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Electron beam welding of components with joint gap using filler wire and adjusted energy distribution

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1. Introduction

Challenge and motivation

- Beam welding processes inherently place high demands on joint preparation and typically require a technical zero-gap.
- Joint preparation is usually carried out by machining, which results in additional effort and increased costs.
- The ability to weld thermal cut edges or without subsequent machining or machined parts with joint gap offers significant savings potential in terms of labor and material costs.

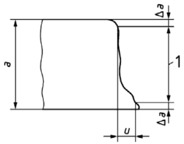
Goal: Development of a welding strategy for reliable welding of thermal cut edges, even in the case of a non-zero gap, by using an adjusted energy distribution and filler wire.

1. Content

Introduction

Thermal cutting technologies

Joint gaps in large-scale parts



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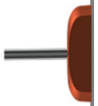
EB welding configuration

Welding configuration at *ifs*



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3

Machine vision methods

Measuring the gap with electron optical imaging

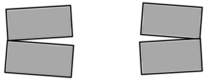
Determination of the welding parameters

4

Welding results

Welding of parts with constant gaps

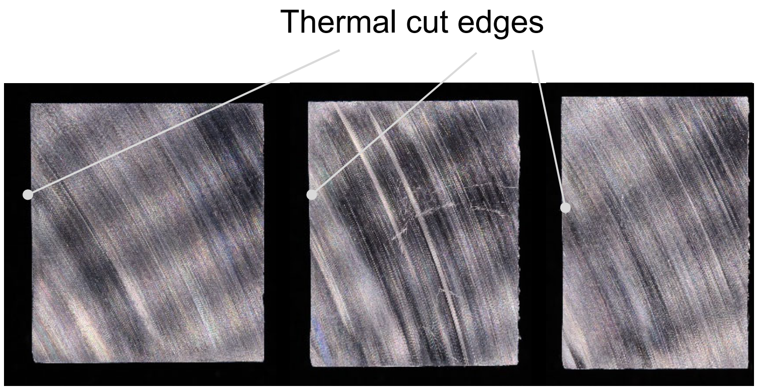
Solutions for opening or closing joint gaps



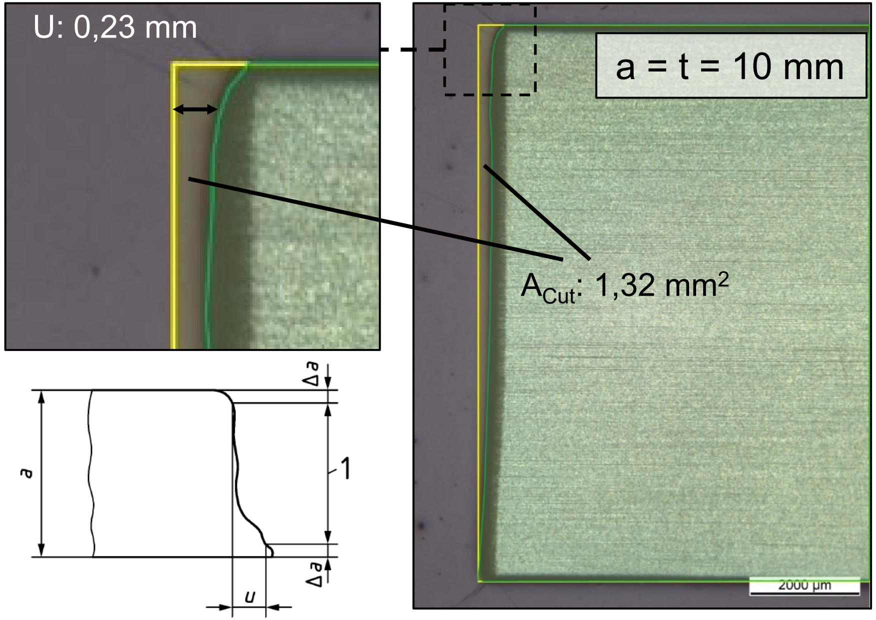
1. Specimen preparation

Coupons were prepared by means of plasma cutting

- Material: P355GH (t = 10 mm and t = 20 mm)
- Characterization of the thermal cut edges according to ISO 9013

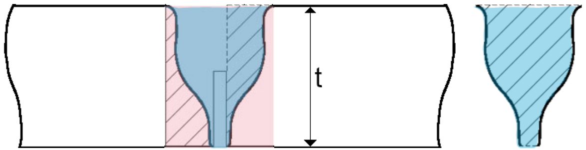


Metallographic cross-sections from thermal cut edges (t = 20 mm)

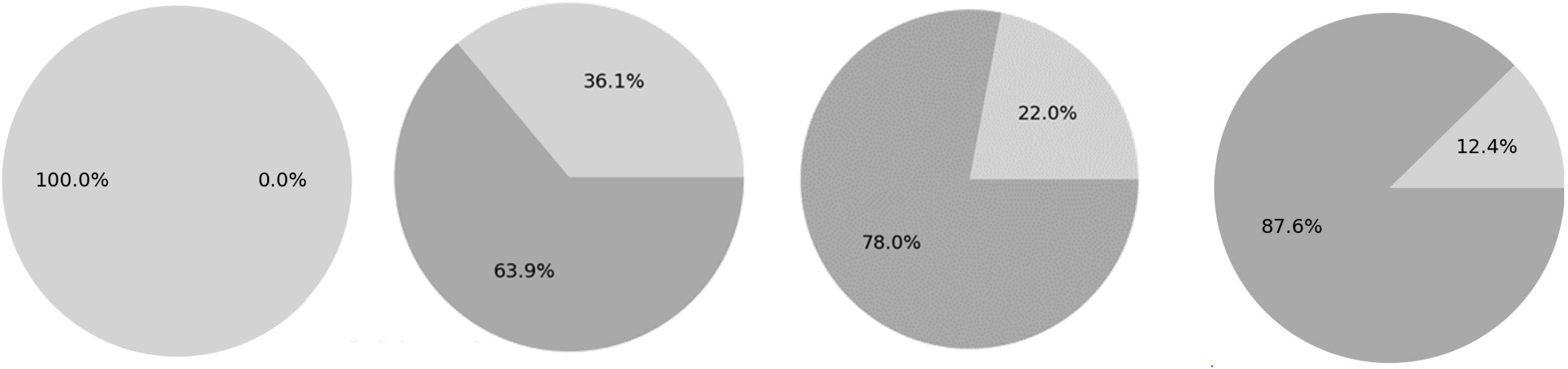


Example for the characterization of a thermal cut edge

1. Specimen preparation



Is the material is missing due to the cut edges or due to the additional gap may occur?



Gap: 0 mm **Gap: 0.5 mm** **Gap: 1.2 mm** **Gap: 2.0 mm**

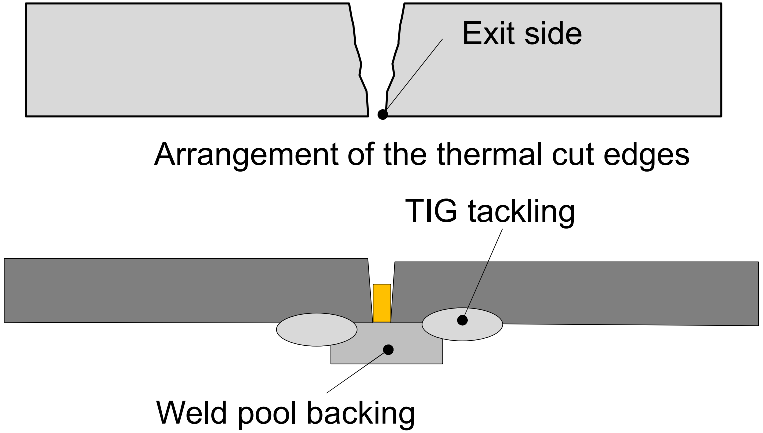
t = 10 mm, Lack of material due to the thermal cut edges: 2.6 mm^2 for the underlying case
Lack of material due to the joint gap: joint gap * material thickness

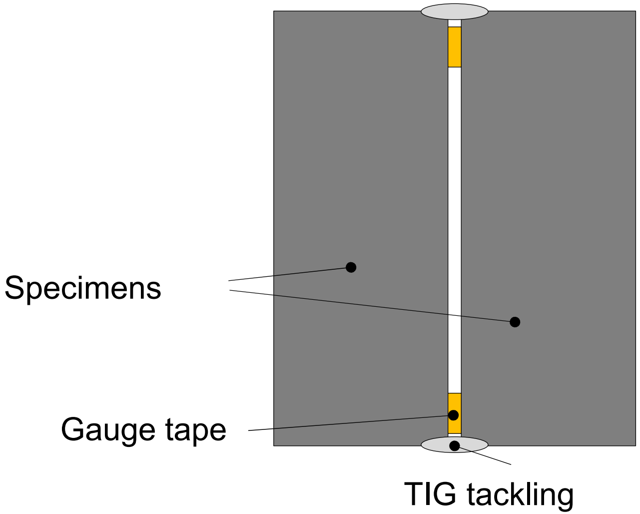
Lack of material due to the thermal cut edge

Lack of material due to the additional joint gap

2. Specimen preparation

The specimens were manually prepared and tackled through TIG welding



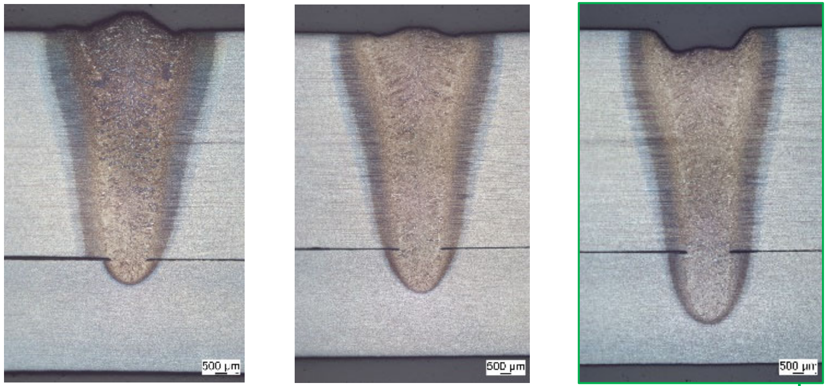


2. EB welding configuration

Subsequently, an experimental matrix was designed

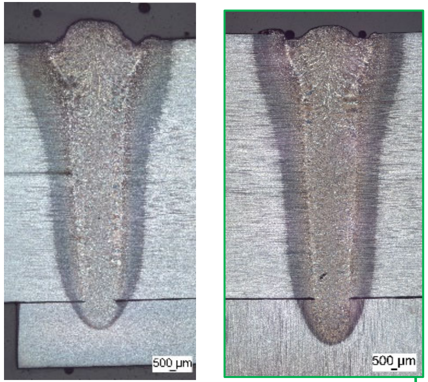
- Lower limit: maximal gap size without filler wire; Upper limit: 2.0 mm
- Up to 0,4 mm joint gap, the gap bridging is possible without filler wire without an incompletely filled groove

t = 10 mm



0 mm | 0,4 mm | 0,5 mm

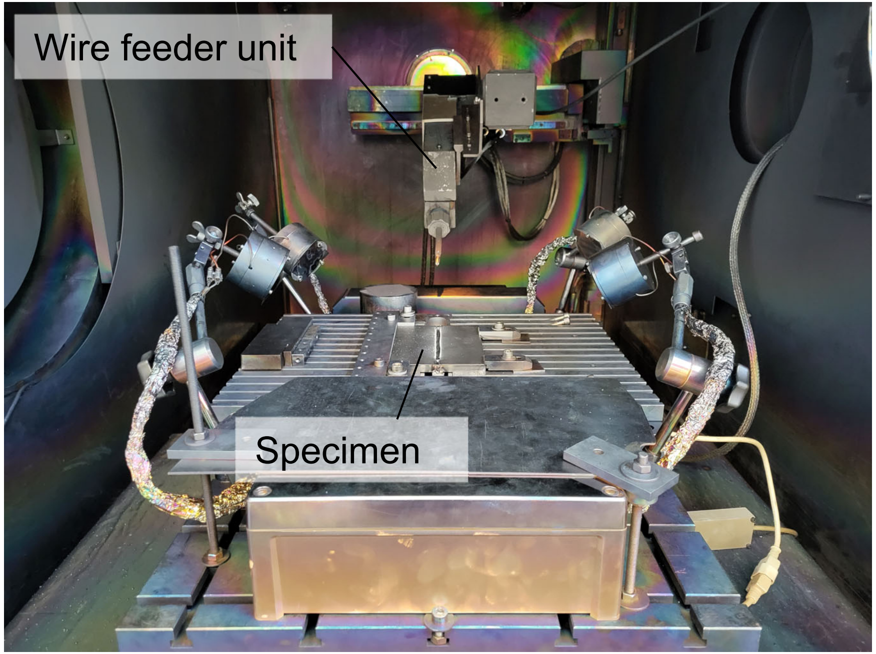
t = 20 mm



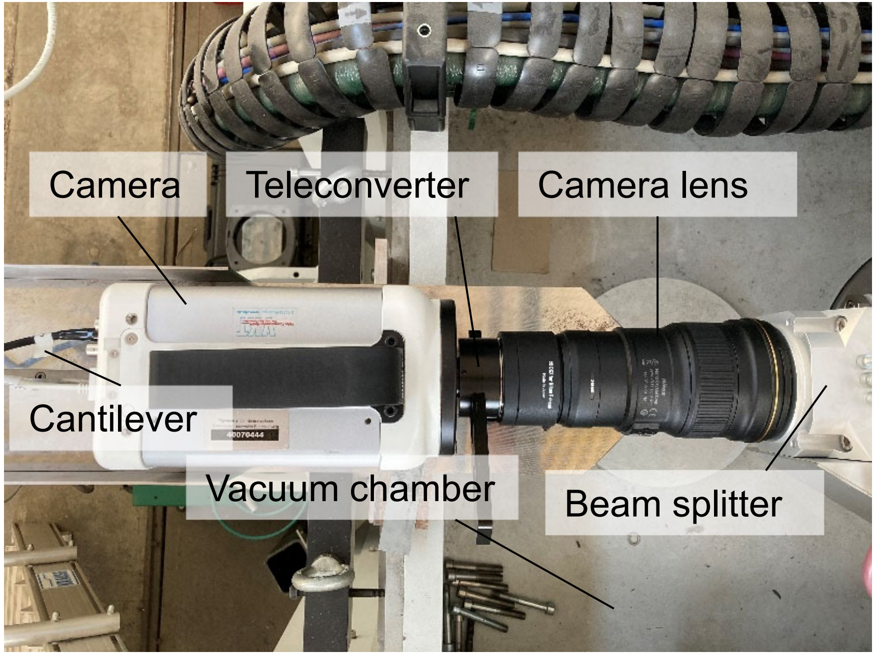
0 mm | 0,5 mm

Lower limit of the subsequent experimental matrix

2. EB welding configuration



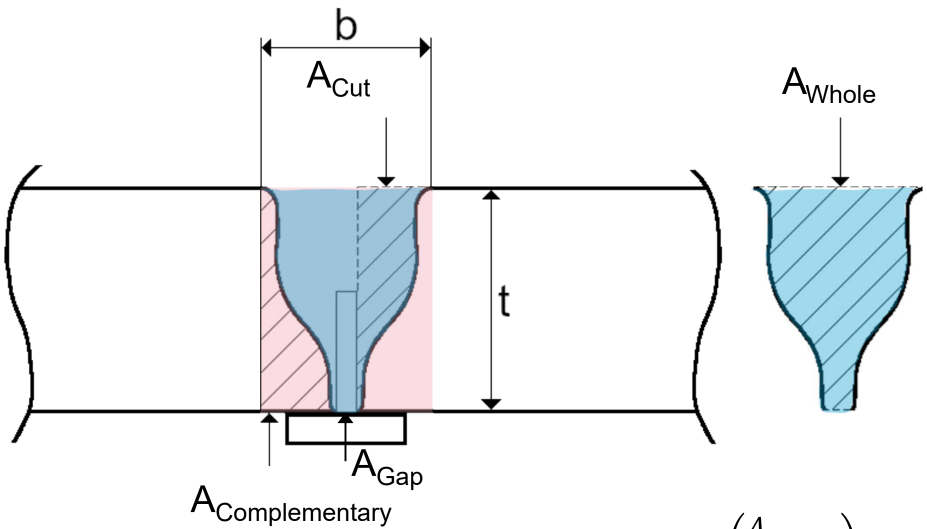
EB welding with integrated wire feeder unit



High-speed videography configuration

3. Calculation algorithm for the wire feed speed

Before each welding trial, the wire feed speed should be calculated based on the gap



$$A_{Whole} = b * t - 2 * A_{Compl.}$$

$$v_{Wire} = \left(\frac{A_{Whole}}{A_{Wire}}\right) * v_{Weld}$$

b: Gap, determined with ELO

t: Material thickness

v_{Weld}: Welding speed

A_{Cut}: Missing area due to the cutting process

A_{Gap}: Missing area due to the additional gap

A_{Whole}: Total missing are

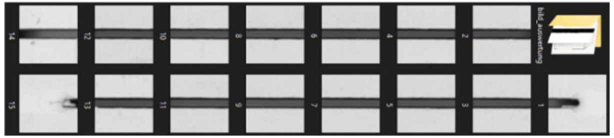
$A_{Complementary}$: Complementary area

3. Measuring the gap

There are two ways to measure the gap with back-scattered electron imaging

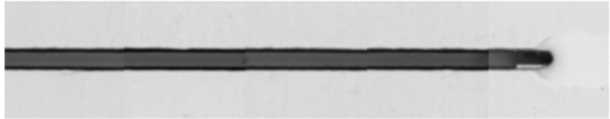
1. Automatic capturing of electron optical imaging while passing along the joint edge

Raw data



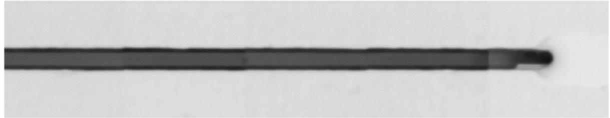
Automatic capturing von ELO images (12 mm × 12 mm)

Assembly



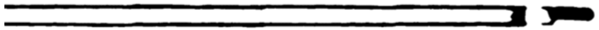
Creating a complete image through merging the individual images

Filtering



Denoising

Binarization



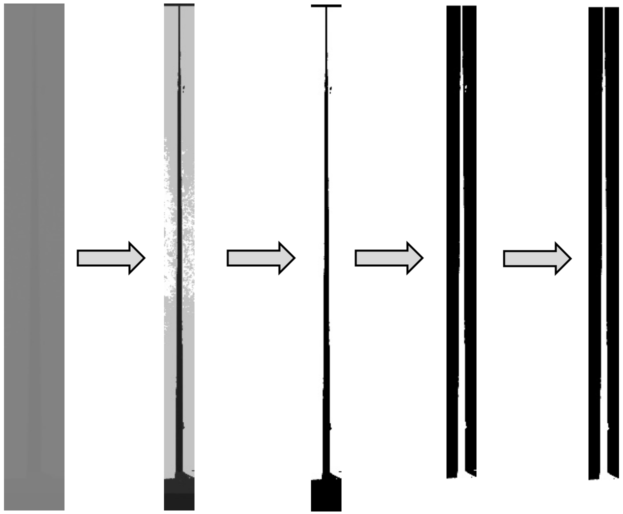
Gap size

Calculation of the mean gap size

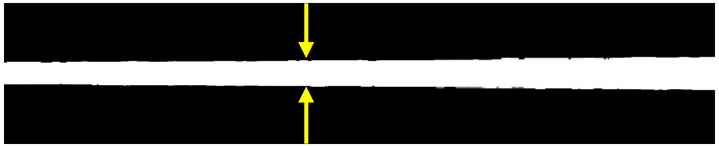
3. Measuring the gap

There are two ways to measure the gap with back-scattered electron imaging

2. Using a free contour tracking (FCT) subroutine

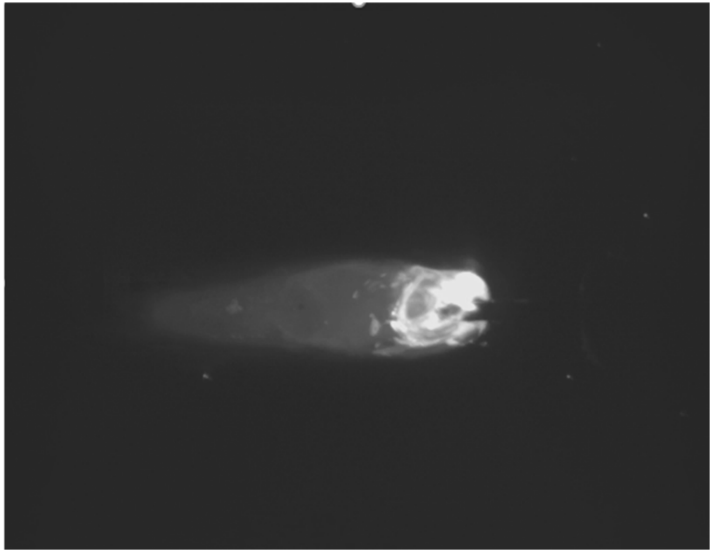


1) Measuring the first and last while pixel
2) Assigning the coordinates to the distances, pixel-distance conversion
3) Calculating the necessary wire feed speed

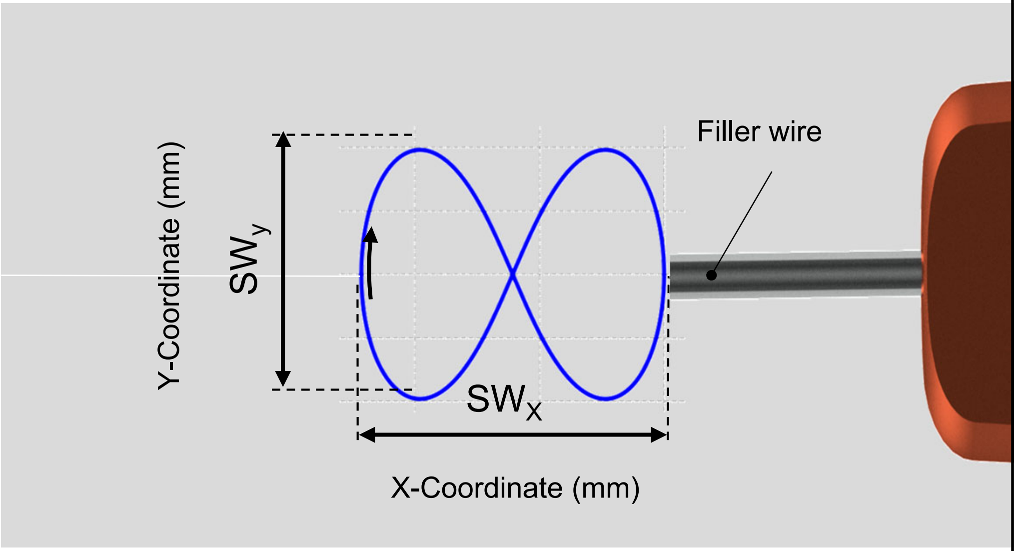


4. Welding results – Welding technology

The welding strategy involves the wire feeding into the melt pool and a wide oscillation



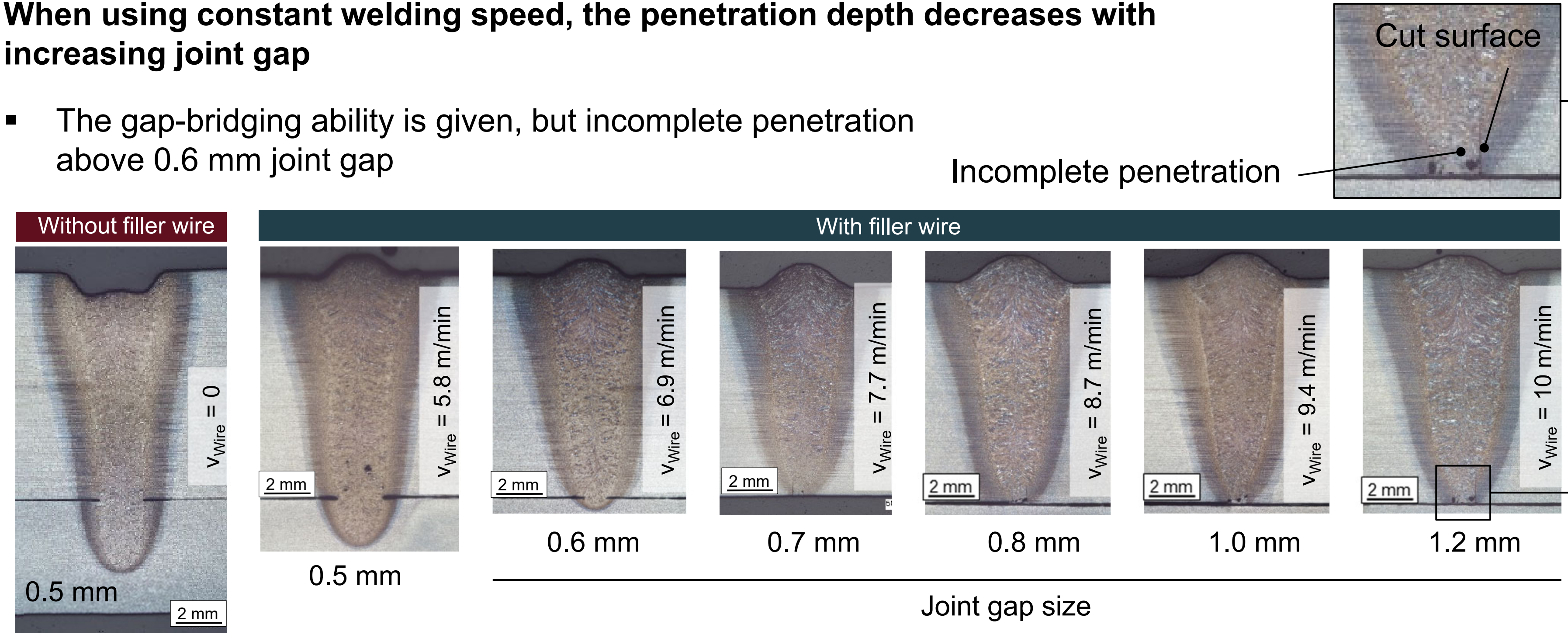
High-speed video of the process



4. Welding results

When using constant welding speed, the penetration depth decreases with increasing joint gap

- The gap-bridging ability is given, but incomplete penetration above 0.6 mm joint gap

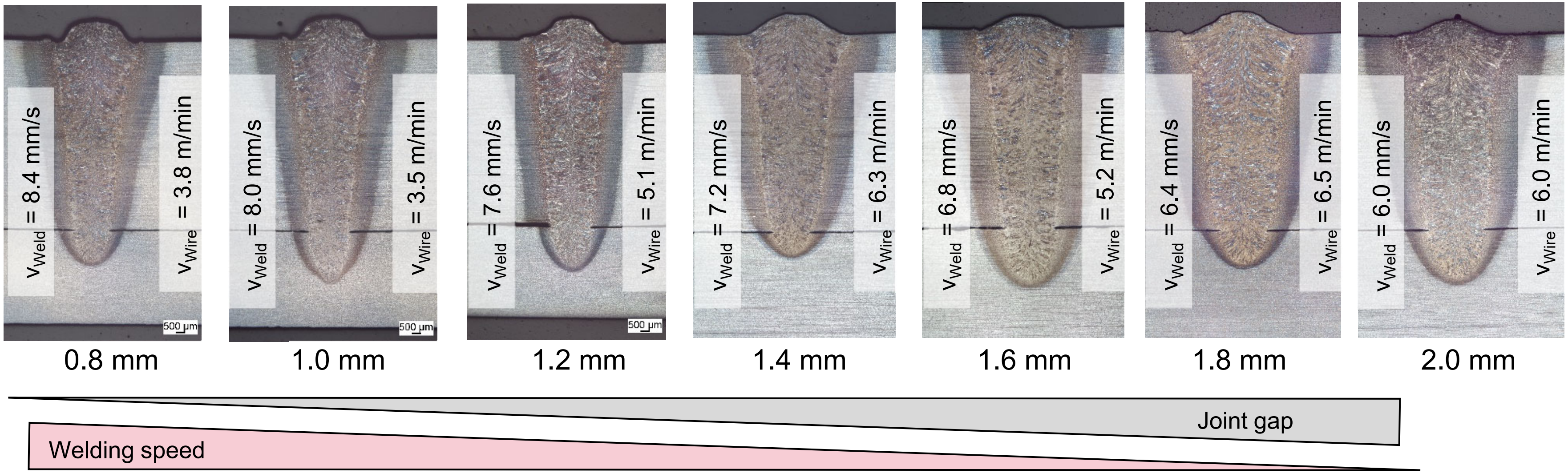


SQ: 60 mA | v_{Weld}: 10 mm/s

4. Welding results

Adjusting the welding speed resulted to full penetration welds in all configuration

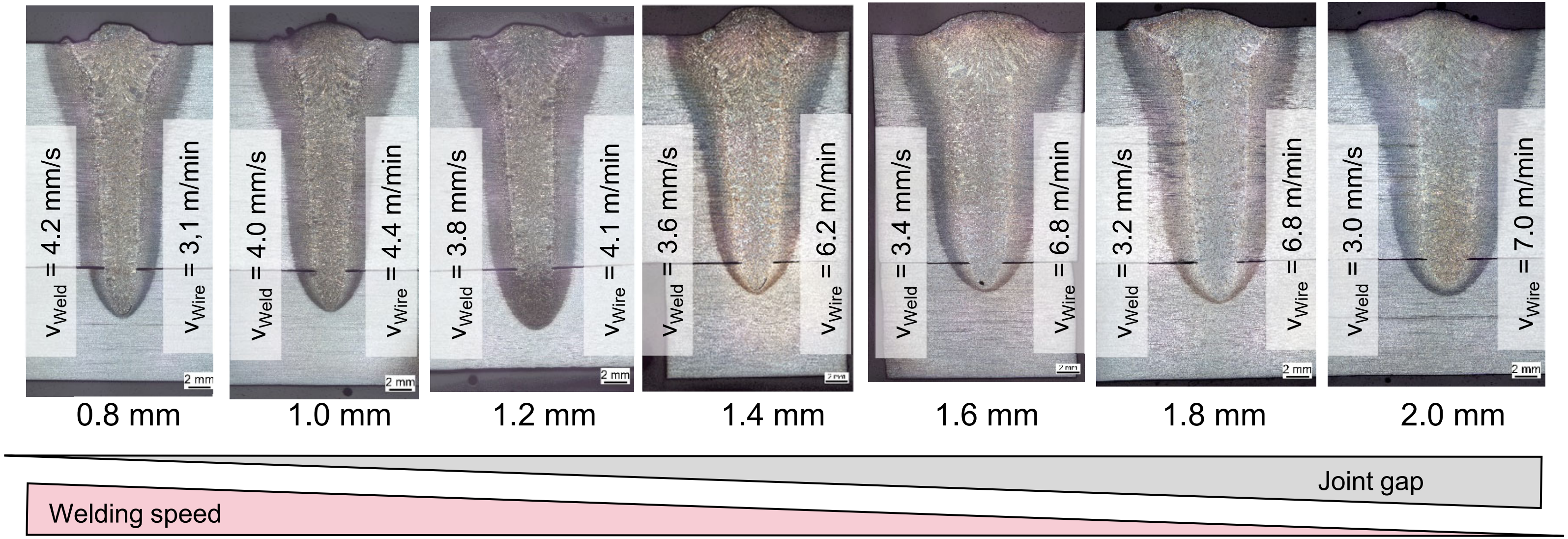
t = 10 mm



4. Welding results

Adjusting the welding speed resulted to full penetration welds in all configuration

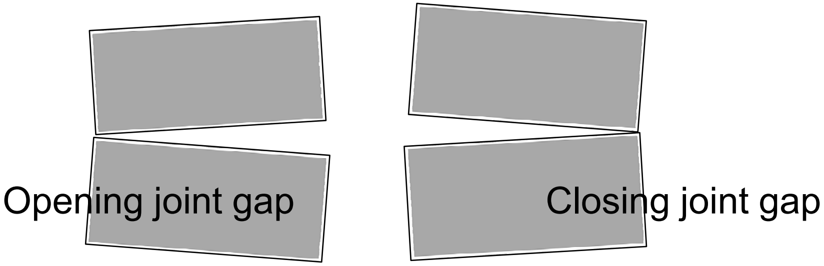
t = 20 mm



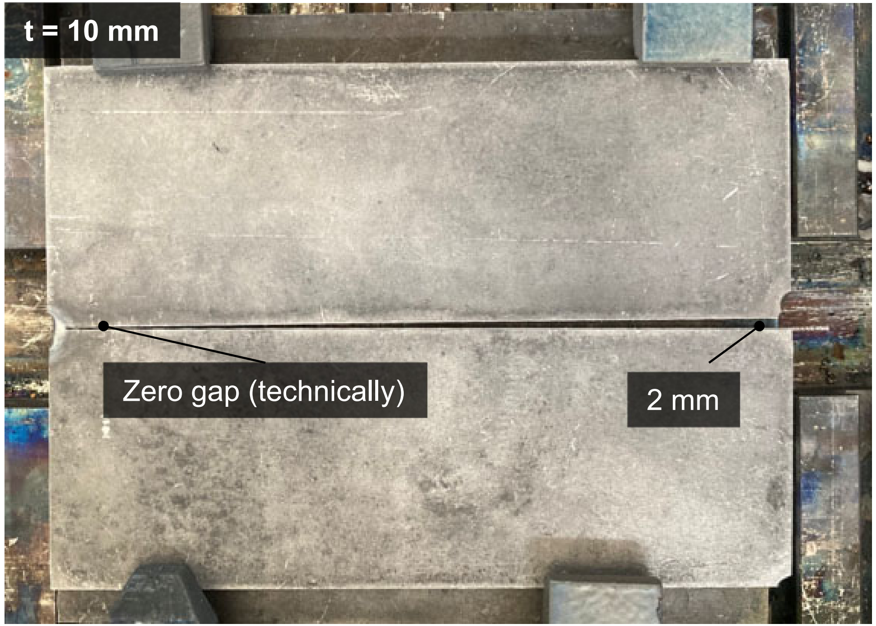
4. Welding results – Varying gap size

A further question was if inconstant joint gaps can be welded with high process stability

- Multiple scenario have been derived:
  - Opening gap
  - Closing gap

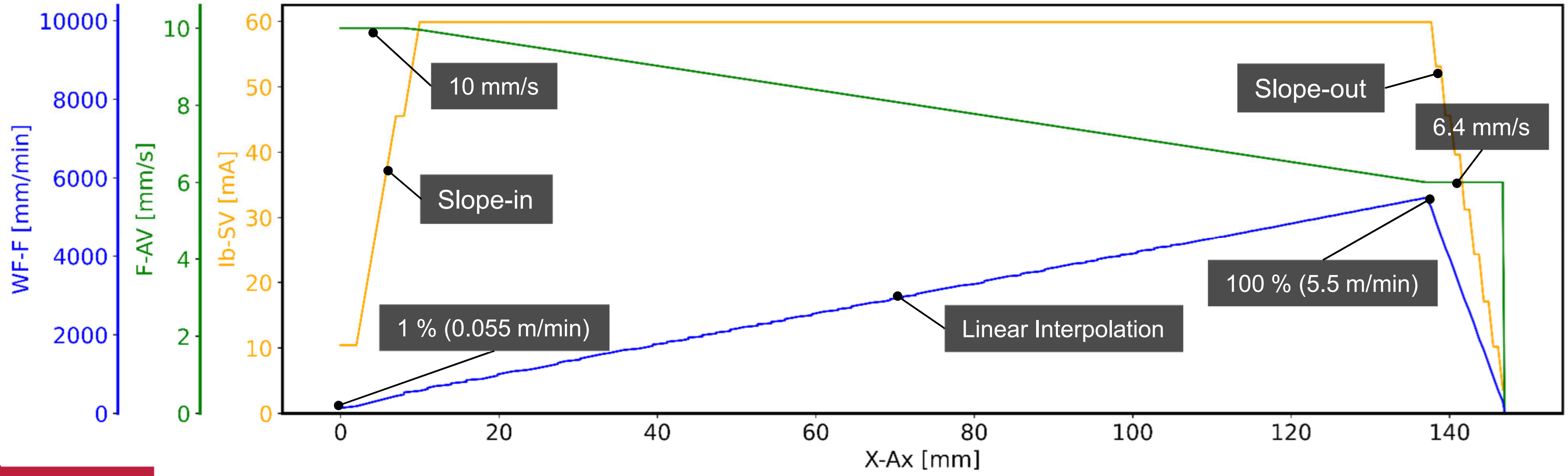


In-process control of the wire feed speed is required and meanwhile possible

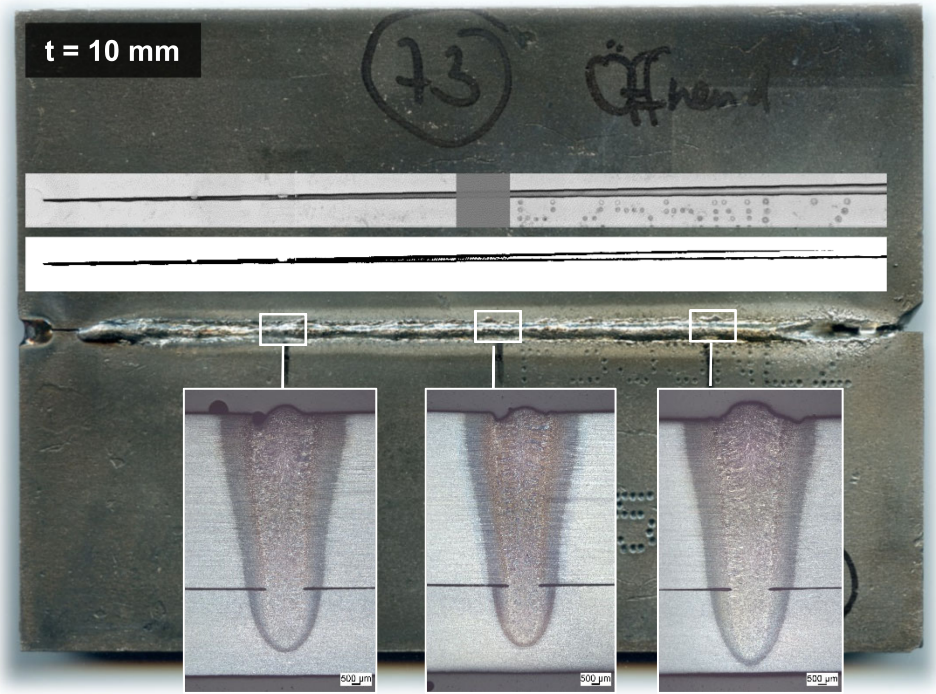


4. Welding results – Varying gap size

The process strategy for opening gap involves the decrease of the welding speed and the increase of the wire feeding speed



4. Welding results – Varying gap size

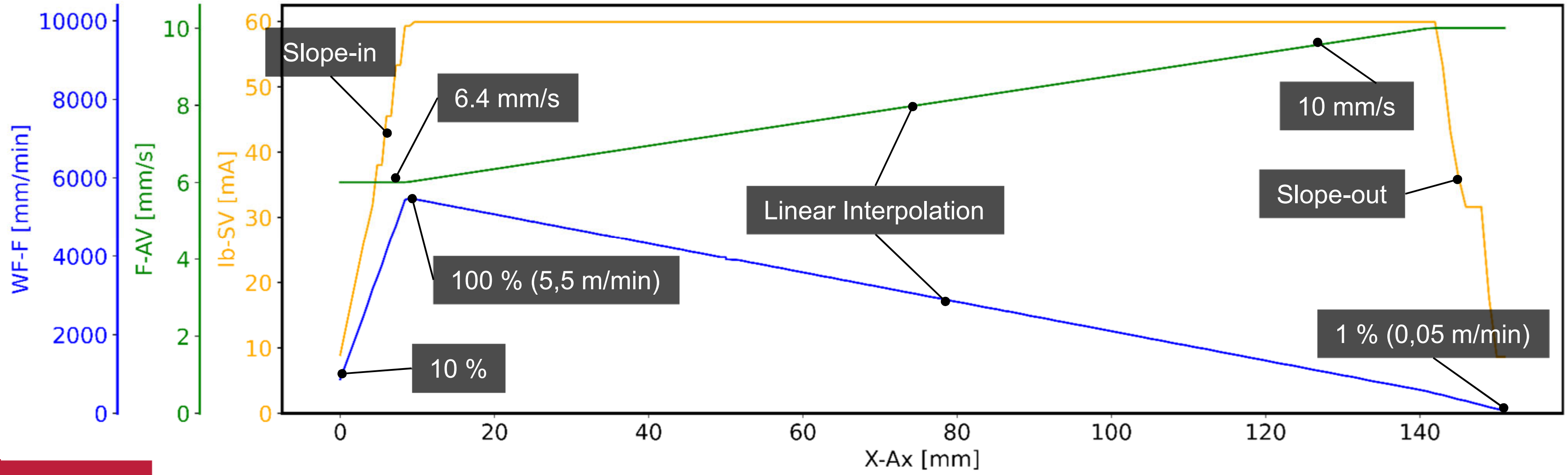


Through the simultaneous control of the wire feeding speed and welding speed, an excellent welding quality was achieved

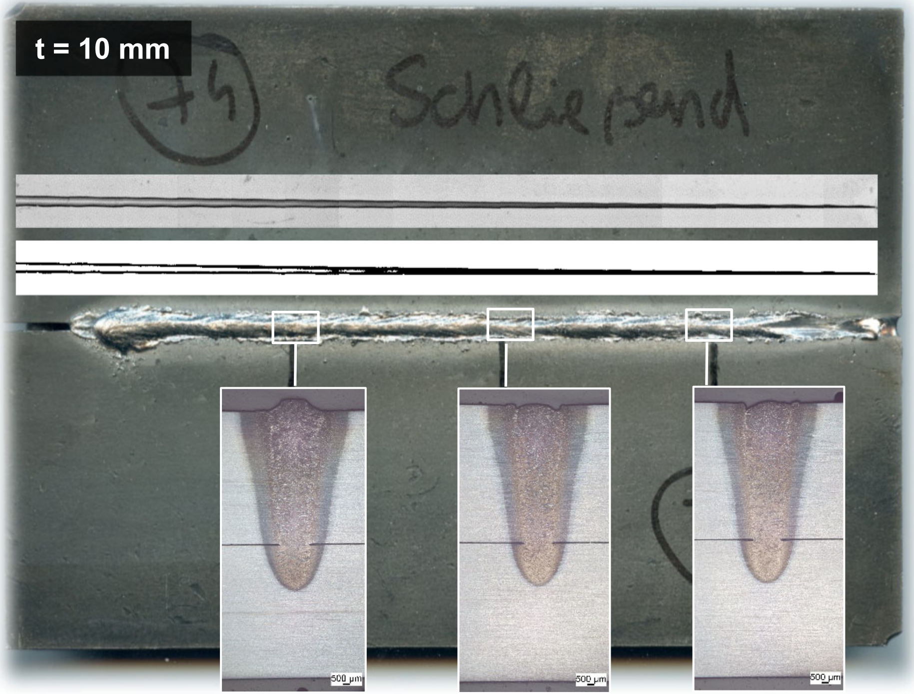
- Excellent gap bridging along the whole weld seam
- Full-penetration weld in every region
- In the beginning, minimal undercuts could be detected
  → Wire feeding speed has been increased from 1 % to 100 % (linear interpolation)

4. Welding results – Varying gap size

The process strategy for closing gap involves the increase of the welding speed and the decrease of the wire feeding speed



4. Welding results – Varying gap size



Good gap bridging along the whole weld seam with good weld quality

- Nearly constant penetration depth
- Only minimal undercuts in the end region of the weld seam

5. Summary

By applying an adapted beam oscillation in combination with the use of filler wire, it was possible to bridge gap sizes of up to 2 mm without any loss in weld seam quality.
The major findings can be summarized as follow:

- The oscillation pattern (“Infinity”) produced nearly parallel seam flanks and enabled the welding process to be scaled with respect to penetration depth
- Electron-optical imaging combined with subsequent image processing proved to be a suitable and reliable method for the automated detection and measurement of gap sizes.
- The required wire feed rate was calculated on the basis of electron-optical data, material thickness, welding speed, bevel angle of the cut edge, and wire diameter.

Further aspects

- Automated in-situ measurement of the gap and closed-loop control
- Investigation of further material groups such as aluminum

Contact

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