Wire Based Additive Manufacturing of Al- and Mg-alloys

LKR Light Metals Technologies Ranshofen,
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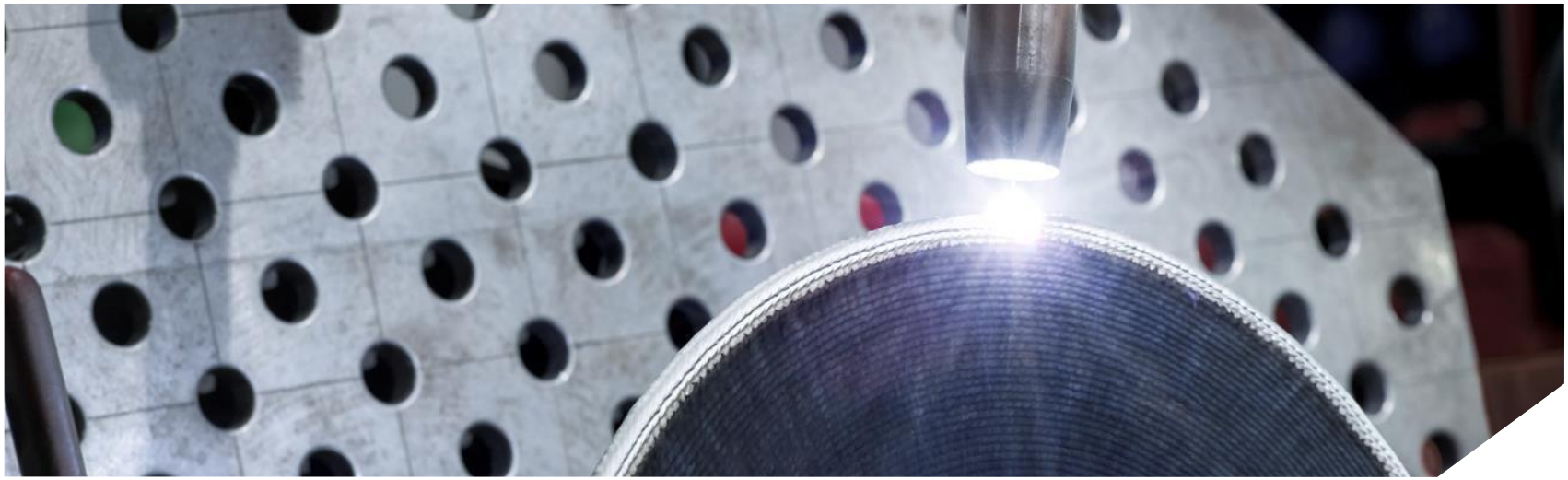

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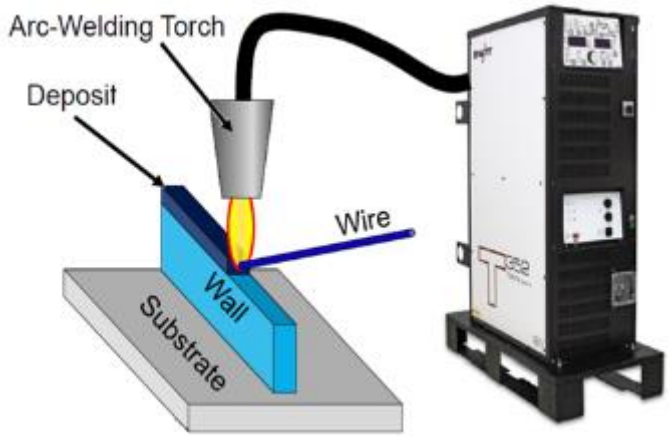
AGENDA

- Wire-based additive manufacturing
  - WAAM-process
  - Filler wire drawing
    - State of the art vs. LKR smart process chain
- Experimental work and results
  - Manufacturing route of the Mg filler wires
  - Welding seams
  - Additive manufactured demonstrator part
- Project example
- Conclusions - Outlook

WIRE-BASED ADDITIVE MANUFACTURING

- **WAAM process in general**
  - Standard welding equipment
  - Selective deposition of multiple layers
  - High production rates with hardly limited installation space
  - Time and material efficient
  - Suitable for titanium, steel, aluminium and magnesium alloys



J.R. Hönnige - Aeromat 2016, Presentation

- **WAAM @ LKR**
  - Robot with 45kg load capacity
  - Swinging platform
  - (Welding) wires and possible deposition rates:
    - Aluminium 2 kg/h
    - Magnesium 1 kg/h
  - Resolution of layer: approx. 3 mm
  - Automatic CAD/CAM interface in prototyping phase

WIRE-BASED ADDITIVE MANUFACTURING

Compared to castings or forgings, wire based ALM methods have:

- Higher degree of freedom
- Almost no limitation in part size
- No additional tooling costs
- Faster production rates for small quantities

but are:

- More dependent on materials/alloys
- Slower and more expensive at larger part numbers

LKR AM welding laboratory

WIRE-BASED ADDITIVE MANUFACTURING

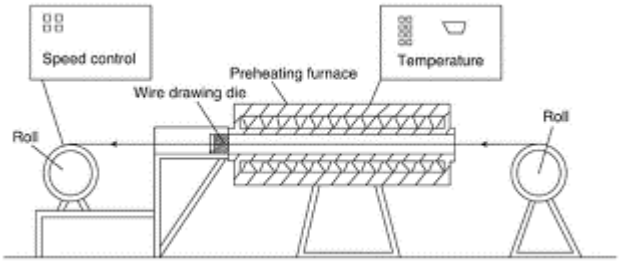
	Powder based methods	Wire based methods
Material	Mg powders	Mg filler wires
Material price	Medium to high	Low to medium
Material diversity	Low	High
Degree of freedom	High	Medium
Ability to create fine structures	High	Low
Deposition rates	Low	High
Productivity	Medium to low	High
Subsequent machining	No	Yes
Investment costs	Medium to high	Medium
	For small to medium sized (complex) parts	Suitable for large parts

STATE OF THE ART

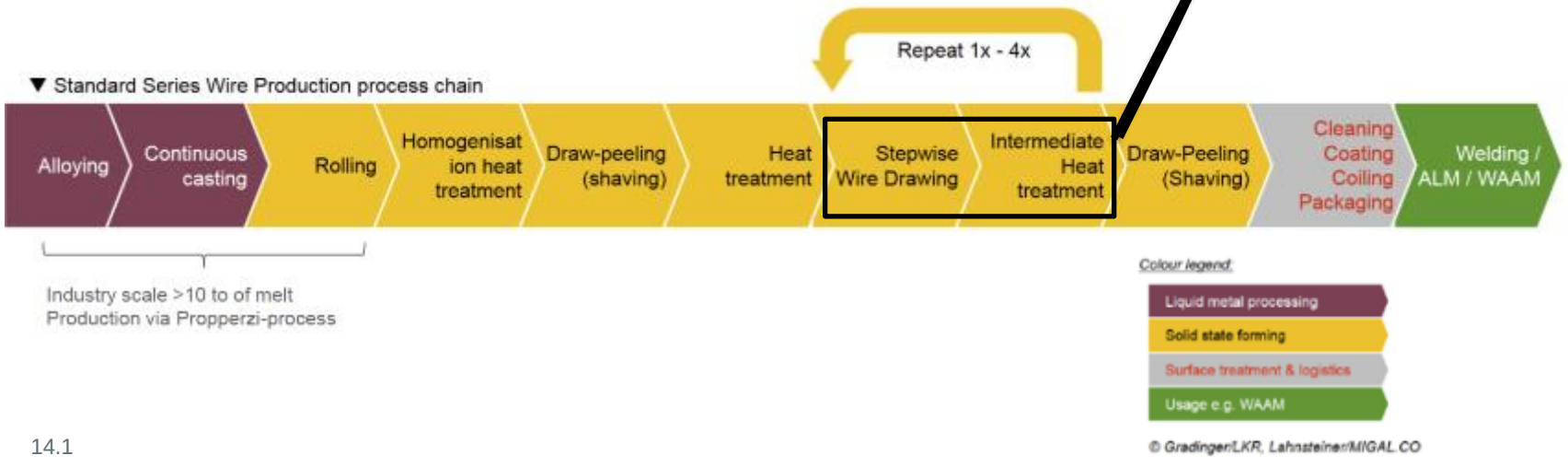
Process chain: wire drawing

- Many important single steps
  - Liquid metal, warm/cold semi-finishes, solid end products
  - Rolling and peeling of initial rod
- Low diameter filler wire drawing → challenging
- Cost / time- intensive

➡ **Efficient only in industrial scale**



Wire drawing(simplified)



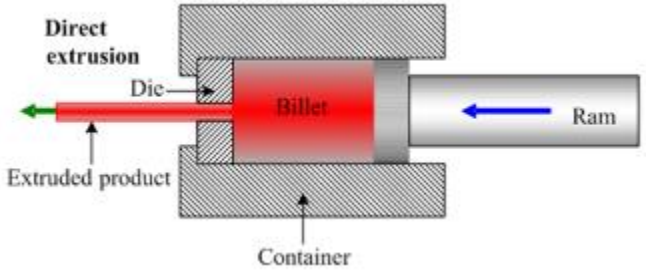
WHICH PROCESS CHAIN FOR SMALL BATCHES OR R&D?

SMART PROCESS CHAIN AT LKR

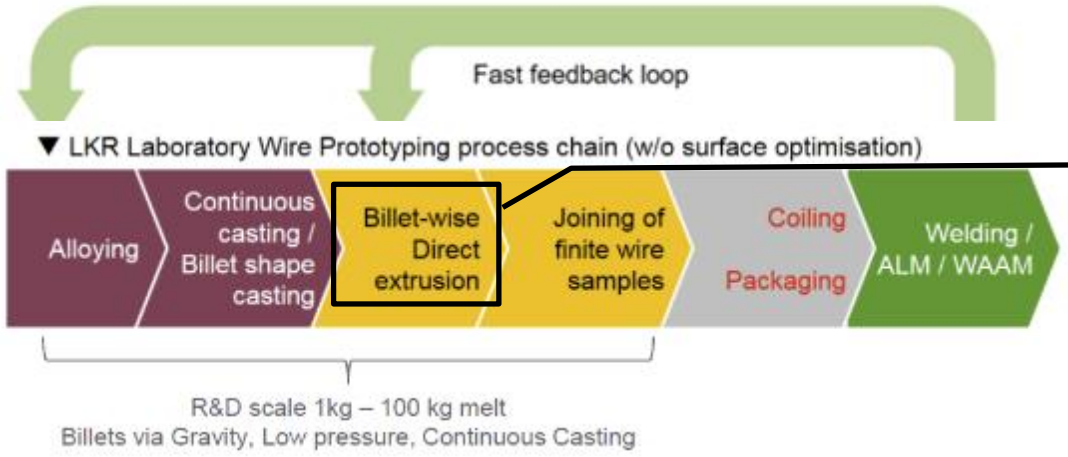
Process chain: wire extrusion pressing

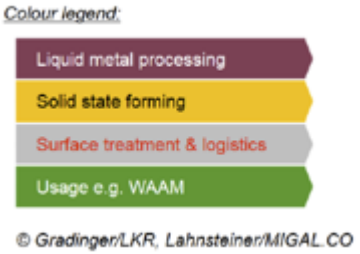
- Low melt quantities for alloy- or process development (1-100kg)
- Few important single steps
  - Direct extrusion of billets,
  - Single strands → joining of strands → coiling
- Good surface qualities
- Cost / time efficient for R&D pre-trials

Efficient for small batches



Extrusion pressing





SMART PROCESS CHAIN AT LKR

Cast billets

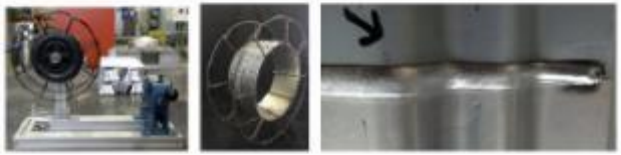
- Casting billets via gravity / high pressure / continuous casting

Extruded wires

- Extrusion of billets to 4m strands (range: 0,8-3,0mm diameter)

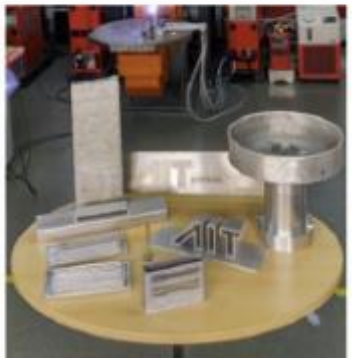
Coiled & Finished

- Joining of strands to wires to >>4m length & Coiling to spools



WAAM

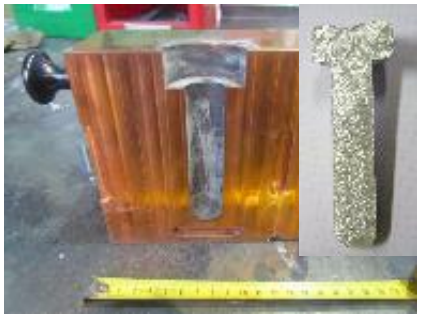
- Additive Manufacturing of Coupons and 3D shaped parts



EXPERIMENTAL WORK AND RESULTS

Manufacturing route for Mg filler wires

- Casting of billets (Ø21 length: 100mm)
  - Casting in copper moulds
    - High cooling rate
    - Small grain sizes
- Extrusion pressing
  - Fourfold stranded extrusion with individual diameters of 1.2 mm
  - Wire extrusion speed: 2 m/min x 4
  - 16 meters per billet
- Coiling /Finishing
  - Joining the 4m single strands and coiling to spools
    - Joining: Mechanical or plasma welding



Cooper mould for billet casting

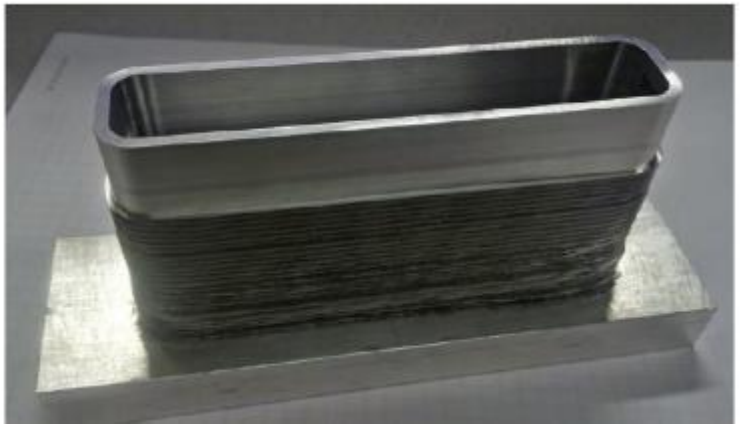
Sample pieces of Mg filler wires made at LKR

LKR coiled wire spool

EXPERIMENTAL WORK AND RESULTS

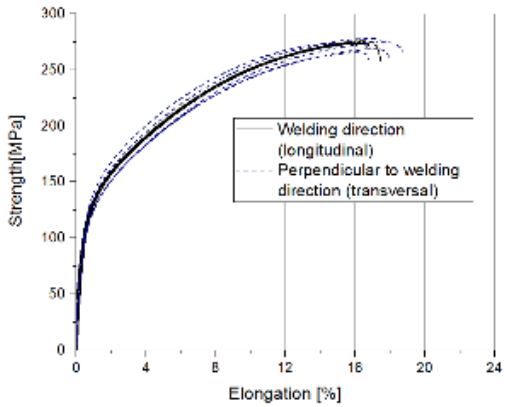
Additive manufactured demonstrator part

- AZ61 Mg-alloy
  - Dimension: 100x30x70mm
  - Welding time: 12min.
- <u>Mechanical properties:</u>
  - Tensile strength (length): 273MPa
  - Elongation/strain: 16,8%
  - Tensile strength (vertical): 271 MPa
  - Elongation/strain: 17,2%

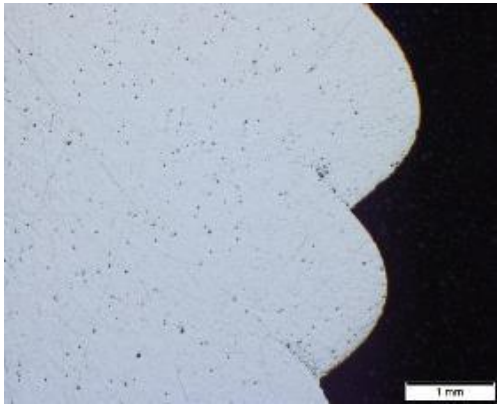


Demonstrator part

Sampling of AM AZ61 prototype



Comparison of the strength longitudinal and perpendicular to the welded layers

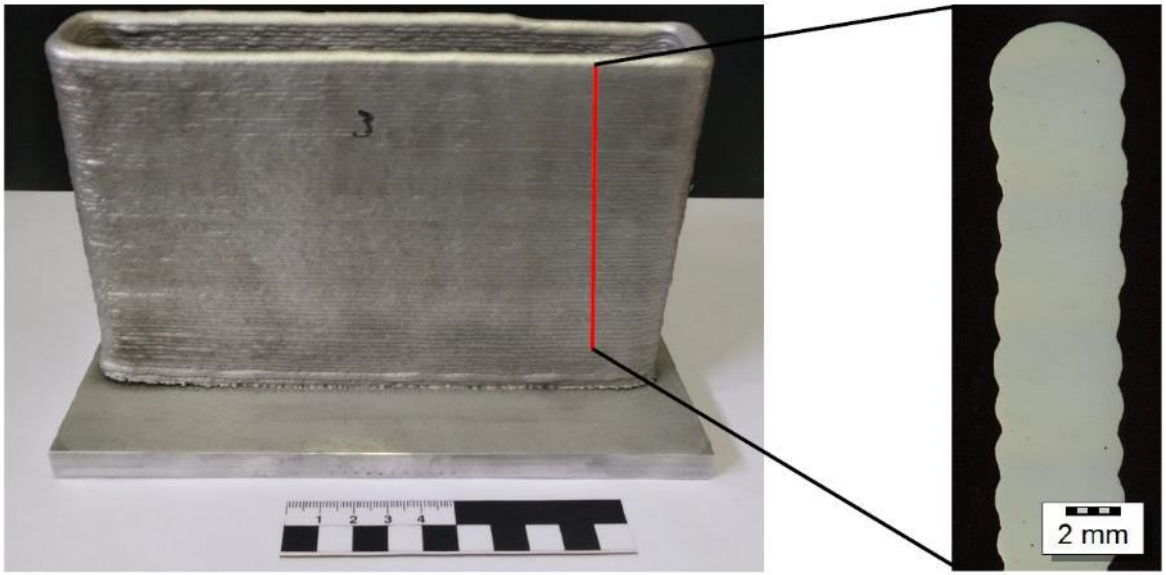


Cross section of the layers

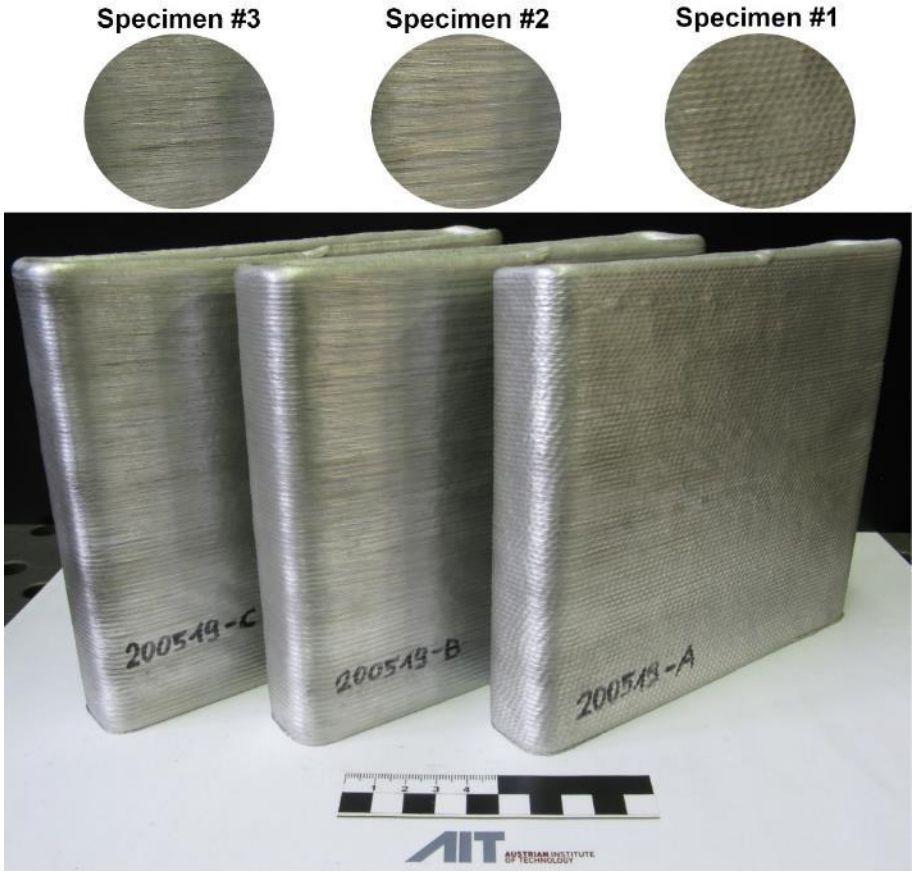
EXPERIMENTAL WORK AND RESULTS

Al special wire for WAAM

- Alloying concept: 7xxx- modified to
  - Avoid hot cracking
  - Mechanical propertise to compeed with other 7xxx processed components.
  - Process: WAAM + heattreatment
  - No mechanical treatment

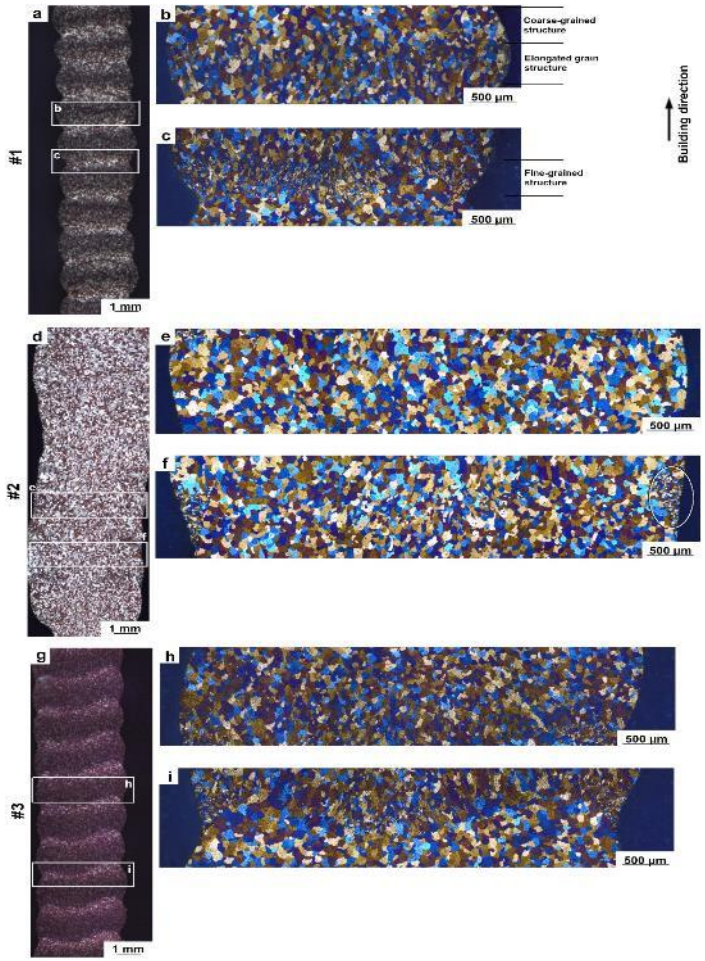


PROCESSING PARAMETERS INFLUENCING SURFACE- AND INTERNAL QUALITY



Al	Mg	Mn	Cr	Cu	Fe	Si	Ti
93.9	5.03	0.64	0.08	0.02	0.16	0.05	0.09

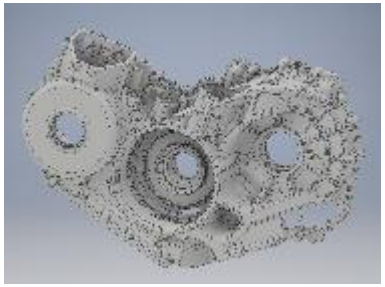
PROCESSING PARAMETERS INFLUENCING SURFACE- AND INTERNAL QUALITY



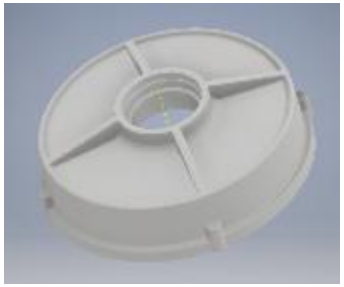
PROJECT EXAMPLE

„Demonstrator gearbox cover “

- Rapid prototyping with series-like component properties
- Replacement of low-pressure casting processes
- Flexible changes of contours / cross-sections without mould construction
- Lower production costs compared to sand casting and machining at quantities < 240 pieces (specific calculated for this component)



Original gearbox housing geometry (Courtesy Magna Powertrain)



Simplified housing section

AM part build up using CMT+

Finished part

CONCLUSIONS

- ALM processes have the potential to replace concurring processes for low number of parts

- Extrusion is a promising production route for magnesium filler wires
  - Overall high quality
    - Weld preparation is essential for good connection between metal/sheet - layer/layer

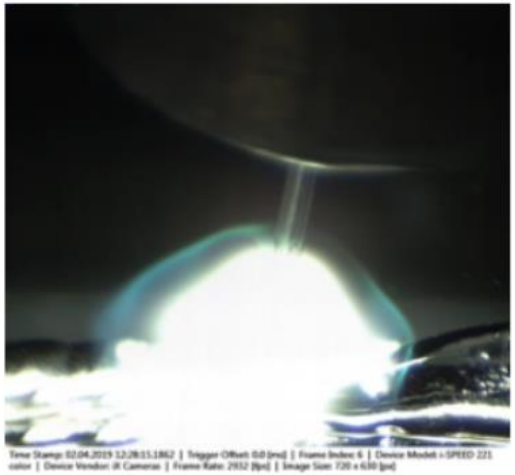
- Weak point of the welding is the heat-affected zone in the sheet metal
  - significant drop in hardness, which in turn indicates grain coarsening

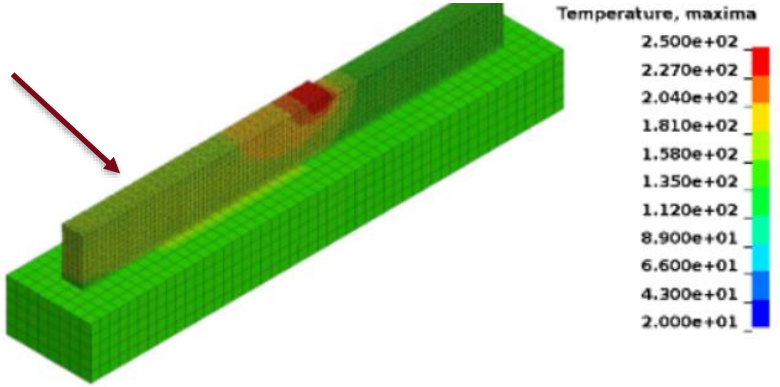
- Wire based ALM methods can reduce the time to market for magnesium parts

- Modified filler wires (e.g. non flammable, particle reinforced, high strength, heat treatable,…) allow tailor made part design

OUTLOOK

- Improvement of material & component properties
  - Specific alloy design
  - Special filler wires for special requirement/parts
- Self-regulating processing parameters
- Numerical process simulation
  - Deeper understanding of the process
  - Prediction of temperature distribution
  - Identification of critical areas
  - Microstructure prediction
    - Grain structure/size
    - Segregation distribution





*Source: S. Brötz, S. Scheiblhofer, Methodenentwicklung zur Prozesssimulation drahtbasierter Additiver Fertigungsverfahren, in: NAFEMS Tagungsband Band 344, 97.

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THANK YOU!

C. M. Chimani, 14.11.2019

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