The results presented were achieved in the framework of the COAMWELD project, a CORNET project funded by Vlaio (Flanders Innovation & Entrepreneurship) under the Grant Agreement HBC.2020.2994

COAMWELD

DVS SLV MÜNCHEN

Improving the Weldability of PBF-LB Manufactured AlSi10Mg Components by Solid-State Welding Process

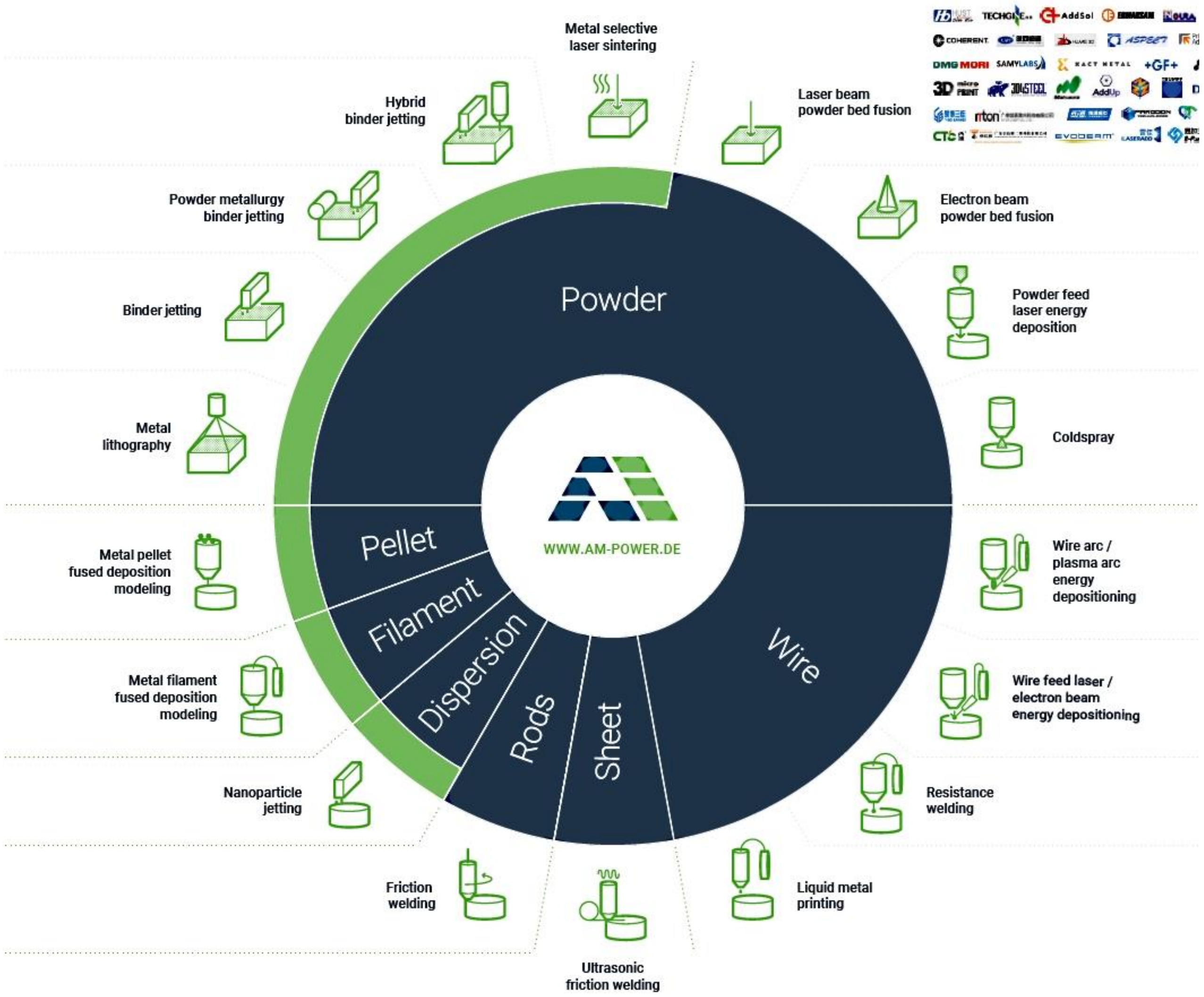
R. Nunes, K. Faes, F. Probst, T. Schweikert, J. De Freese, W. De Waele, A. Simar, M. Lezaack

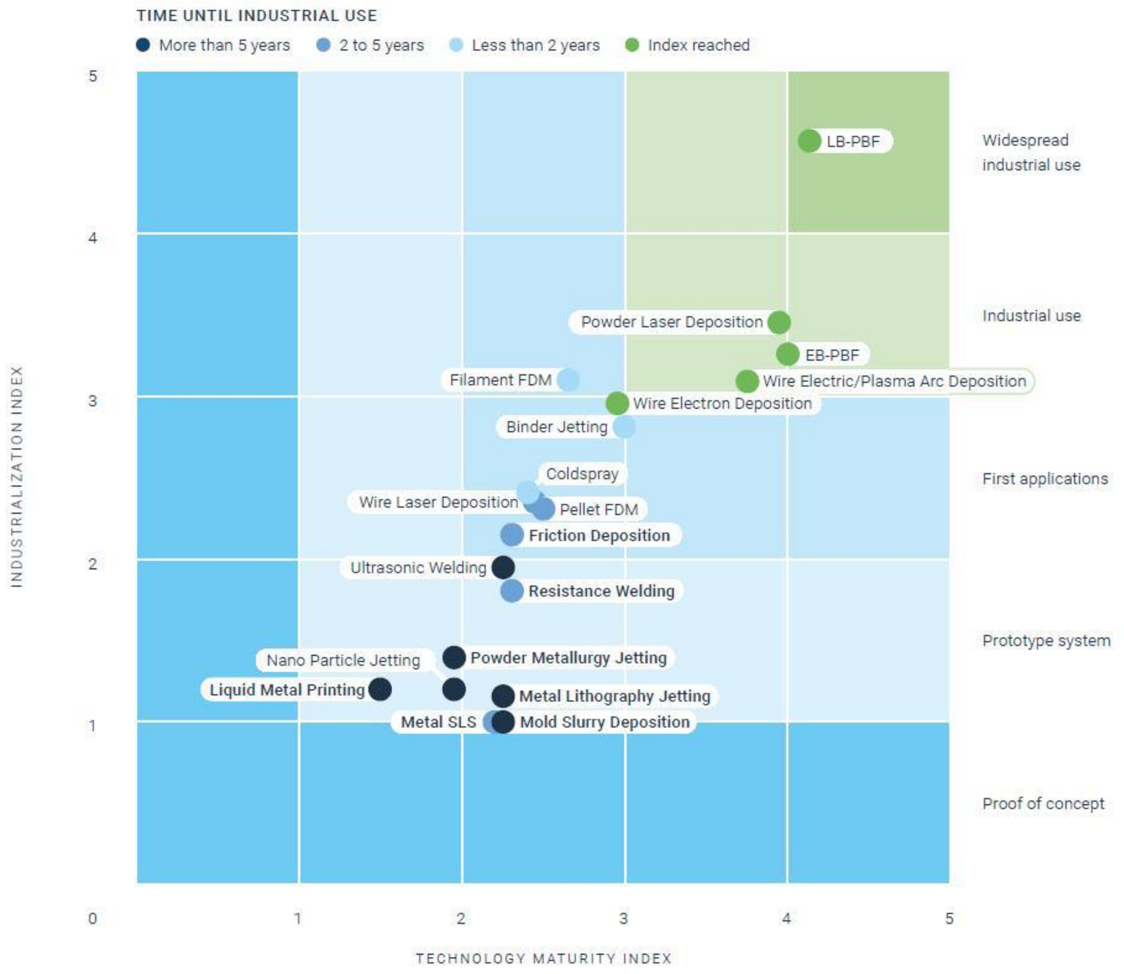
BS research

GHENT UNIVERSITY

UCLouvain
Institute of Mechanics, Materials and Civil Engineering (iMMC)

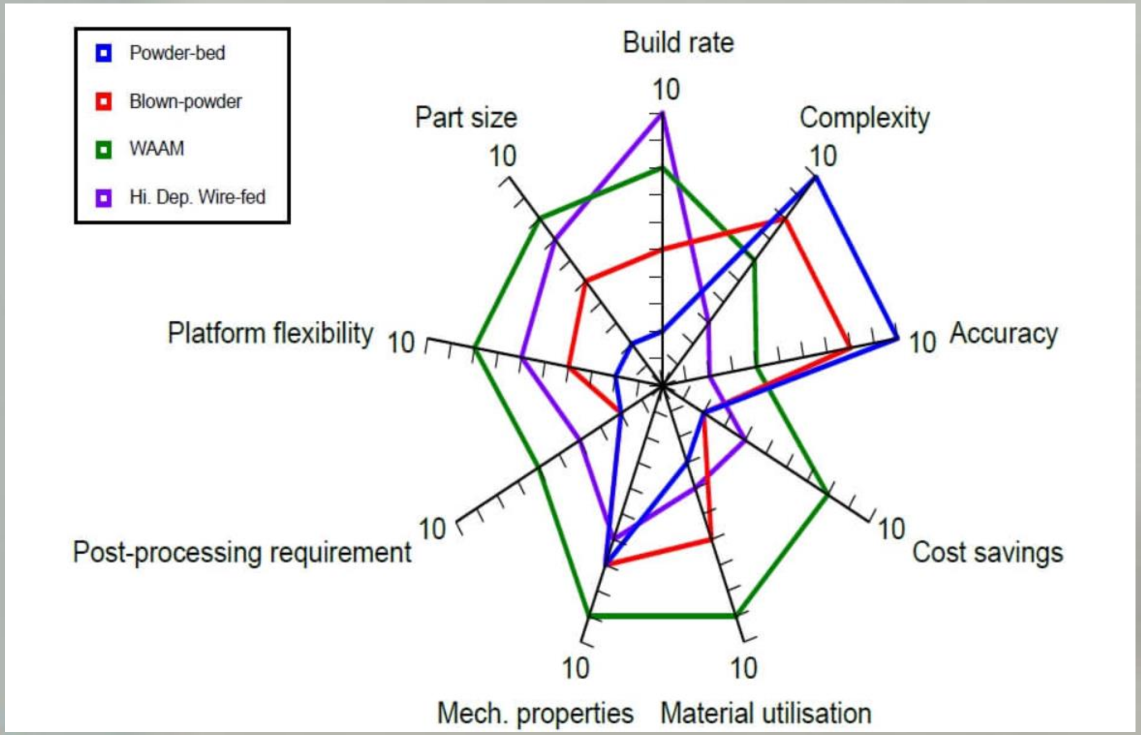
Selection of Additive Manufacturing Process





AMPOWER (*https://ampower.eu/*)

Selection of Additive Manufacturing Process



Complexity / Resolution

Deposition Rate

Current Status of the Art | Weldability of AMed Al Alloy Parts

Only 39 published articles : in peer-reviewed journals, congresses, conferences, and technical magazines

19 articles (49 %) evaluating <u>fusion welding processes</u>

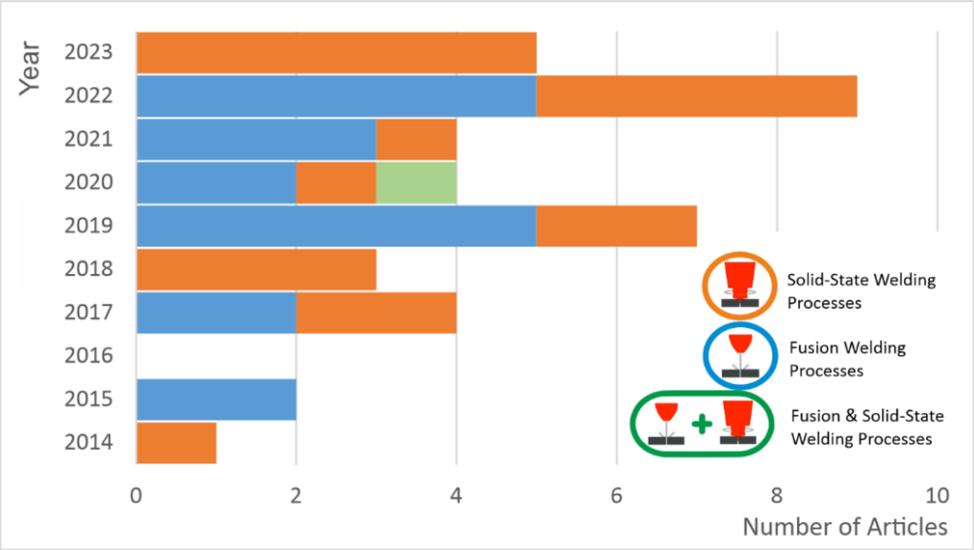
- 18 articles evaluating PBF-LB parts and 1 article evaluating DED-Arc (DED-Arc) parts
- 14 articles evaluating LBW
- 4 article evaluating EBW
- 3 articles evaluating GTAW

19 articles (49 %) evaluating <u>solid-state welding</u> processes

- 11 articles evaluating PBF-PB parts
- 9 articles evaluating FSW process
- 1 article evaluating RFW process
- 1 article evaluating RFSSW process

1 article (2 %) evaluating <u>fusion & solid-state welding</u> processes

- 1 article evaluating PBF-PB parts
- 1 article evaluating GTAW and FSW welding processes



Evolution of Number of Publication on Welding of AMed Al Alloys per Year

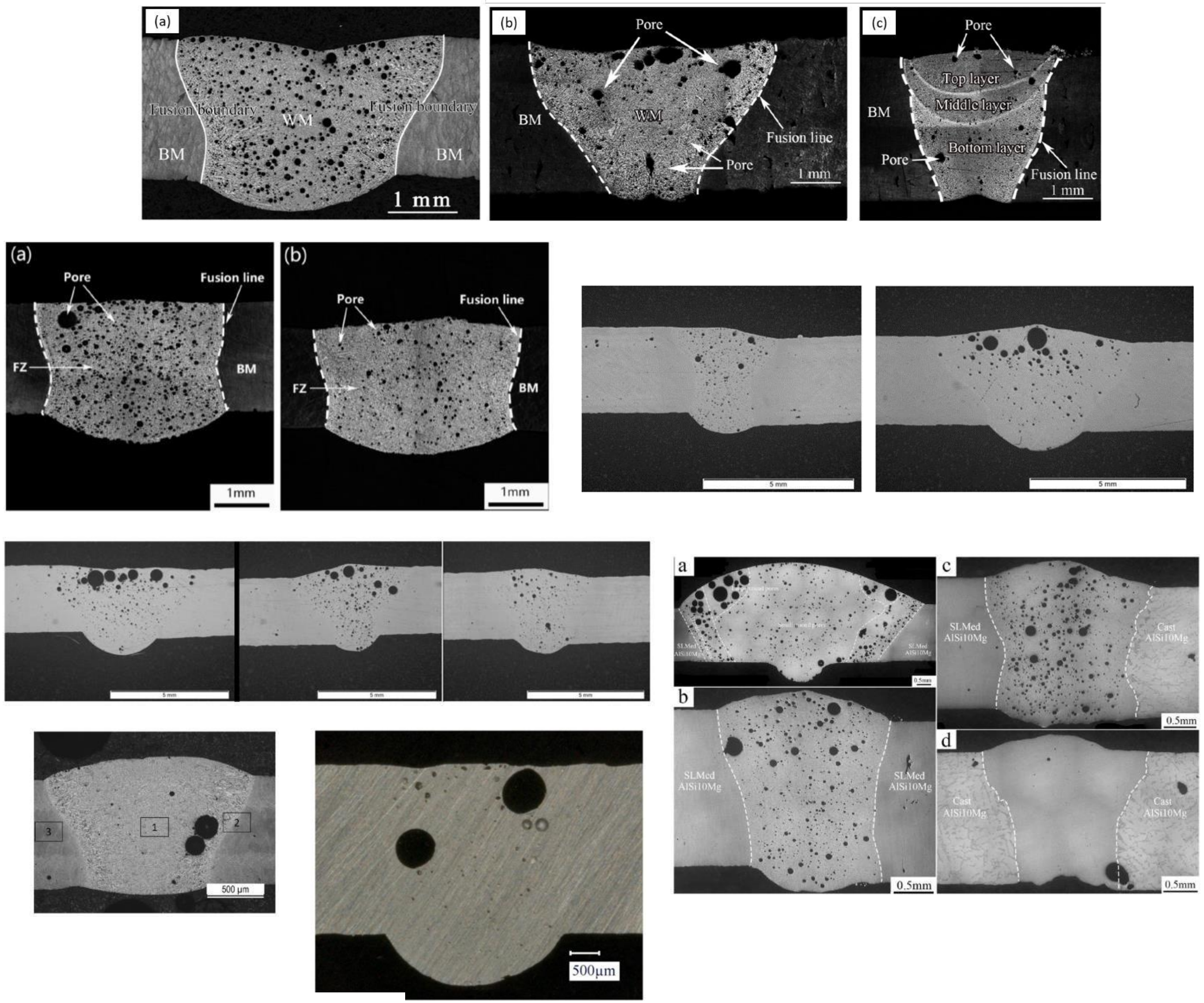

metals MDPI

Review

A Review on the Weldability of Additively Manufactured Aluminium Parts by Fusion and Solid-State Welding Processes

R. Nunes *et al.* **A Review on the Weldability of Additively Manufactured Aluminium Parts by Fusion And Solid-State Welding Processes**. Metals. Vol 13(10), 2023.
https://doi.org/10.3390/met13101724

Current Status of the Art | Weldability of AMed Al Alloy Parts



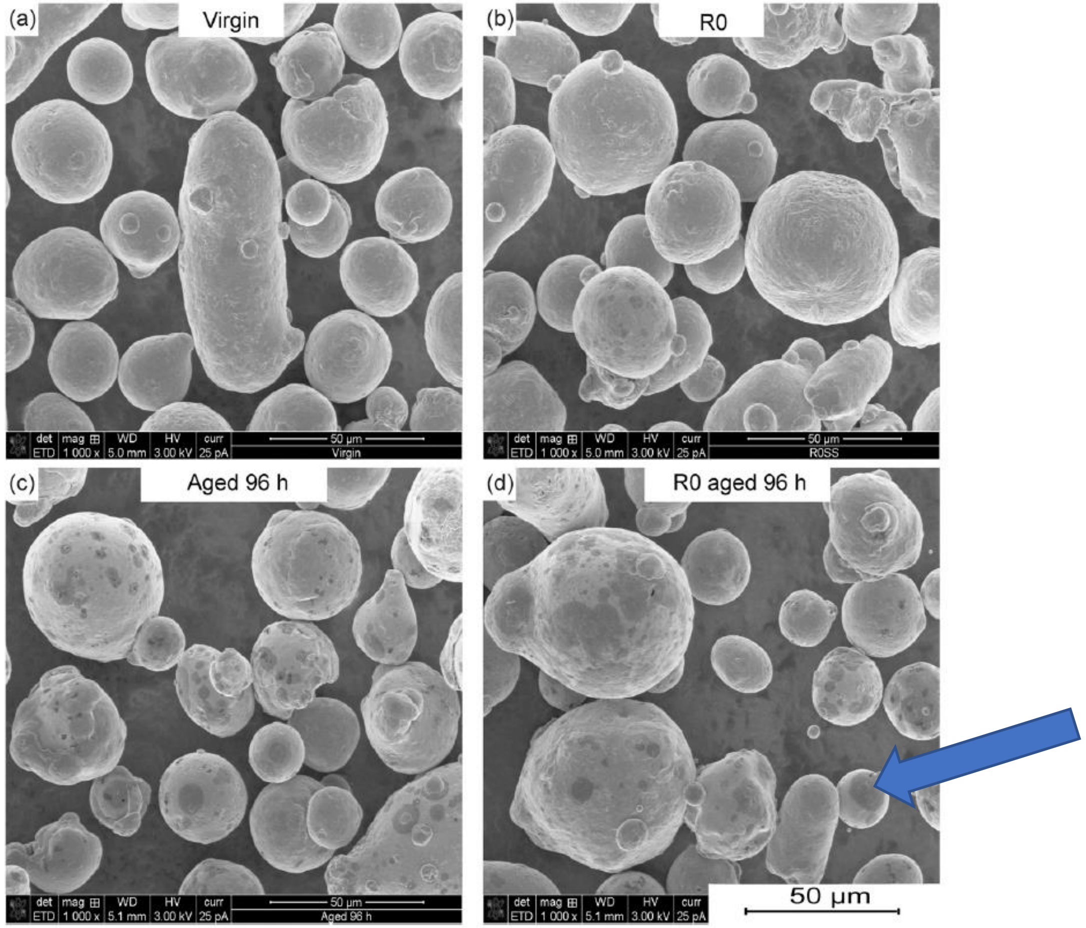
Unlikely the porosity can be entirely avoided by optimization of welding parameters,
Other fusion welding processes are likely to suffer from porosity issues.

Main theory:
High porosity level in PBF-LB joints are formed due to the hydrogen porosity in the PBF-LB base material.

- Higher surface area to volume ratio compared to wire filler material,
- Common to recycle powder in PBF-LB process.

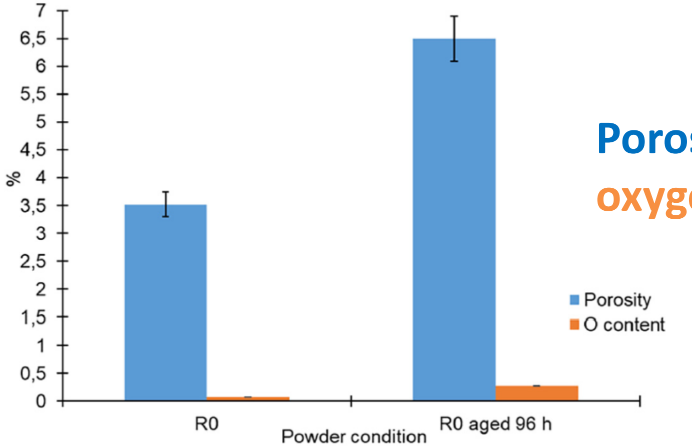
Current Status of the Art | PBF-LB AlSi10Mg Powder Recycling

Particle Morphology, Porosity and Surface Oxidation



Morphology and surface oxidation condition of new and recycled AlSi10Mg powder

Sample	Density [%]	Porosity [%]
R0	99.03	0.97
R0 aged 96 h	89.88	10.12



Porosity & oxygen content

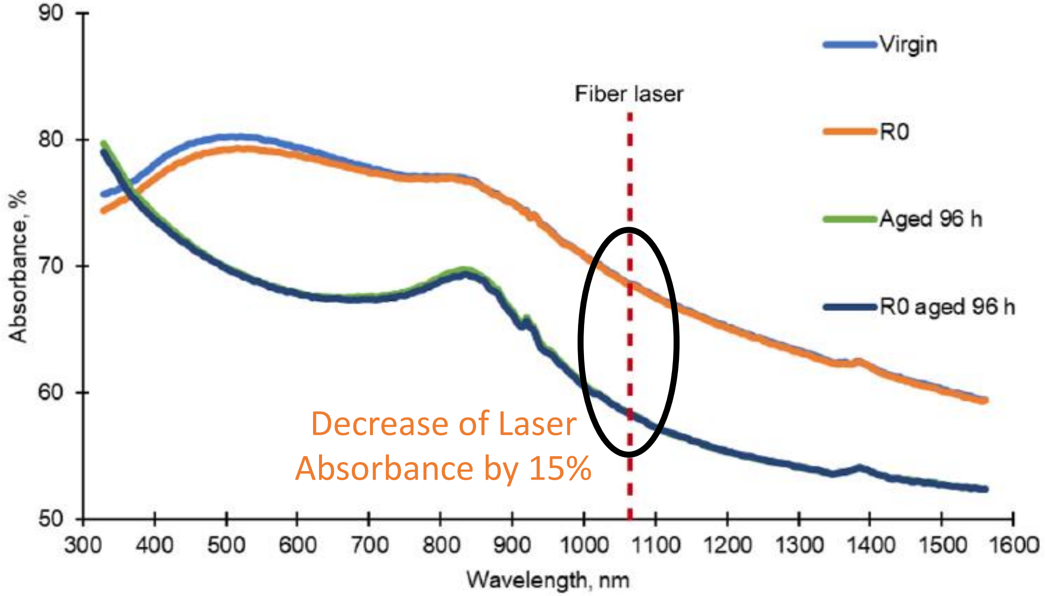
Correlation between porosity in final parts and oxygen content, depending on powder condition

- R0 – recycling condition where virgin powder was processed once
- Aged 96 – powder condition after aging (400°C) the powder during 96 h
- R0 aged 96 h – recycling condition where virgin powder was processed once and aged (400°C)during 96 h

Fedina, T. *et al.* Influence of AlSi10Mg Powder Aging on the Material Degradation and its Processing in Laser Powder Fusion. Powder Technology 412 (2022) https://doi.org/10.1016/j.powtec.2022.118024

Current Status of the Art | PBF-LB AlSi10Mg Powder Recycling

Laser Beam Absorbance

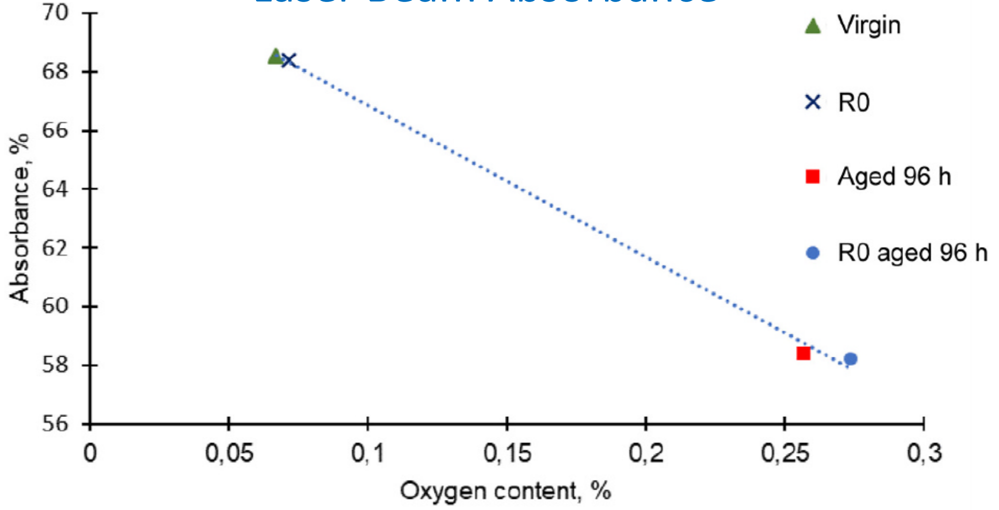


Laser beam absorbance by new and recycled AlSi10Mg powder as a function of wavelength

Powder state	Average laser light absorbance [%]
Virgin	68.55 (±0.10)
R0	68.48 (±0.09)
Aged 96 h	58.23 (±0.13)
R0 aged 96 h	58.13 (±0.09)

Average laser beam absorbance by new and recycled AlSi10Mg powder

Laser Beam Absorbance

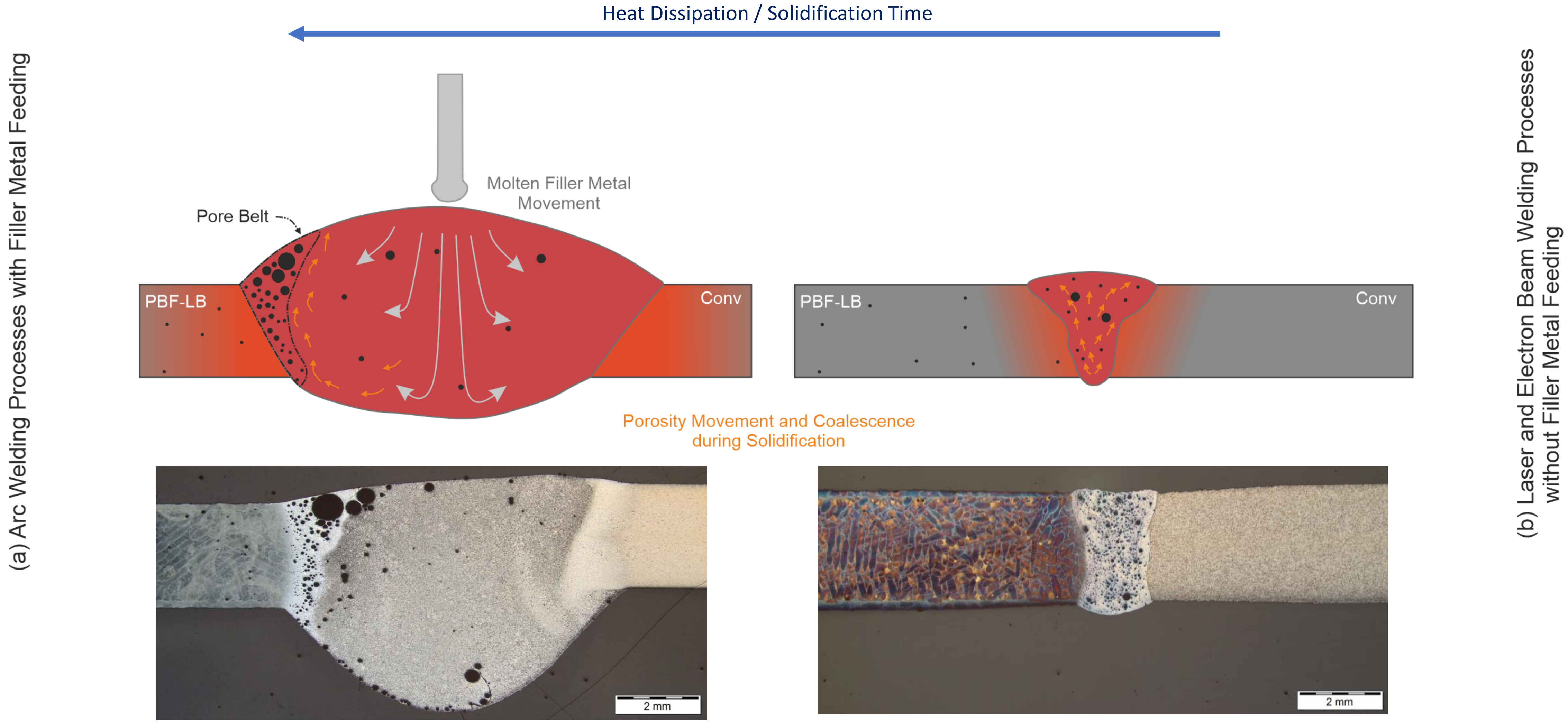


Average laser beam absorbance by new and recycled AlSi10Mg powder as function of measured oxygen content

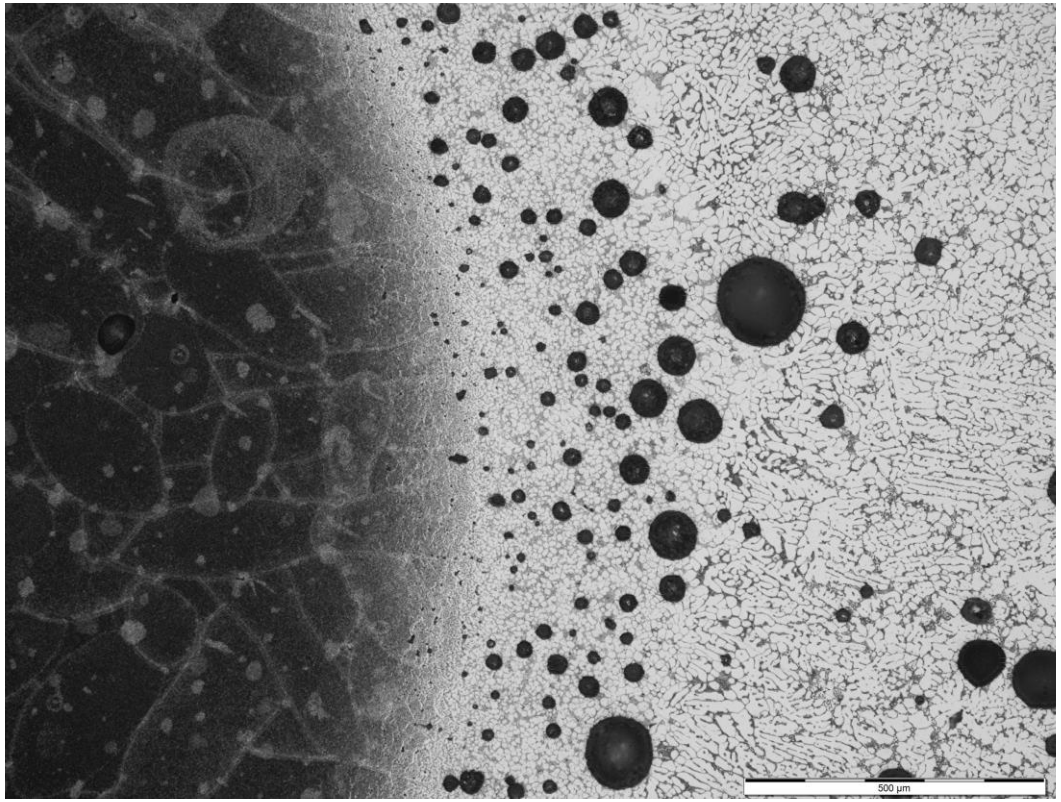
- R0 – recycling condition where virgin powder was processed once
- Aged 96 – powder condition after aging (400°C) the powder during 96 h
- R0 aged 96 h – recycling condition where virgin powder was processed once and aged (400°C)during 96 h

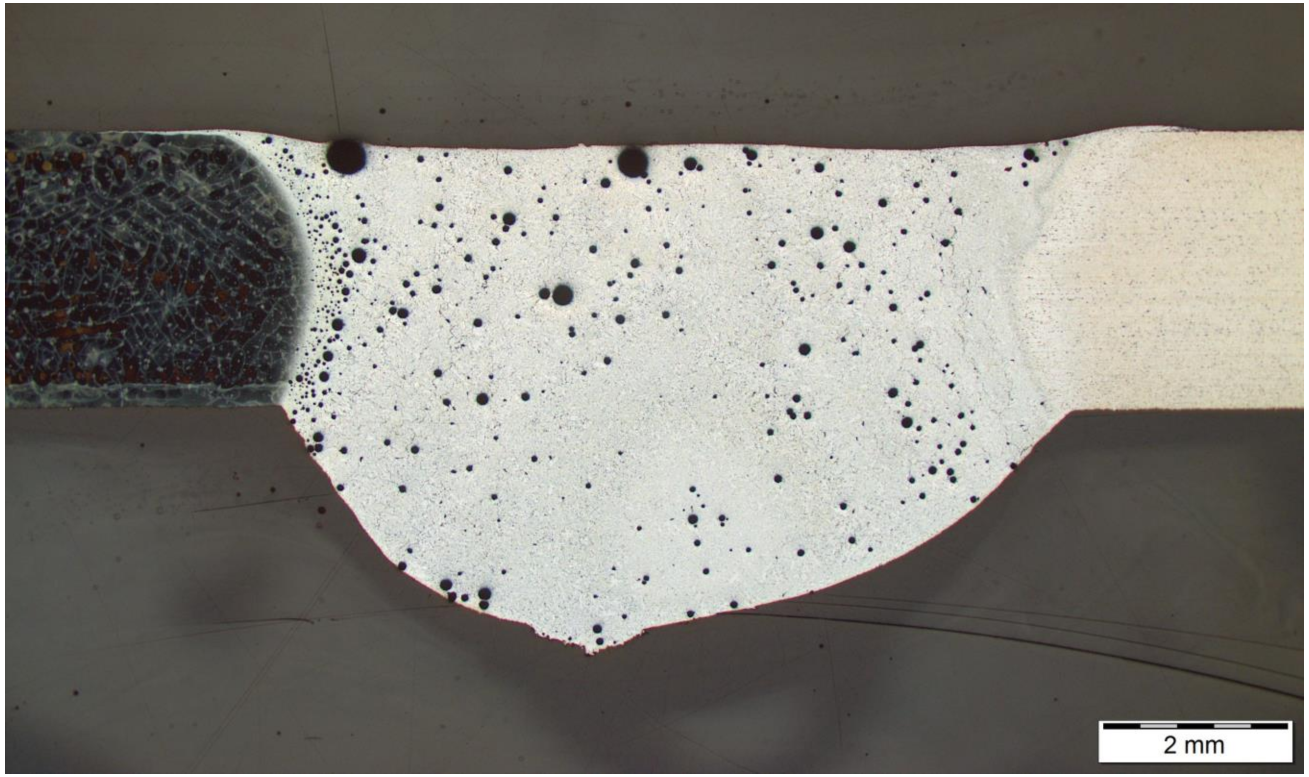
Fedina, T. *et al.* Influence of AlSi10Mg Powder Aging on the Material Degradation and its Processing in Laser Powder Fusion. Powder Technology 412 (2022) https://doi.org/10.1016/j.powtec.2022.118024

Porosity on Welding of PBF-LB Al Alloy Parts | Pore Belt Region



Porosity on Welding of PBF-LB Al Alloy Parts | Pore Belt Region





Pore Belt Region in the arc weld between conventionally and additively (PBF-LB) Al alloy parts:
Optimal case: Laser Cleaning prior to welding

Literature Review | Literature Gap and Research Objective

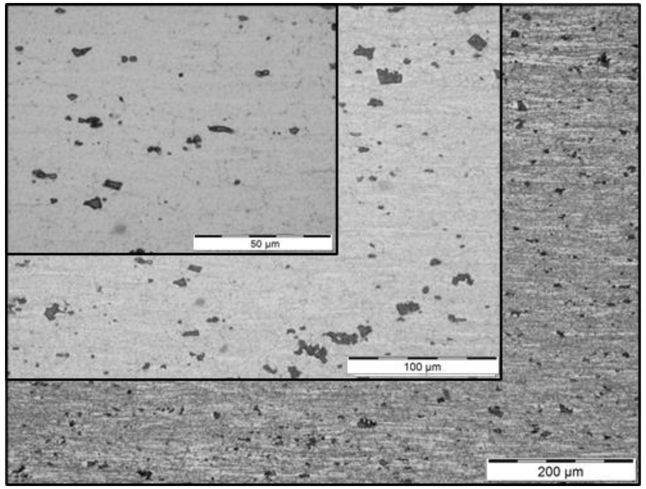
- High importance to create hybrid structures made by additive and conventional manufacturing
- BUT : Lack of literature evaluating the weldability of AM aluminium parts
- Existing articles focus on :
  - Feasibility of using specific welding processes, without comparing them,
  - Different AM processes.

→ Friction welding of AMed Al Alloys

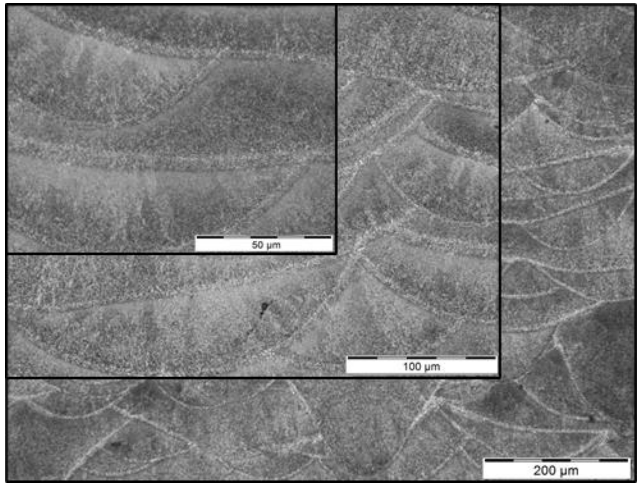
→ Weldability of DED-Arc vs PBF-LB Al parts

Base Materials

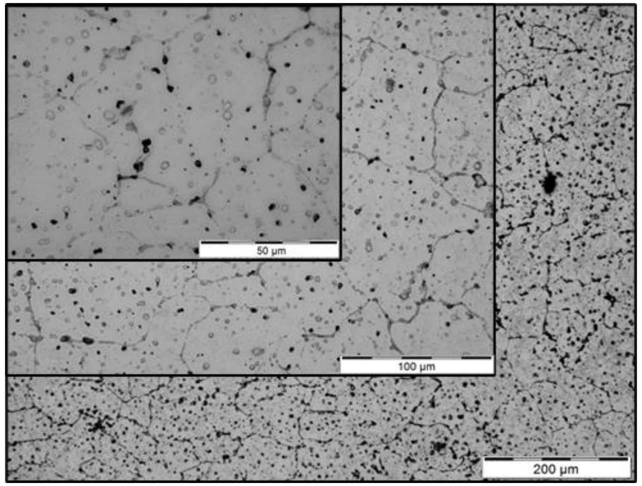
CONV 5083 Longitudinal



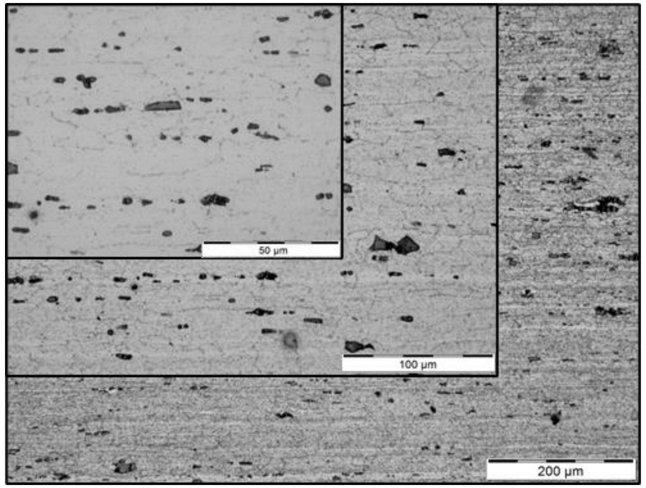
PBF-LB AlSi10Mg PBD



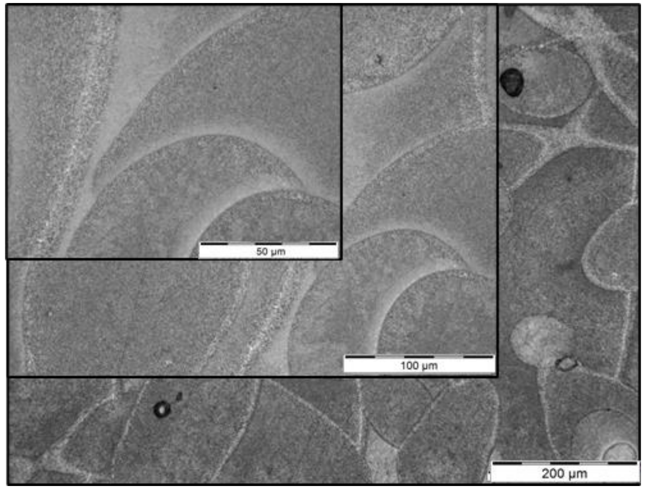
DED-Arc 5183 PBD



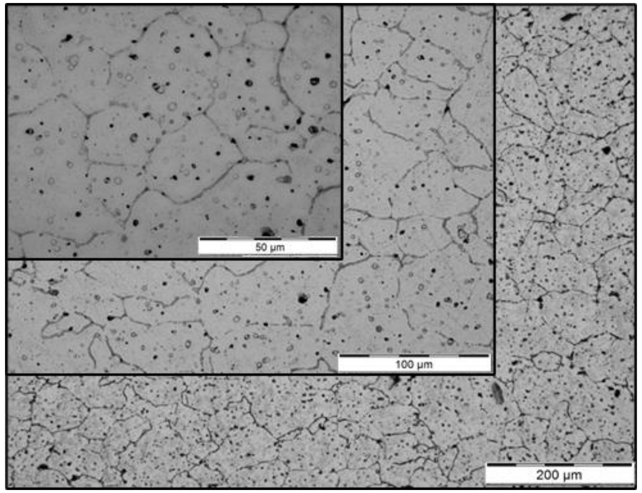
CONV 5083 Transversal



PBF-LB AlSi10Mg PDD



DED-Arc 5183 PDD

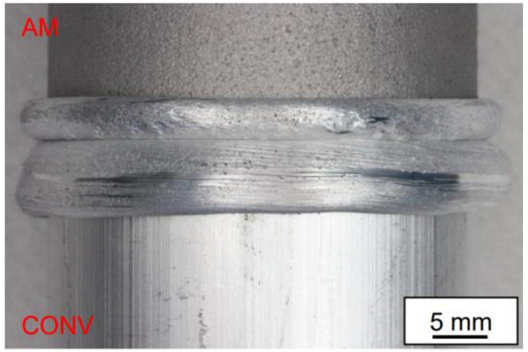


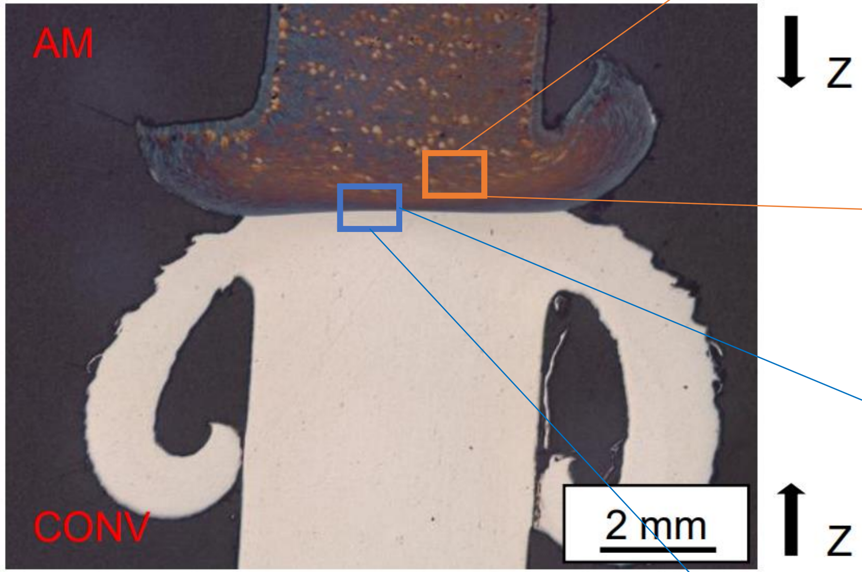
CONV UTS: 310.6 MPa

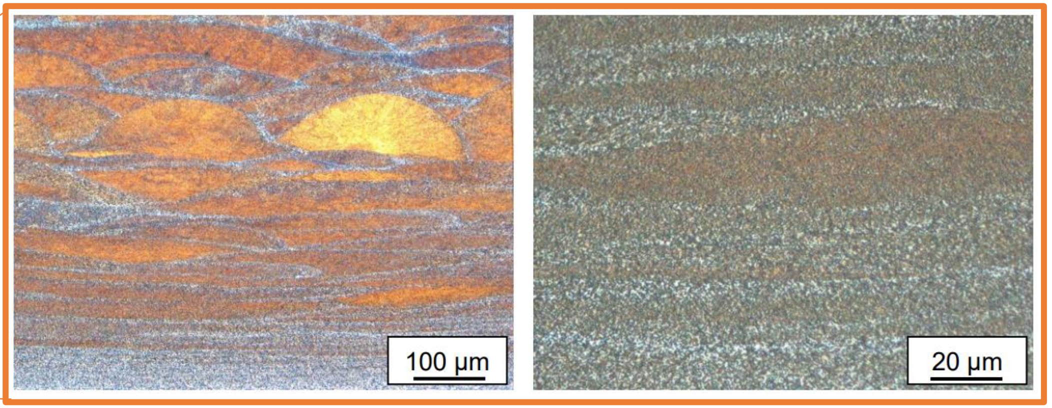
PBF-LB UTS: 435.6 MPa

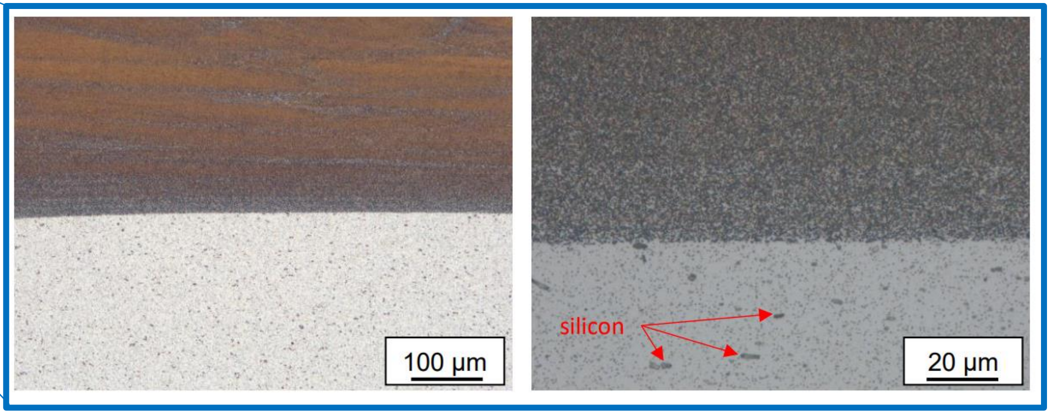
DED-Arc UTS: 288.4 MPa

Friction Welding of PBF-LB Al Alloy Parts





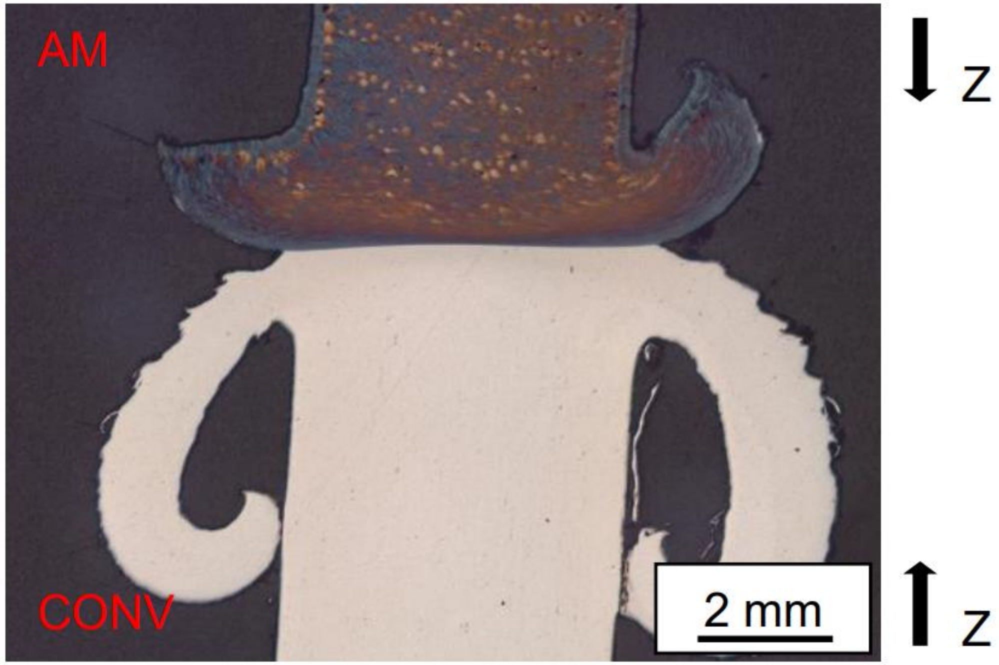




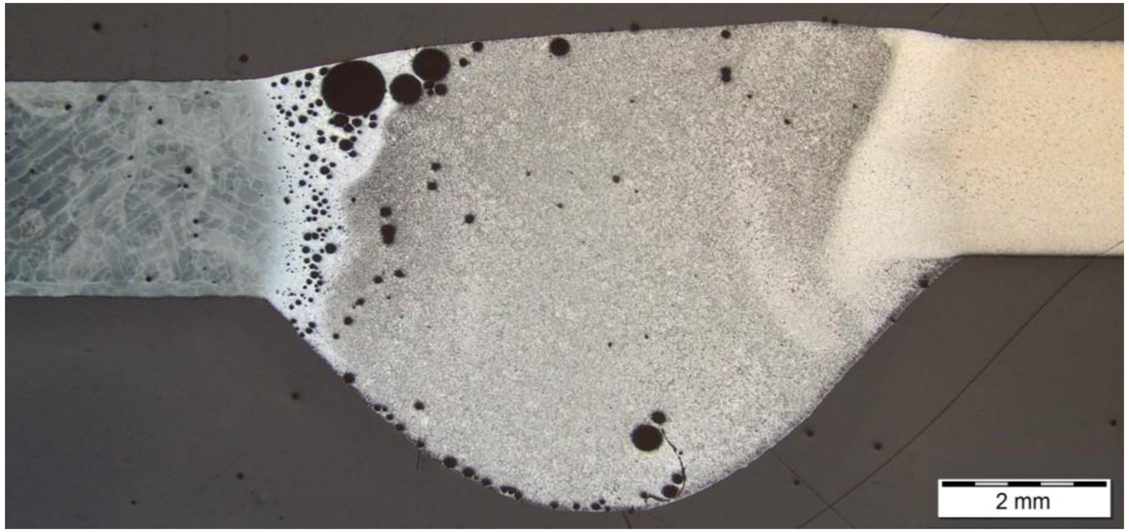
Friction welding between conventionally and PBF-LB manufactured Al alloy tubes

- CONV – larger flash formation
- Increasing of the intermetallic phases with the proximity to the weld line
- Flattening of the typical fish-scale PBF-LB structure
- No internal discontinuities found

Weldability



Friction welding between conventionally and PBF-LB manufactured Al alloy tubes



GMAW welding between conventionally and PBF-LB manufactured Al alloy sheets

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Friction Welding of PBF-LB Al Alloy Parts

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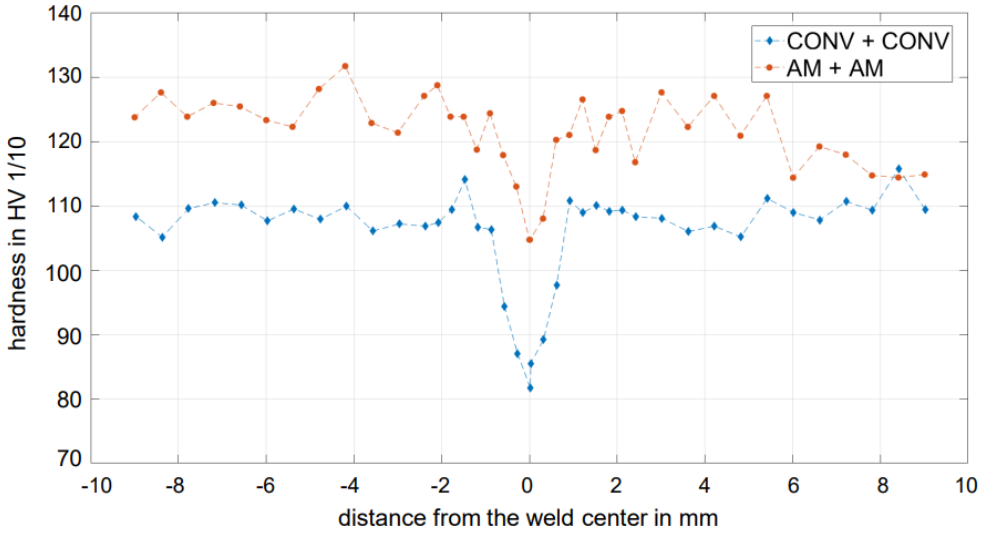
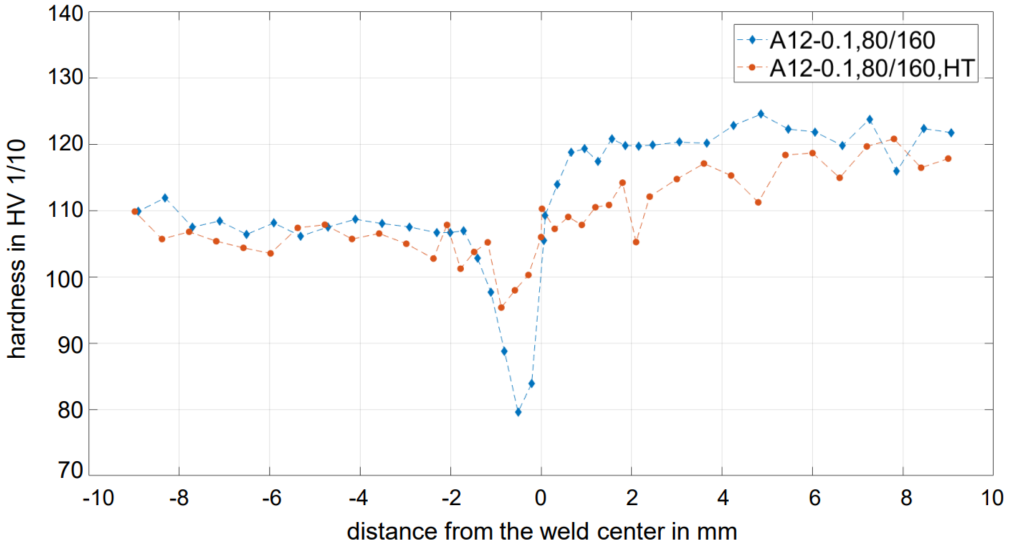




AM + AM

Significant softening in the weld zone,

- Depletion of principates in the microstructure in the weld zone (almost only Al matrix)
- Residual stress introduced during PBF-LB are, at least partly, neutralized by the welding heat.

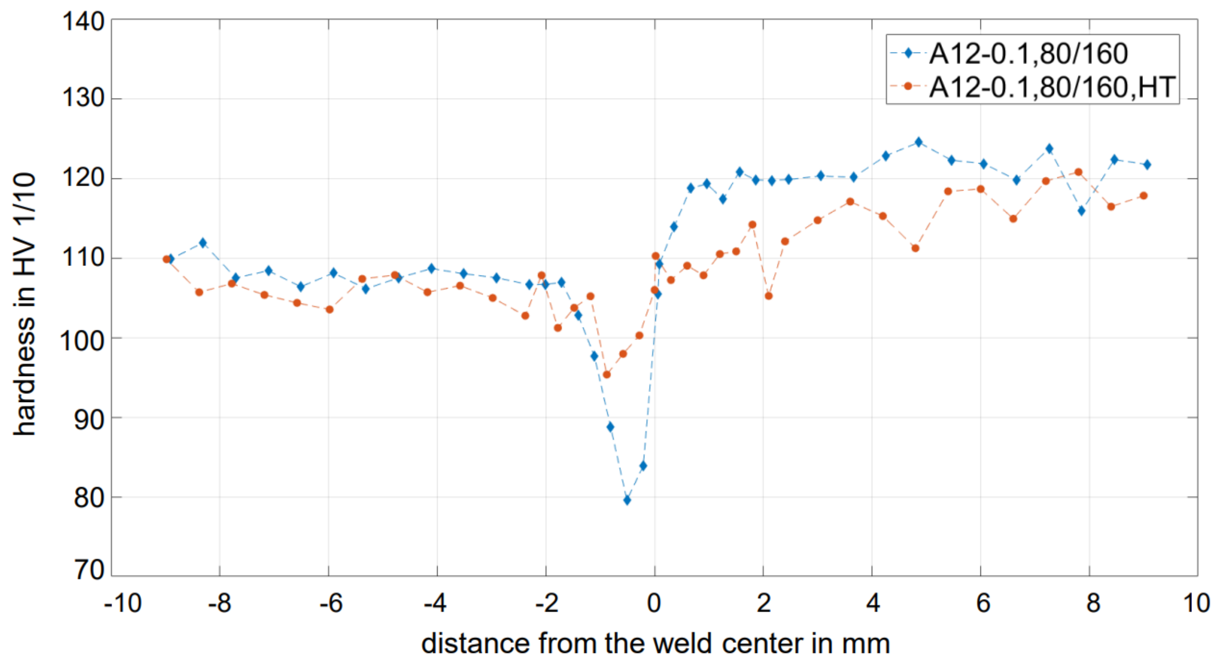
Heat Treatment

Natural cooling (60s) + 140 °C (72 h)

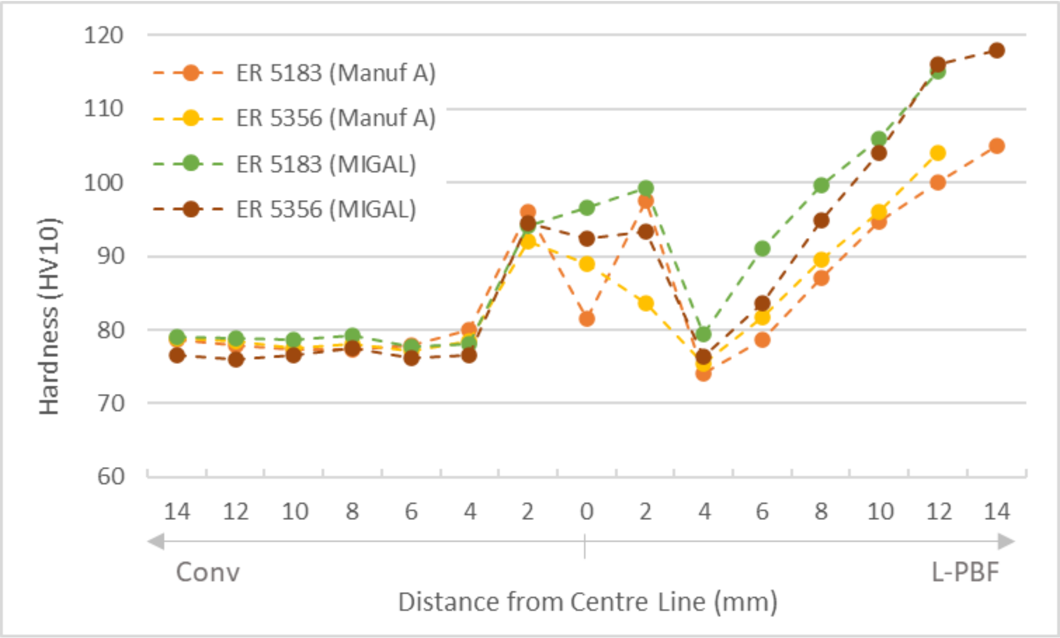
Reduction in the hardness from 25% to 15% by PWHT

Friction Welding of PBF-LB Al Alloy Parts

Weldability

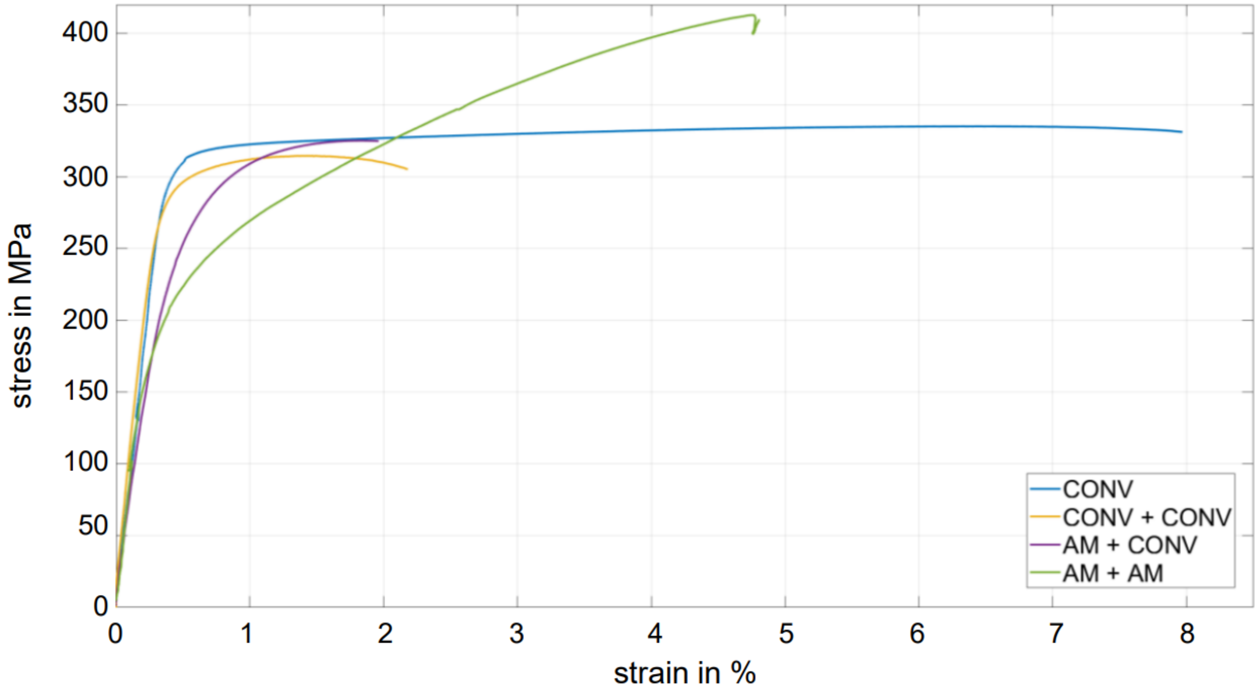


Friction welding between conventionally and PBF-LB manufactured Al alloy tubes



GMAW welding between conventionally and PBF-LB manufactured Al alloy sheets

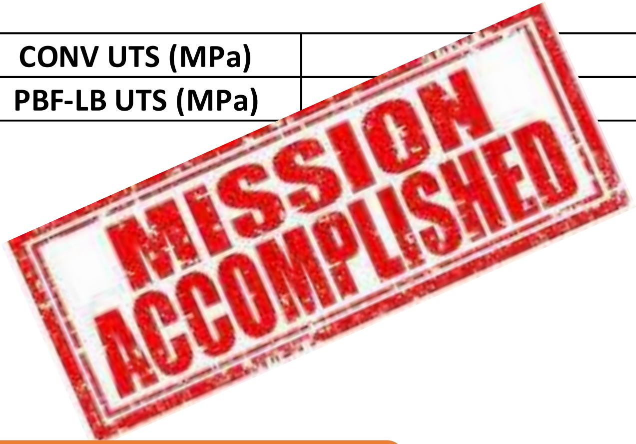
Friction Welding of PBF-LB Al Alloy Parts



	CONV/CONV		AM/CONV		AM/AM	
YS [MPa]	306	297	277	255	224	211
	301.5		266		217.5	
UTS [MPa]	320	315	326	301	395	418
	317.5		313.5		406.5	
ETF [%]	1.8	2.1	1.7	1.7	3.7	5.6
	2.0		1.7		4.6	

	Fusion Welding Process	Solid-State Welding Process
	GMAW	FRW
UTS (MPa)	225.1 ± 14.1	313.5 ± 12.5

CONV UTS (MPa)	310.6 ± 5.2
PBF-LB UTS (MPa)	435.6 ± 6.9

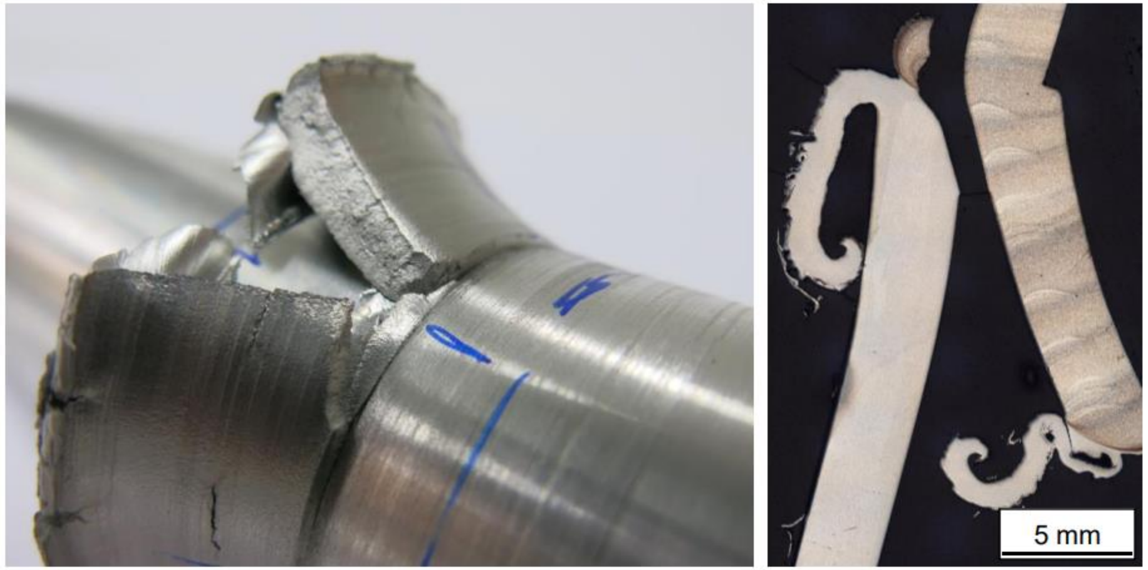


UTS achieved by FRW equal to UTS of base material (CONV)

Fracture location: Conv Base Material

Friction Stir Welding (FSW) is under evaluation, already showing very similar promising results

Friction Welding of DED-Arc Al Alloy Parts



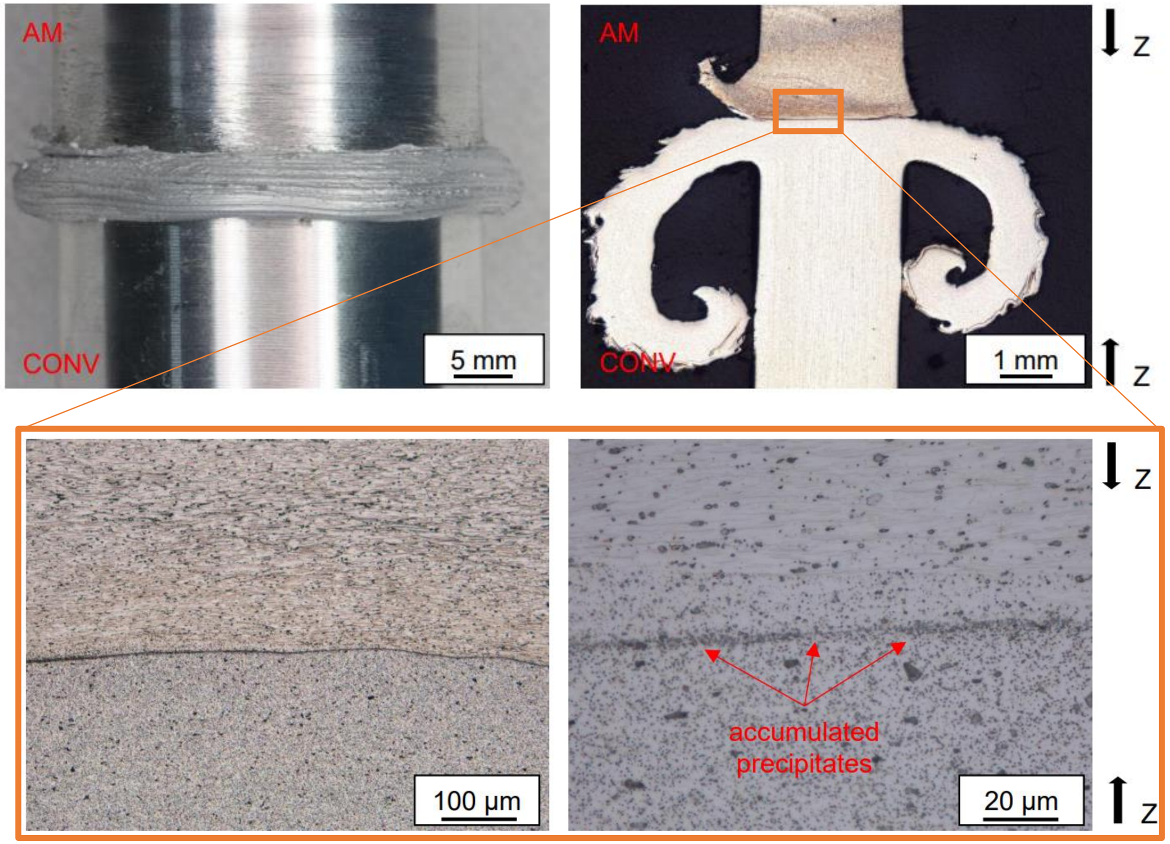
High degree of plasticization of the Conv part
Extremely low plasticization of the DED-Arc part (with subsequent failure)

First theory: due to the inter-layer regions of the DED-Arc ✗

Second theory: large amount of the plasticized Conv material forces into the DED-Arc part ✗

Failure reason: Mechanical load in the FRW process is too high for the DED-Arc part

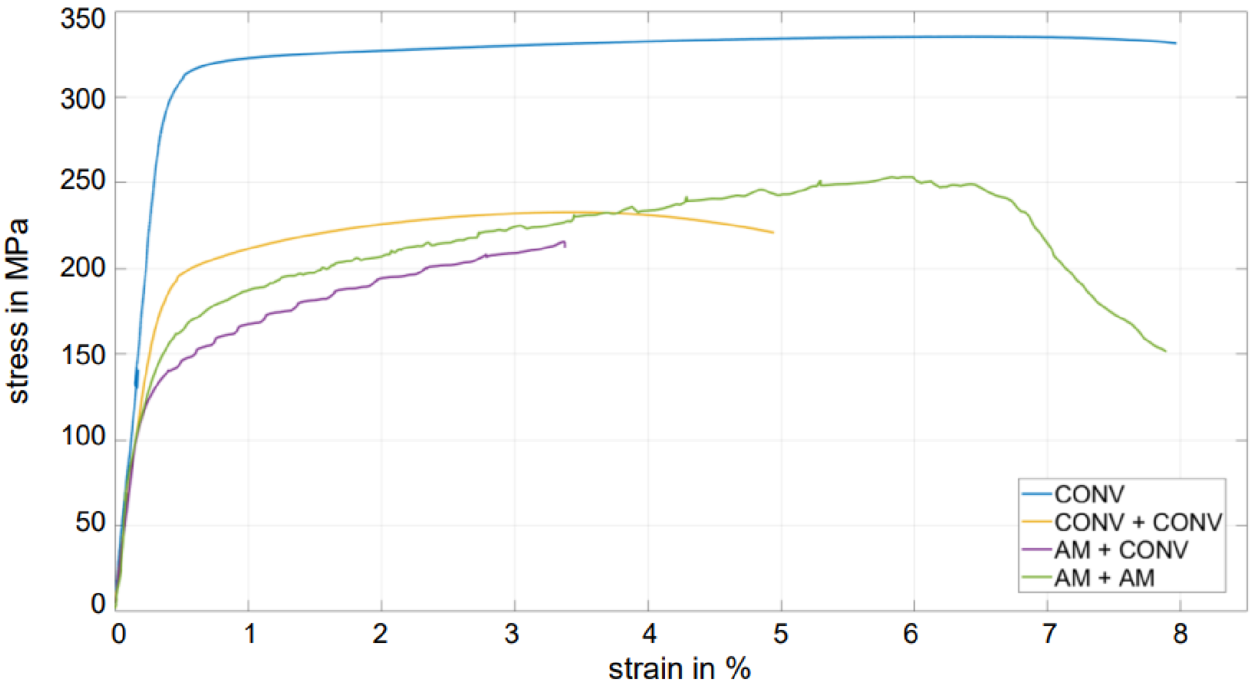
Usage of low process pressure



Accumulation of precipitates in the weld line

(Macro) lack of bonding due to the low process pressure

Friction Welding of DED-Arc Al Alloy Parts



	CONV/CONV		AM/CONV		AM/AM	
YS [MPa]	231	200	125	141	159	158
	215.5		146		158.5	
UTS [MPa]	259	234	221	216	254	225
	246.5		218.5		239.5	
ETF [%]	2.3	5.1	6.9	3.1	9.5	6.9
	3.7		5.0		8.2	

	Fusion Welding Process	Solid-State Welding Process
	GMAW	FRW
UTS (MPa)	285.9 ± 4.1	218.5 ± 2.5

CONV UTS (MPa)	310.6 ± 5.2
PBF-LB UTS (MPa)	435.6 ± 6.9

Low UTS:

Lack of bonding (low process pressure)

Conclusion and Final Remarks

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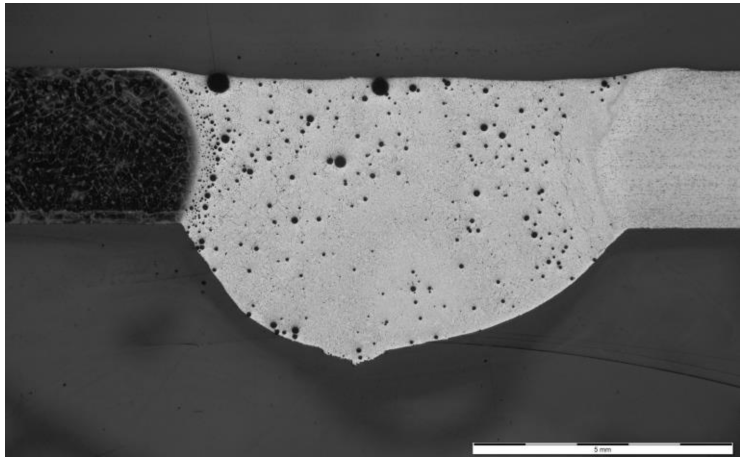
Fusion Welding Processes

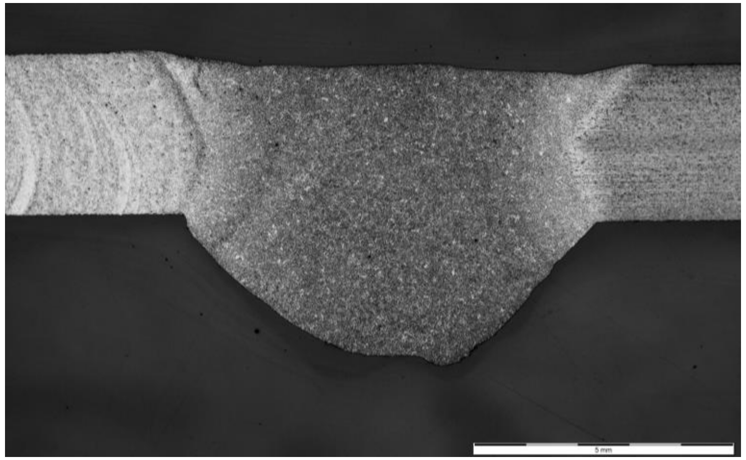
Solid-State Welding Processes (FRW)

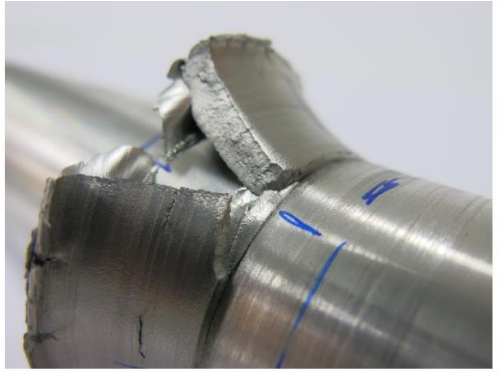
Friction Welding of PBF-LB Al Alloy Parts



Weldability

Friction Welding of DED-Arc Al Alloy Parts





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Thank you for your attention!

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