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Institut für Füge- und  
Schweißtechnik

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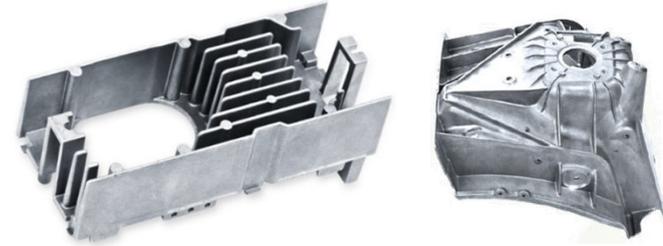
# Electron beam welding of aluminum die castings using multi-bath technique

Tamás Tóth, Kai Noack, Klaus Dilger

# 1. Introduction

## Die casting light metal parts became the part of everyday life

- **Aluminum alloys** has become popular for its distinctive features such as corrosion resistance, high stability for complex shapes and high tensile strength
- The **transportation sector** is the largest end-use segment for this industry
- Lightweight parts with high complexity and stiffness
- **Increasing market size** and increasing **demand** for die cast components e.g. for electric vehicles
- **High-volume production on a cost-efficient way**



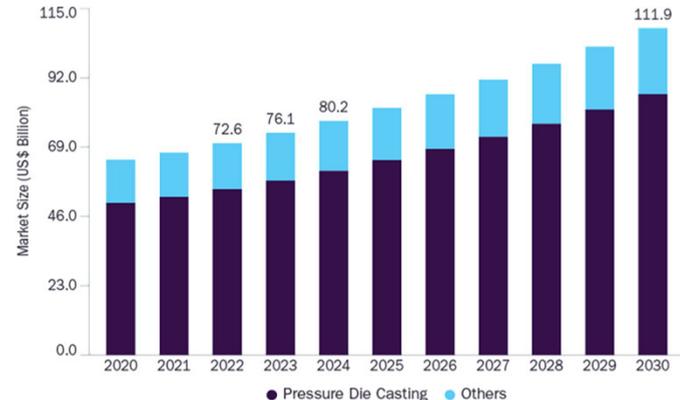
Die casting aluminum parts

Source: RHEINFELDEN ALLOYS GmbH & Co. KG

**Aluminum die castings are occasionally welded together with other aluminum parts to fabricate larger components or seal electronic parts**

## Aluminum Die Casting Market

Size, by Production Process, 2020 - 2030 (USD Billion)



● Pressure Die Casting ● Others



**5.8%**

Global Market CAGR,  
2025 - 2030

Source:  
www.grandviewresearch.com



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18.09.2025 | Tamás Tóth, Kai Noack, Klaus Dilger | Electron beam welding of aluminum die castings using multi-bath technique | Slide 2

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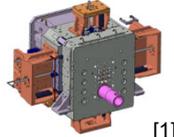


# 1. Introduction

## Basics of high pressure die casting

Low-cost series production of lightweight metal parts

Complex parts with high stiffness



[1]

## Welding of complex parts

Challenges with complex non-linear contours

Solutions with advances hardware and high-velocity data streams



1

2

3

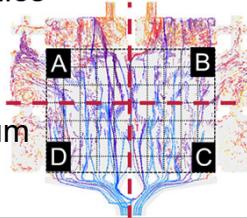
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## Challenges in welding of die casts

Non-laminar flows in casting dies

Necessity of release agents

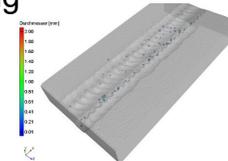
Hydrogen solubility in aluminum



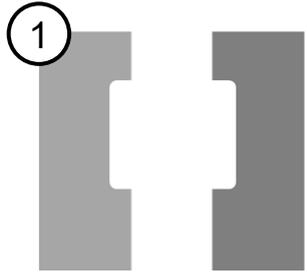
## Multi-bath EB welding of die casts

Subsequent, simultaneous re-melting

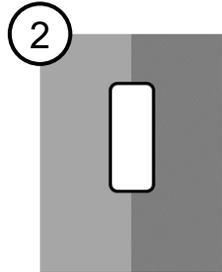
Reduction the porosity through parameter optimization



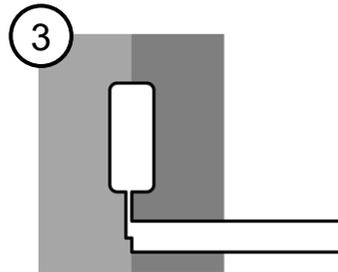
# 1. Basics of light metal die casting



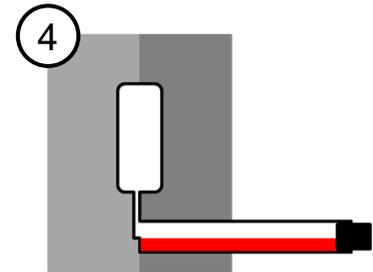
Steel mold (2 halves)



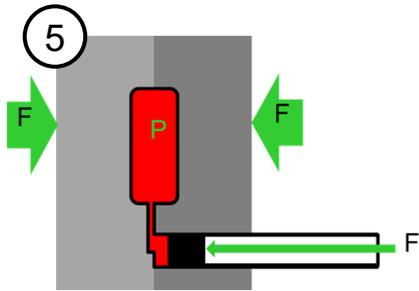
Steel mold closed



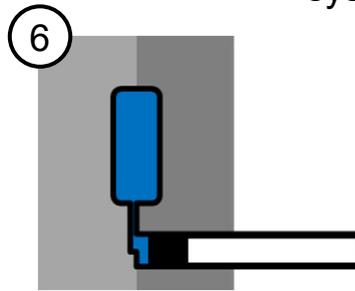
Steel mold with gating system and chamber



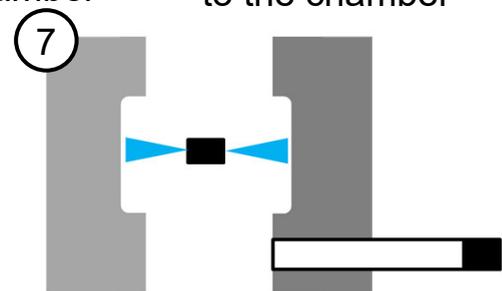
Liquid metal transported to the chamber



Filling the cavity and solidification under pressure



Solidification



Opening the form and ejecting the part, spraying of release agent

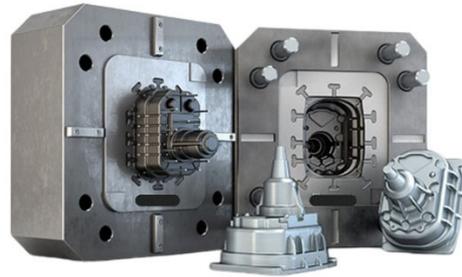
# 1. Basics of light metal die casting

Die casting is associated with extremely low cost per unit for larger series

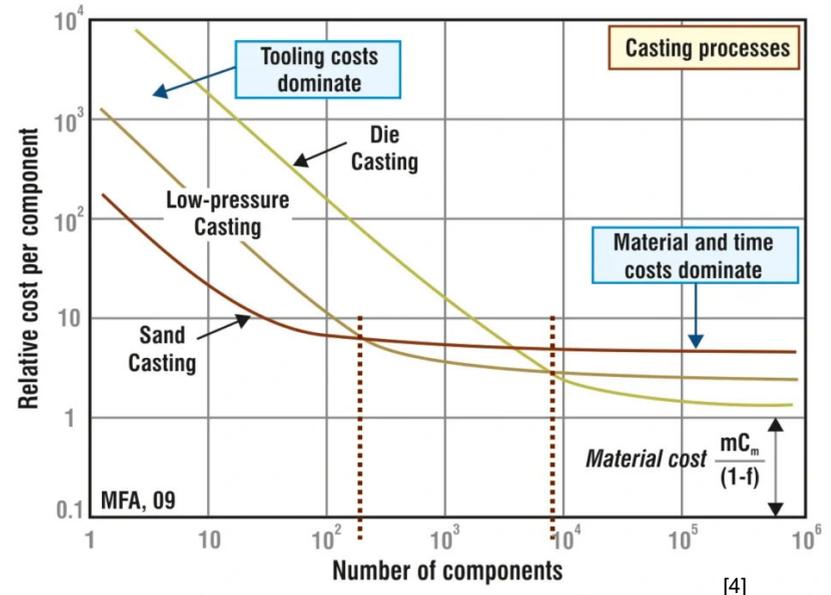
- Material and time costs dominate
- Complex and expensive tools, but their relative costs are low due to the high number of units



Die casting part [2]



Complex mold [3]

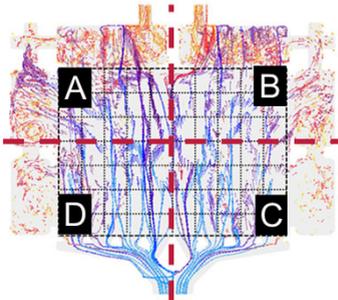


Unfortunately, the weldability of die castings is limited due to the processing route

## 2. Non-laminar flows in the die cavity

The cavity filling is a complex phenomenon even when high pressure die casting parts with low geometrical complexity

- Depending the location and the flow speed, the flow may become **turbulent**
- The cavity contains **air** and also **release agent**
- Turbulent flow is associated with entrapment of gases like air (**gas inclusions with high internal pressure**)
- Additionally, flow fronts may collide



Inhomogeneities  
specific for castings

v01  
Cycle 1, Filling, Temperature  
1.10%, 47.01 %  
Plunger position: 258.00 mm  
X-Ray: on



## 2. Release agents

**Release agents are sprayed onto the die surface and have different functions**

- Preventing the cast material from bonding or sticking to the mold surface
- Guaranteeing the metal flow
- Lubrication of moving components and cooling the die surface

**They could have different components**

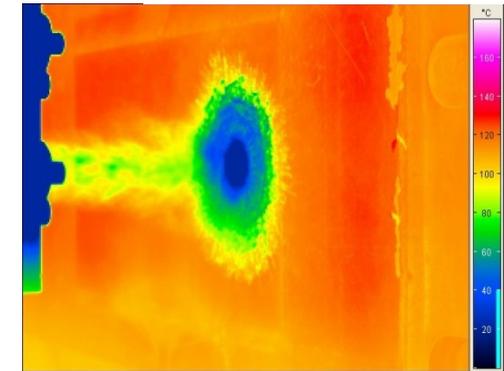
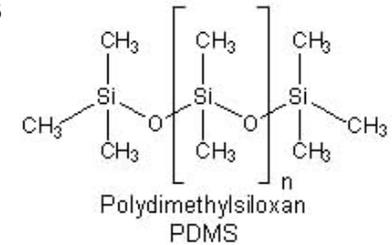
- Waxes, oils or polysiloxane
- Different additives such as graphite, talcum etc.



**Challenge**

**Release agents have direct contact with the hot, molten aluminum during the filling of the cavity**

- Dissociation and solving of hydrogen into the liquid aluminum



## 2. Hydrogen porosity in aluminum die cast

The solubility of hydrogen is strongly dependent on the temperature

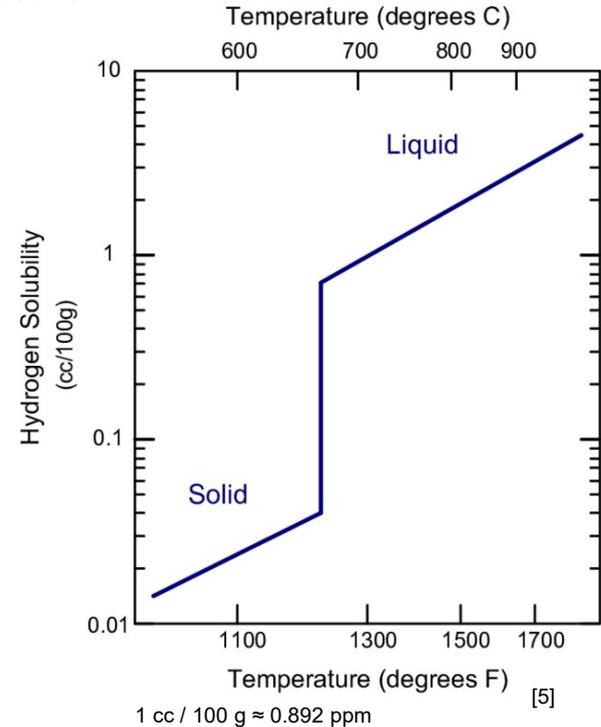
- The molten aluminum solves a high amount of hydrogen
- Decreased hydrogen solubility upon cooling
- Large drop during the solidification



Formation of gas pores



Blister after a heat treatment of a cast plate



# 3. General recommendations in welding of aluminum die casts

**There are some recommendation to improve the weld quality in welding of die casts**

**From casting point of view:**

- Optimization of the mold filling to optimize regions with subsequent welding joints
- Cleaning the melt with different methods
- Higher quality control of the aluminum raw material
- Improved process control, advanced release agents

**From welding point of view:**

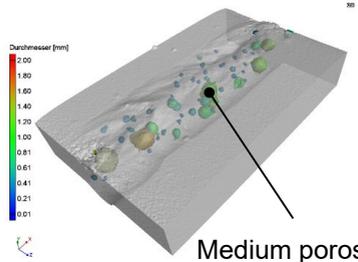
- Keeping the melt pool volume low to limit the amount of dissolved hydrogen
- Use of filler metal to introduce cleaner material into the weld pool
- Use of vacuum to improve the degassing
- Use of beam oscillation to stir the melt pool

# 3. Welding of aluminum die casts

Different approaches had been established for welding of aluminum die casts

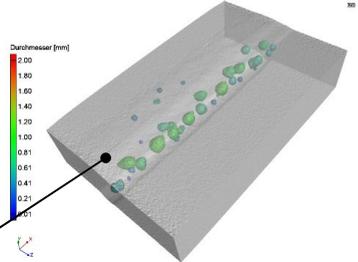
AC-AISI10MnMg  
AC-AISI9MnMo

Laser beam welding

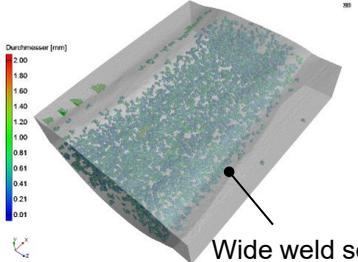


Medium porosity  
Few but large pores

Laser beam welding HF

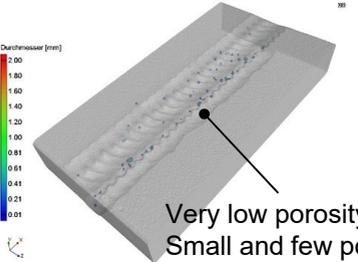


GMAW (MIG Welding)



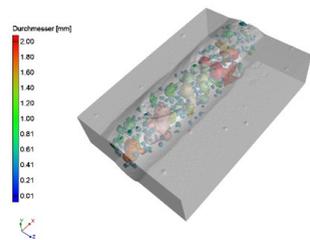
Wide weld seam

EB welding (3 bath)

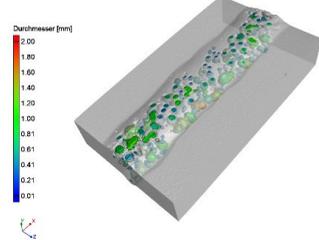


Very low porosity  
Small and few pores

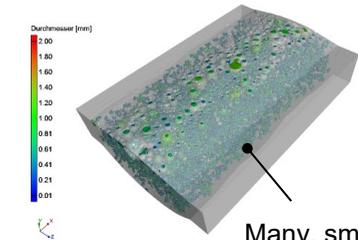
AC-AISI9MnMo



AC-AISI9MnMo

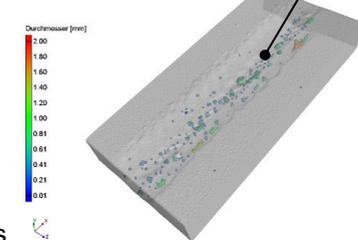


AC-AISI9MnMo



Many, small pores

AC-AISI9MnMo



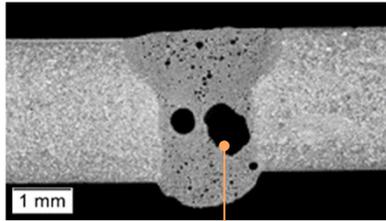
CT images from the project IGF-Nr.: 20.628 N

# 3. Welding of aluminum die casts

Different approaches had been established for welding of aluminum die casts

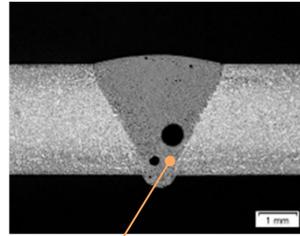
AC-AISI9MnMo

Laser beam welding



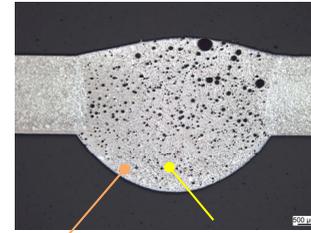
Few, large pores

Laser beam welding HF



Few, large pores

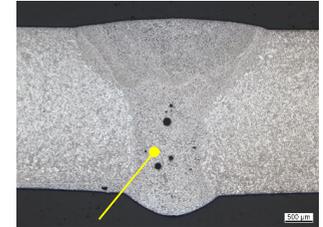
GMAW (MIG Welding)



Wide weld seam

Many, small pores

EB welding (3 bath)



Few, small pores

Metallographic cross-sections from the project IGF-Nr.: 20.628 N

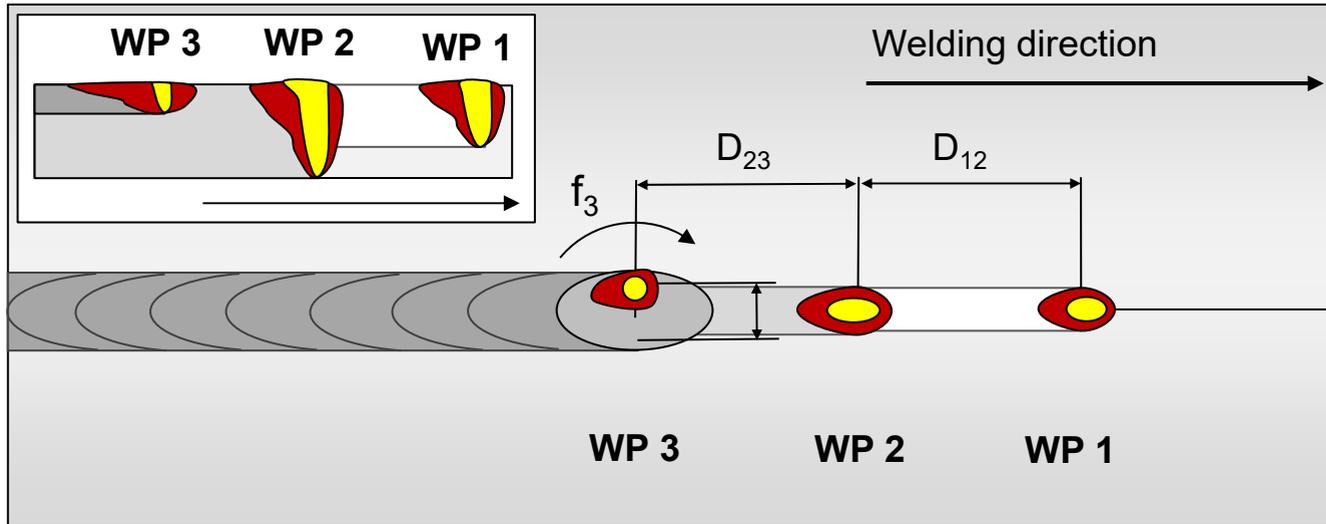
**Electron beam welding with three baths resulted in a narrow weld seam with low porosity**

- The high quality resulted in superior tensile and fatigue properties
- Low overall heat input, narrow weld seam

### 3. EB welding of aluminum die casts

For full penetration welds, following welding strategy has been proven to be beneficial

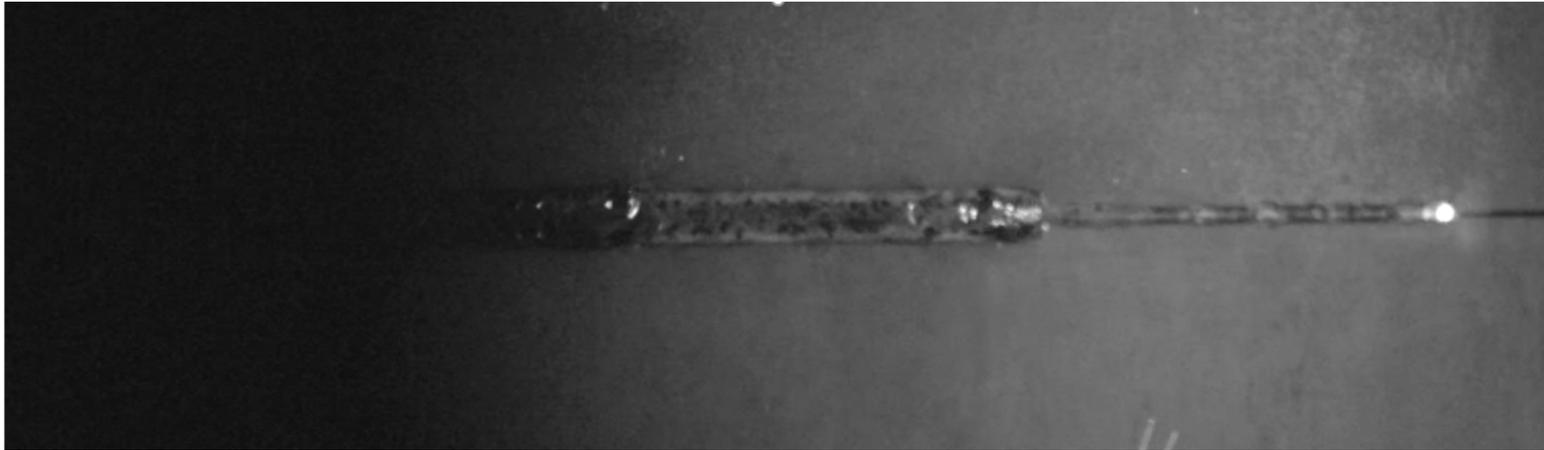
Sequence: Weld with lower penetration → Deep penetration weld → Cosmetic seam with oscillation



### 3. EB welding of aluminum die casts

For full penetration welds, following welding strategy has been proven to be beneficial

Sequence: Weld with lower penetration → Deep penetration weld → Cosmetic seam with oscillation

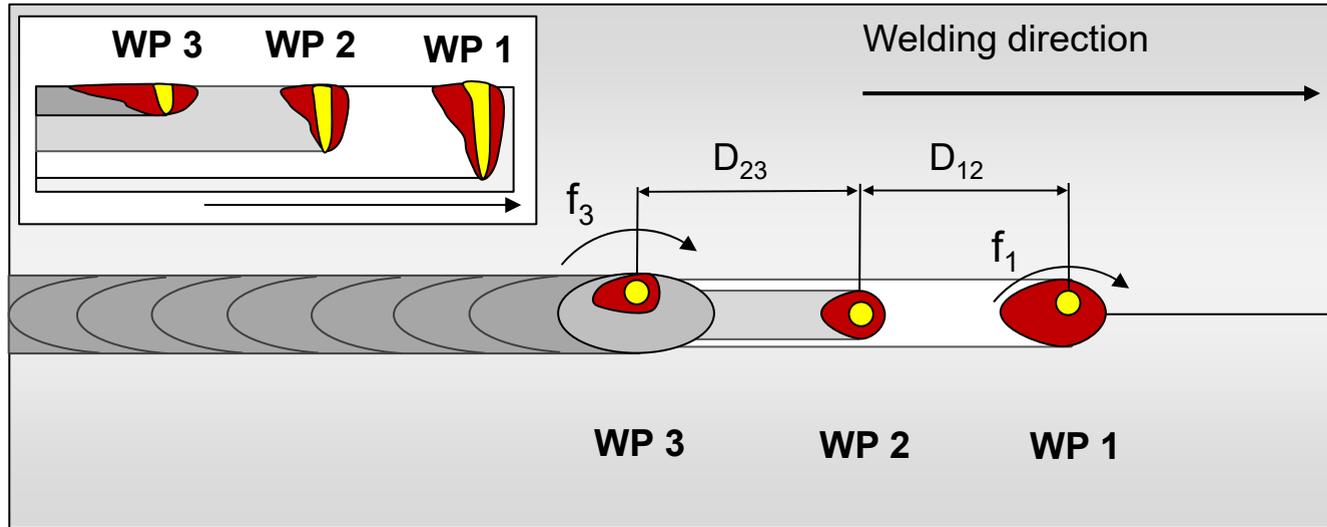


Capturing from a high-speed video of a 3-bath EB welding process

### 3. EB welding of aluminum die casts

For partial penetration welds, following welding strategy has been proven to be beneficial

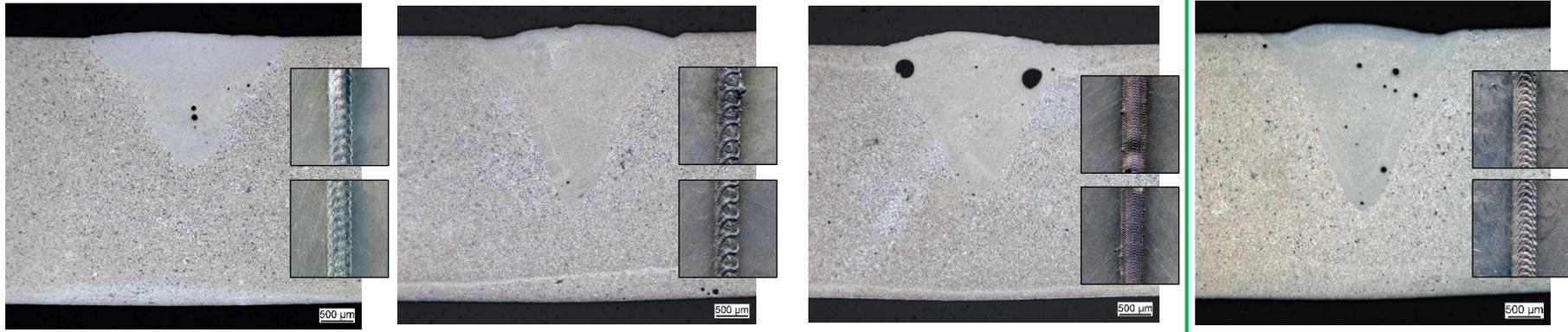
Sequence: Deep penetration weld with oscillating beam → Weld with lower penetration  
→ Cosmetic seam with oscillation



### 3. Welding of aluminum die casts

Additional trials were carried out to investigate the influence of the multi-bath parameters

- AlSi12Cu(Fe) casted plates with a thickness of 4 mm, goal was a partial penetration weld
- The plates had an overall good quality

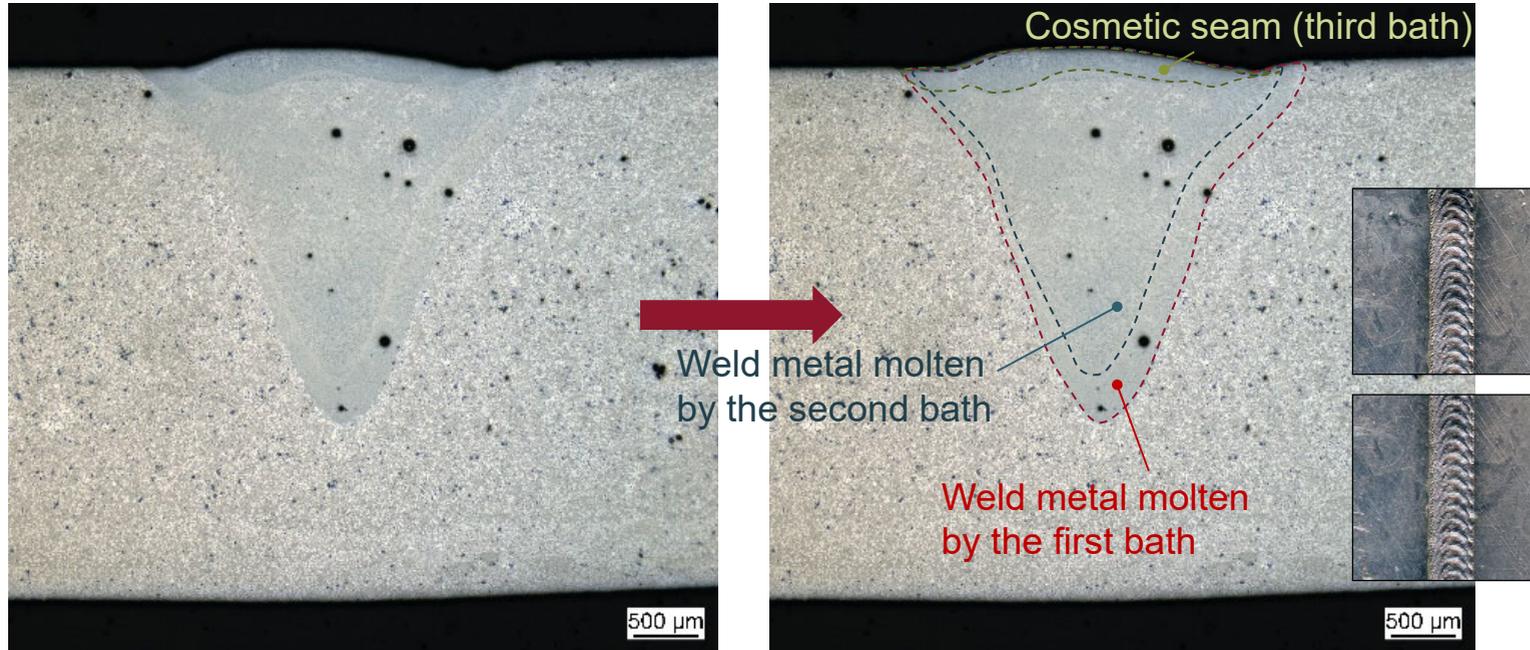


Increasing the slice-times  
Decreasing the jumping frequency

Adjusting the oscillation frequency for the  
cosmetic seam

### 3. Welding of aluminum die casts

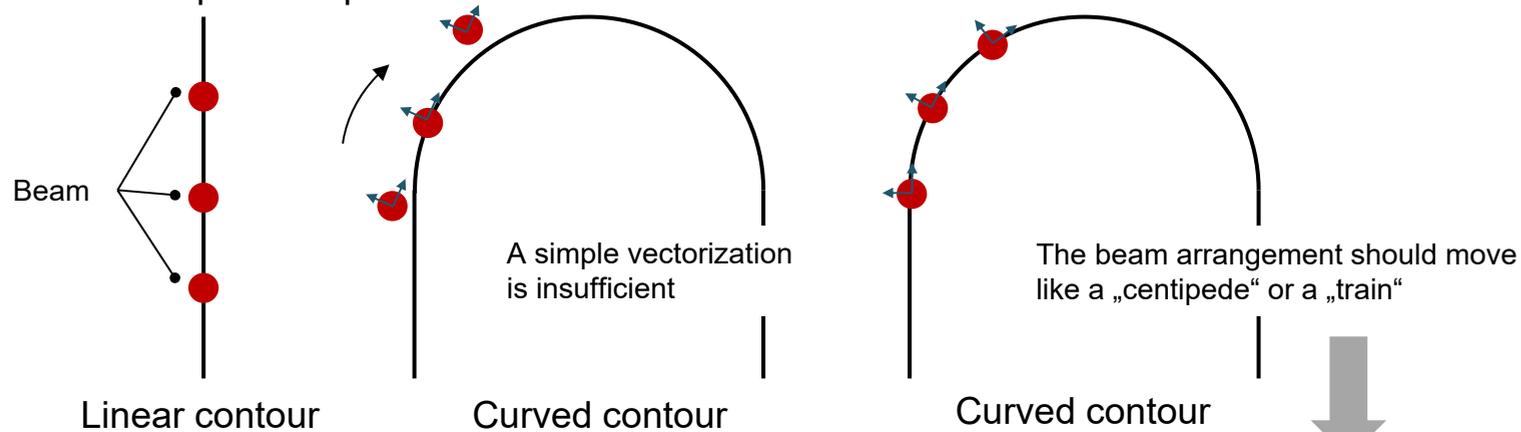
The re-melted regions are visible on the metallographic cross-sections



## 4. Welding of complex parts

The parameters are working excellent on linear weld contours.  
Challenges arise when complex contours should be welded

- The complexity is given due to the nonlinear contours
- These nonlinear contours present challenges when it comes to welding with multiple weld pools

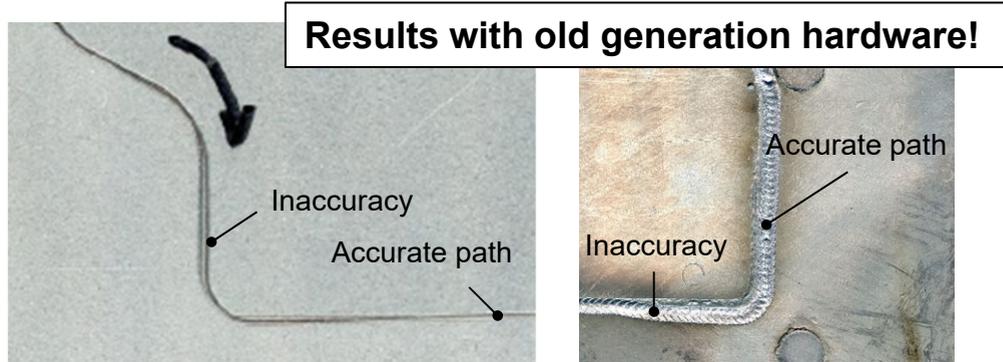


**The beam arrangement should be frequently recalculated**

# 4. Welding of complex parts

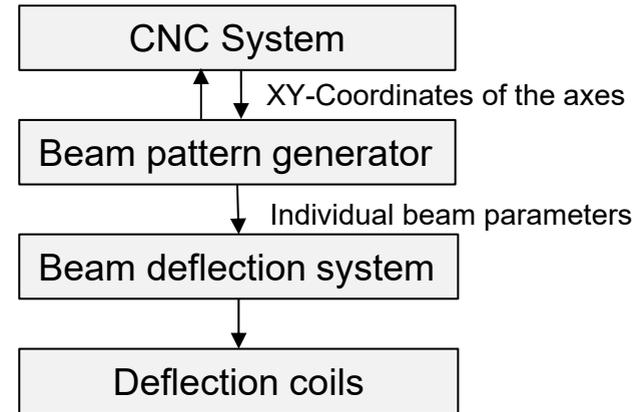
Following the path in the curves represents a challenge

- There are mathematical solutions to calculate the desired (theoretical) beam position
- Deflecting the beam requires the interplay of hardware and software
- A test contour similar to a casted part was designed and tested



Engravings into zinc-coated steels

Welding in die cast plate

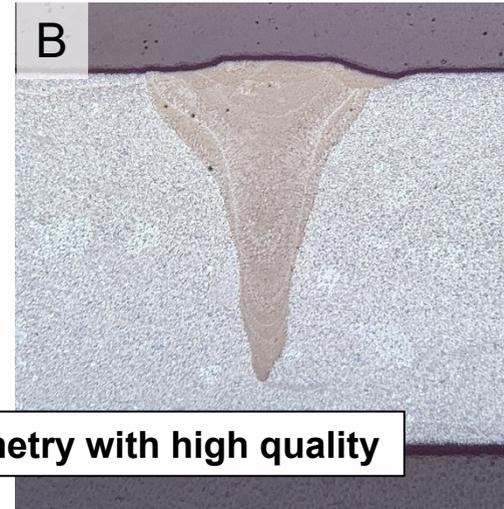
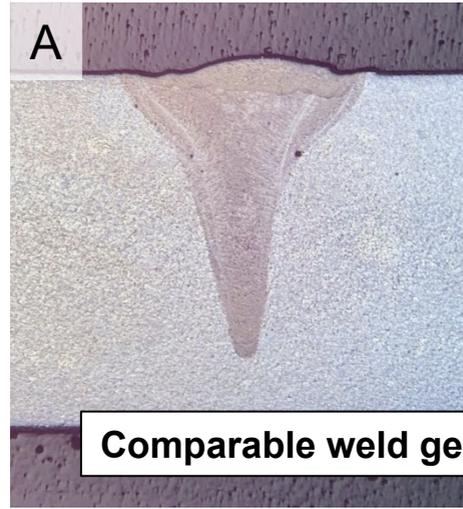
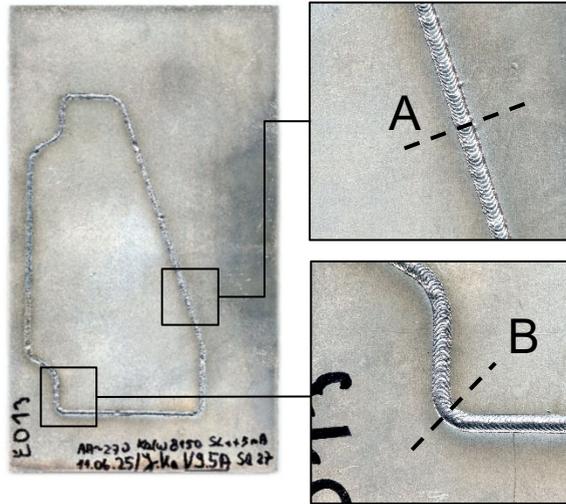


**If there are latencies in the system, the real weld path deviates from the desirable one**

# 4. Welding of complex parts

## Novel solutions enable the accurate following of the path

- Faster commercial CNC systems (Lower IPO cycle time, quicker intercommunication within the control system)
- More advanced hardware in the beam deflection system



Comparable weld geometry with high quality

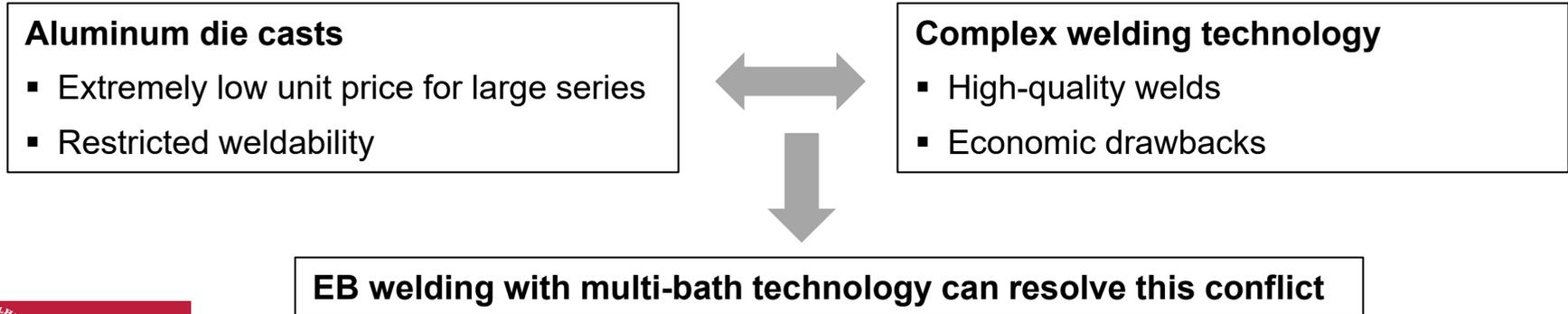
# 4. Welding of complex parts

No significant porosity was found at the corners



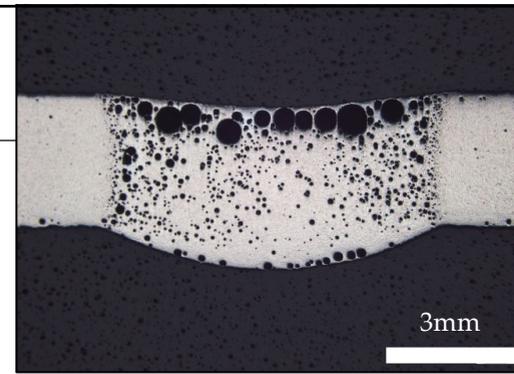
# 5. Summary

- Novel software and hardware systems enable the multi-path welding configuration, with a good accuracy, also for complex geometries
- The multiple re-melting in one sequence greatly improves the cycle time per unit
  - High-quality welds
  - Short welding time due to the absence of multiple runs
- This could make electron beam welding attractive, especially under consideration of economic aspects



# 5. Further perspectives

- Welding of additively manufactured aluminum
  - Complex, expensive parts
  - High hydrogen content → Tendency to weld seam porosity → Even worse weldability than die casts
  - High quality applications
  - Low weight, high strength
  - Parts designed with structural optimization



TIG welding joint on AISi10Mg



Examples for additively manufactured parts made of aluminum

# Contact

We would like to express our sincere thanks to the Dobeneck-Technologie-Siftung for funding research projects in the field of electron beam welding of aluminum die casts.

Furthermore, we would like to express our appreciation to pro-beam for providing technical support during our public-funded projects!

## Contact (EB welding)

**Tamás Tóth, M.Sc.**

Tel: 0531 / 391 955 72  
t.toth@tu-braunschweig.de

**Kai Noack**

Tel: 0531 / 391 955 74  
k.noack@tu-braunschweig.de

**Prof. Dr.-Ing. Klaus Dilger**

Tel: 0531 / 391 955 00  
k.dilger@tu-braunschweig.de

## Contact (Die casting)

**Dr.-Ing. Norbert Hoffmann**

Tel: 0531 / 391 955 23  
norbert.hoffmann@tu-braunschweig.de