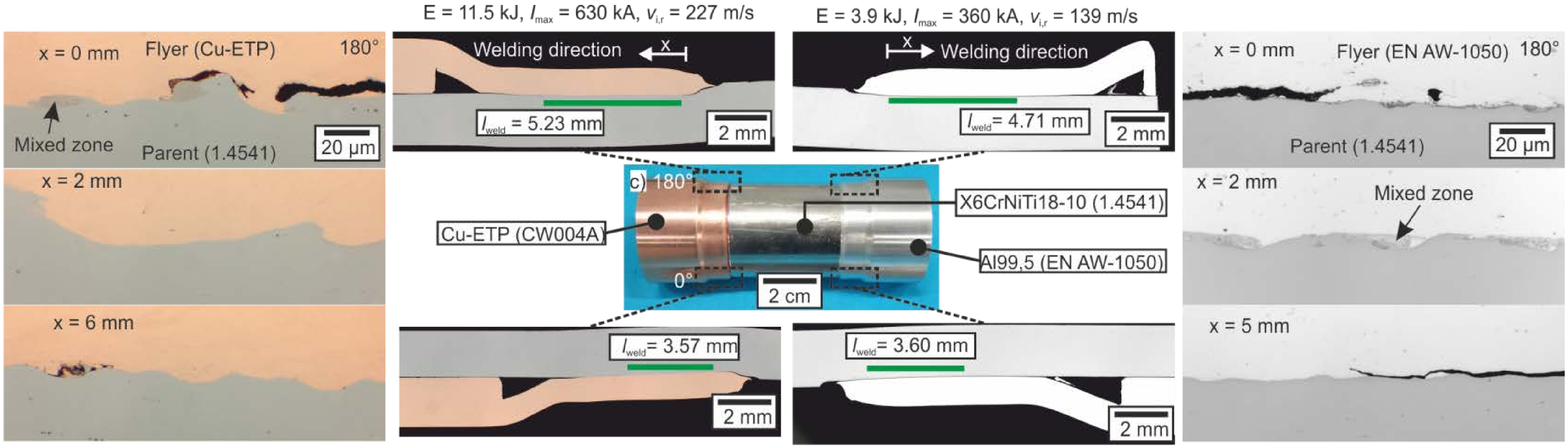
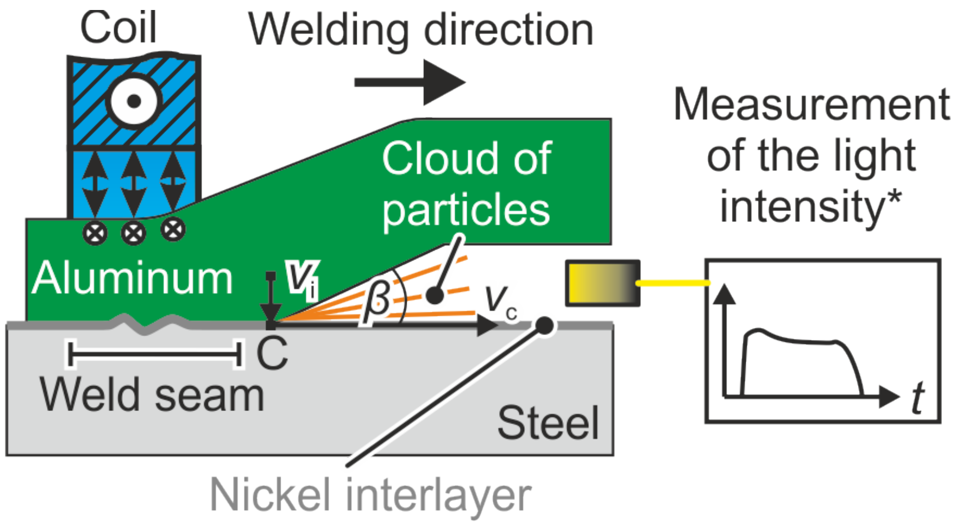
Testing of MPW parts
Leakage testing and metallographic analysis

- 15 times: shock cooling and heating from room temperature to 77 K and vice versa
- Proof of leak-tightness with an inner pressure of 10^{-2} mbar at both temperature levels



Conclusions



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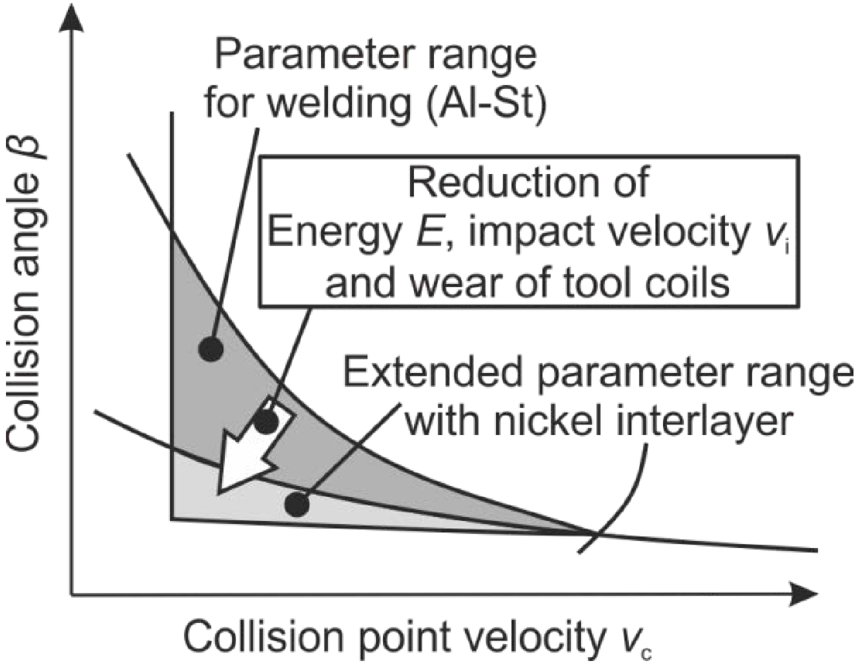


Highlights

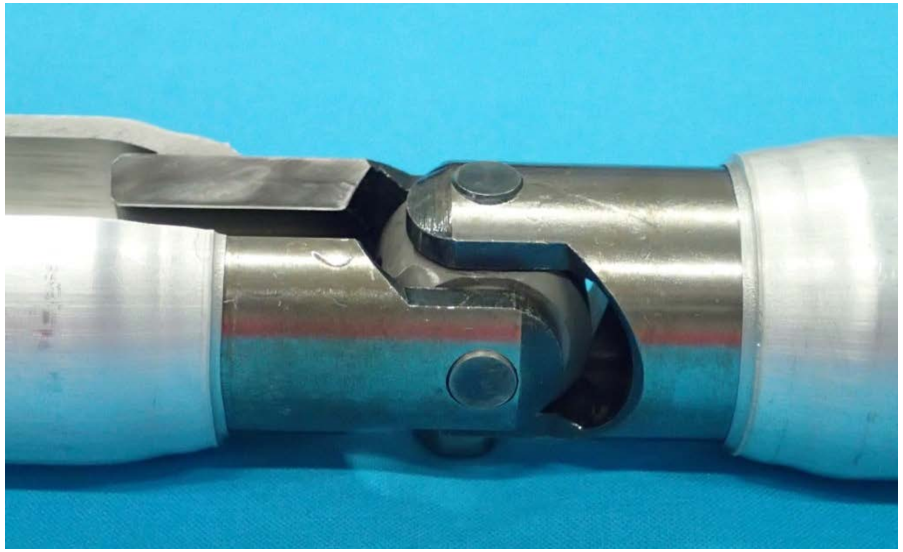
- New optical measurement system
- Improved MPW process with nickel interlayers
- Reduced energy input during MPW
- High mechanical strength

Competences at Fraunhofer IWS

Magnetic Pulse Welding

Our service

- Consulting and feasibility studies
- Research & development in cooperation with partners from industry and also within public projects
- Tool and system development
- Industrialization



Contact and Acknowledgment

Thank you for your attention!

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