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

Enhancing Performance of Welded Additively Manufactured Aluminium Alloy Components Through Friction Stir Welding

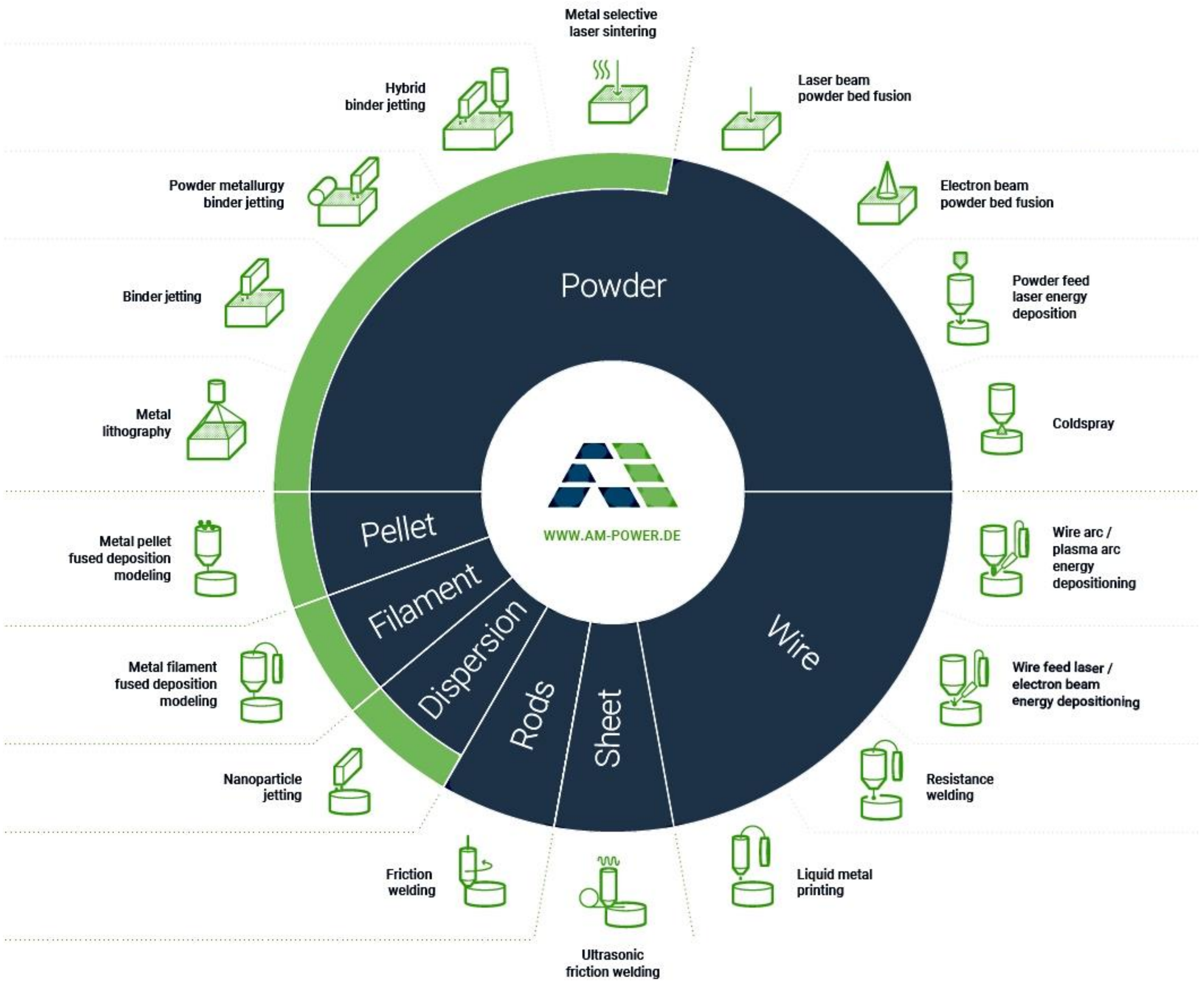
R. Nunes, M. Lezaack, A. Simar, K. Faes, W. De Waele

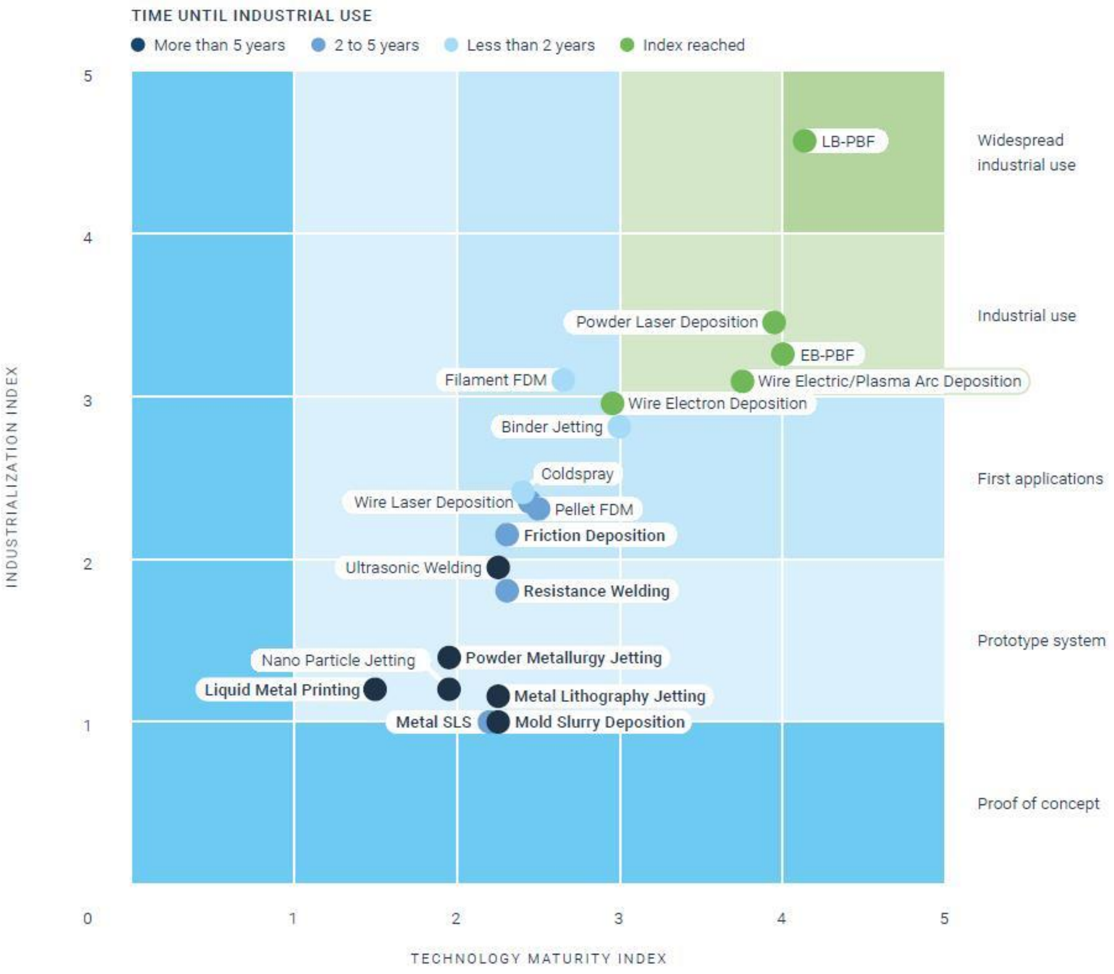
BS research

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

GHENT UNIVERSITY

Selection of Additive Manufacturing Process

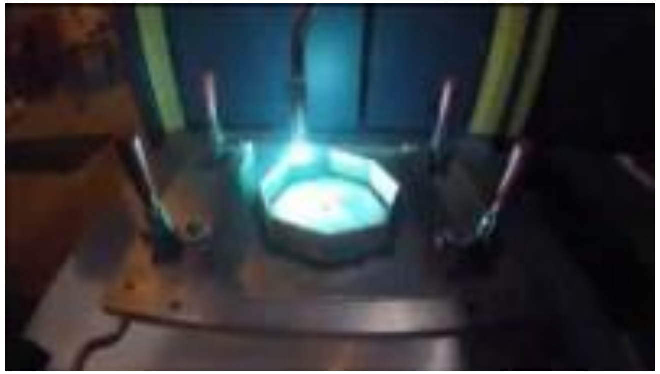




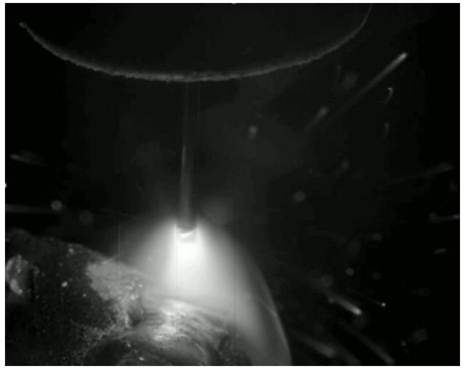
AMPOWER (*https://ampower.eu/*)

Selection of Additive Manufacturing Process

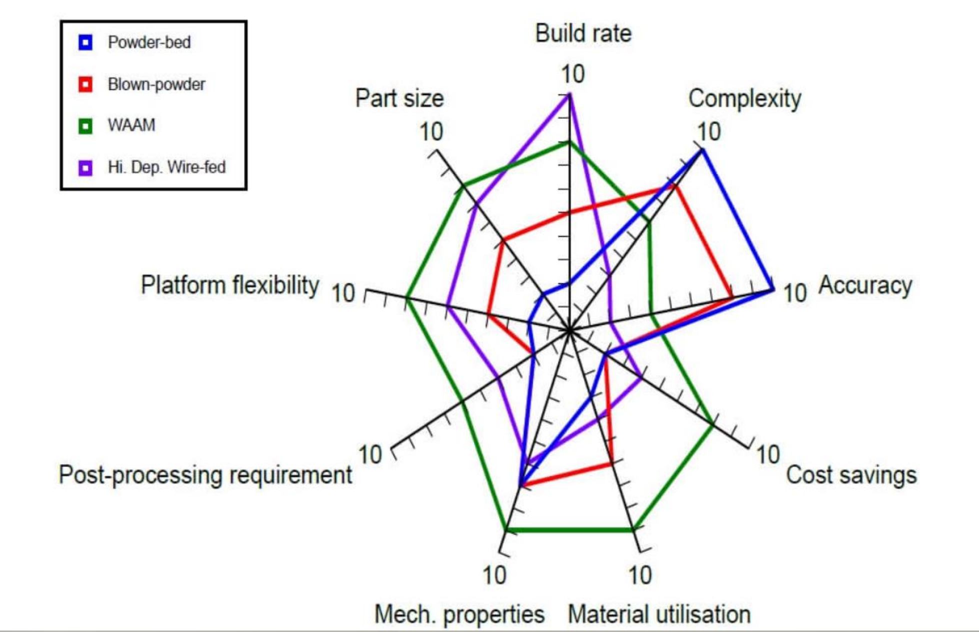
WAAM (DED-Arc)



WAAM (DED-Arc)



PBF-LB



WAAM (DED-Arc)

Complexity / Resolution

Deposition Rate / Printing Size

PBF-LB

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 fusion welding processes

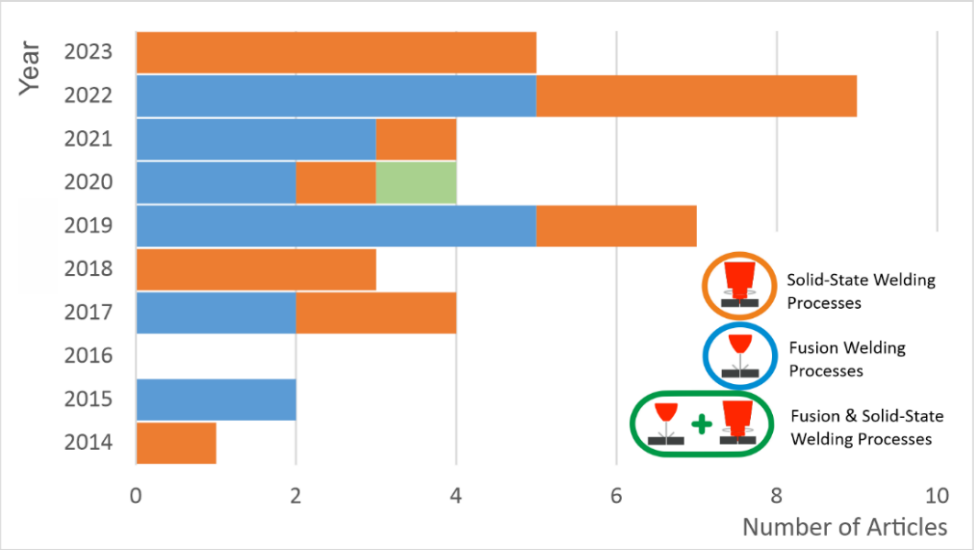
- 18 articles evaluating PBF-LB parts and 1 article evaluating DED-Arc (DED-Arc) parts
- 14 articles evaluating LBW
- 4 article evaluating EBW
- 3 articles evaluating GTAW

19 articles (49 %) evaluating solid-state welding 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 fusion & solid-state welding 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

Literature Review | Literature Gap and Research Objective

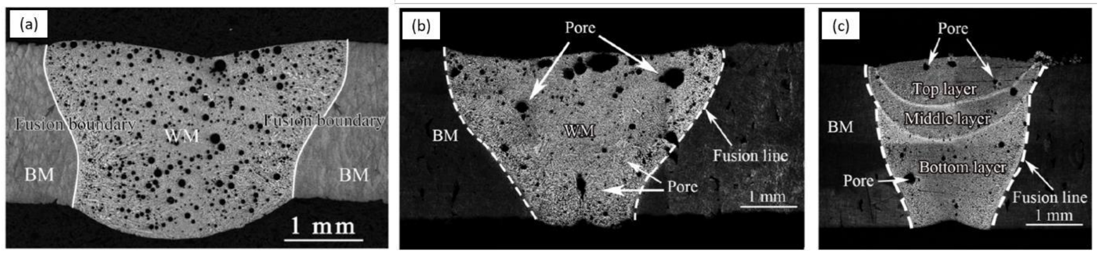
- High importance to create hybrid structures made by additive and conventional manufacturing
- BUT : Lack of literature evaluating the weldability of AMed aluminium parts
- Existing articles focus on :
    - Feasibility of using specific welding processes

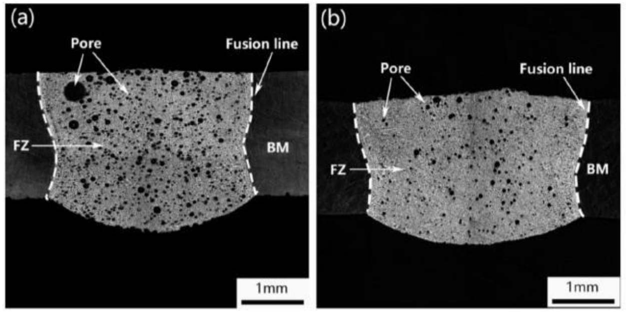
→ Comparison between different welding processes

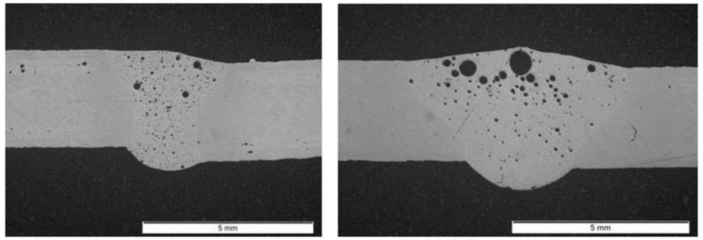
→ Comparison on the weldability between different AM materials

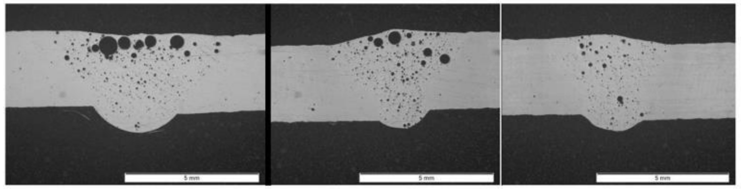
→ Non-evaluated processes: GMAW, PAW, FRW

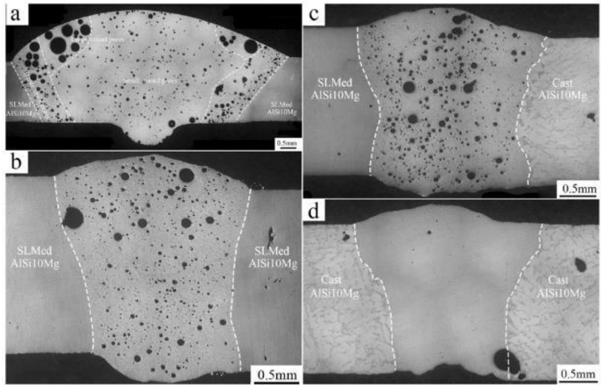
Current Status of the Art | Weldability of AMed Al Alloy Parts – Fusion Welding

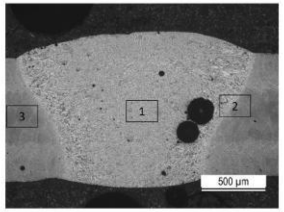


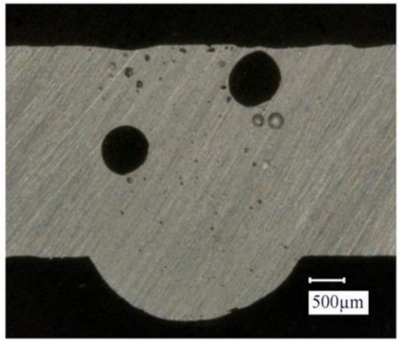


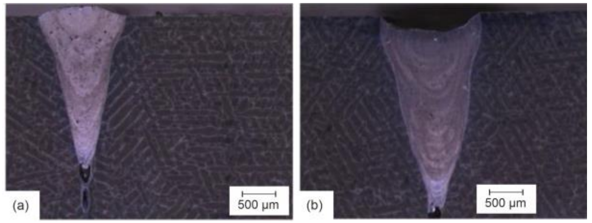












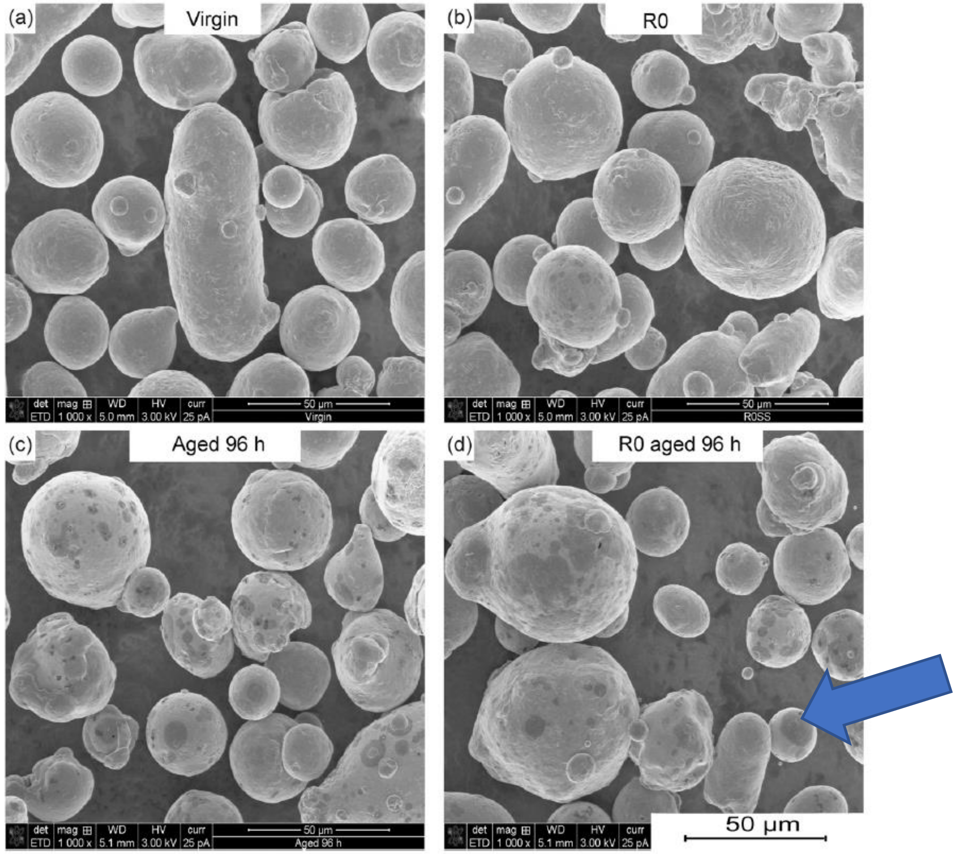
Unlikely the porosity can be entirely avoided by optimization of welding parameters,
Other fusion welding processes are likely to suffer from porosity issues.

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

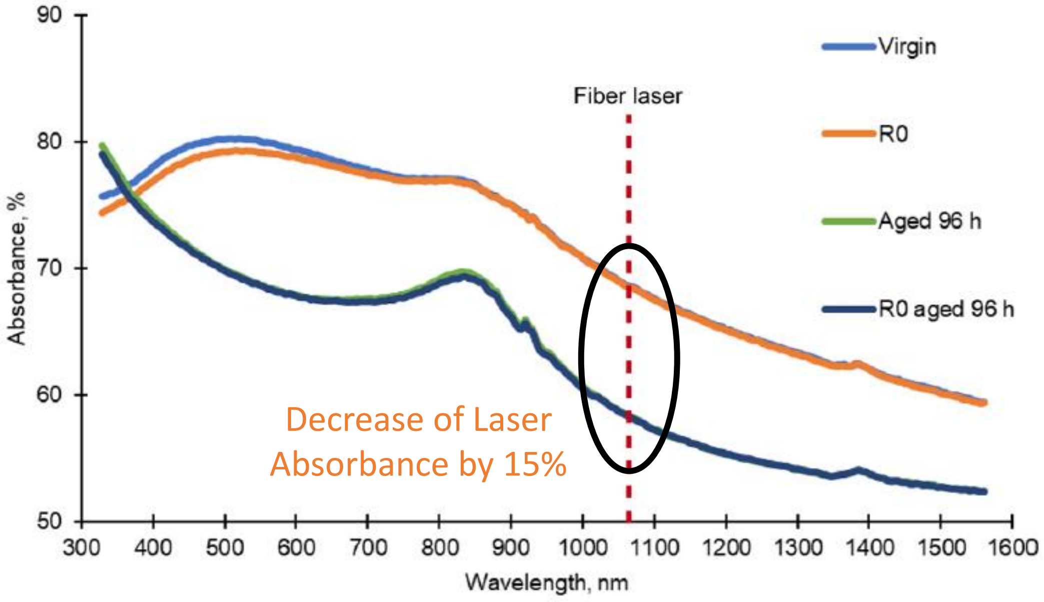
→ Higher surface area to volume ratio compared to wire filler material,

→ Common to recycle powder in PBF-LB process.

Particle Morphology, Porosity and Surface Oxidation



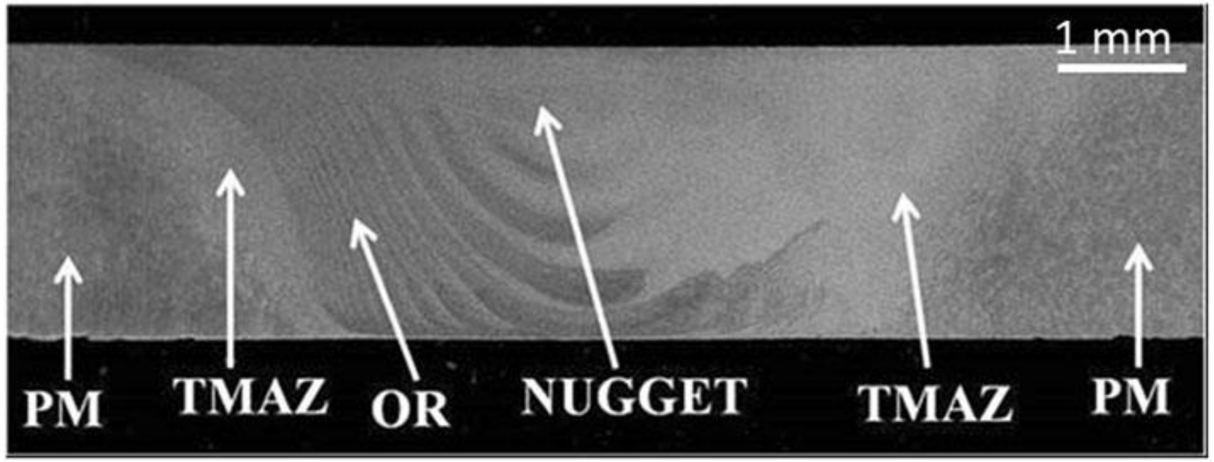
Morphology and surface oxidation condition of new and recycled AlSi10Mg powder

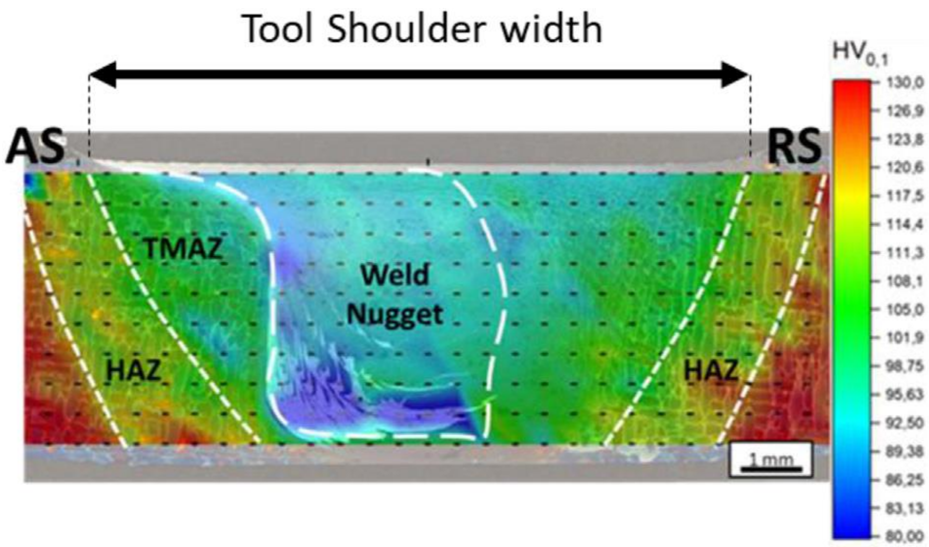


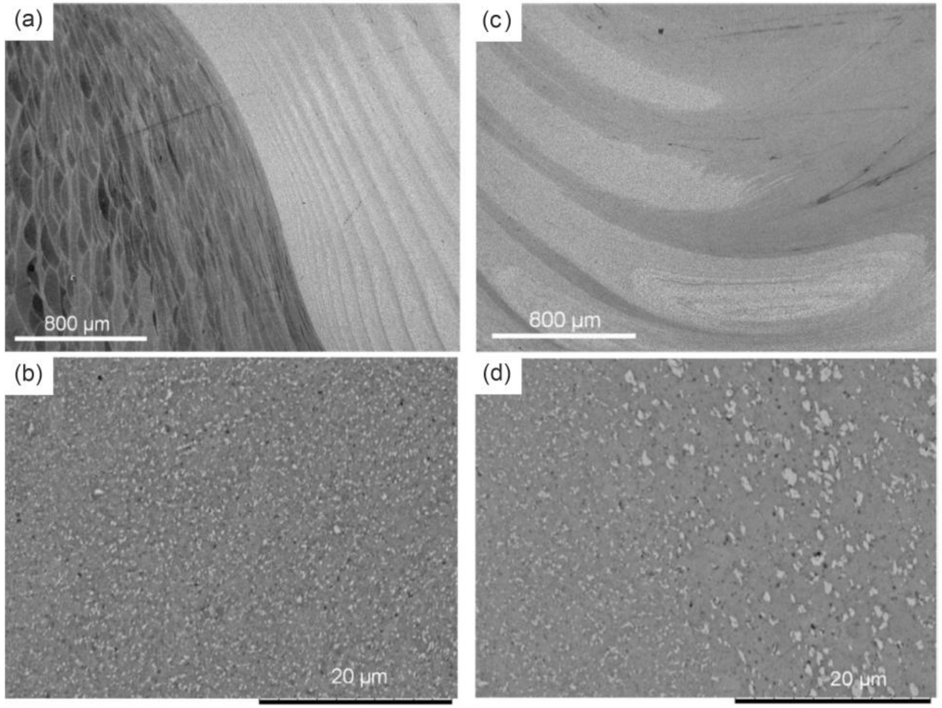
Powder state	Average laser light absorbance [%]
Virgin	68.55 (±0.10)
R0	68.48 (±0.09)
Aged 96 h	58.23 (±0.13)
R0 aged 96 h	58.13 (±0.09)

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 | Weldability of AMed Al Alloy Parts – Solid-State Welding







Four distinct regions presenting different levels of recrystallization and grain refining:

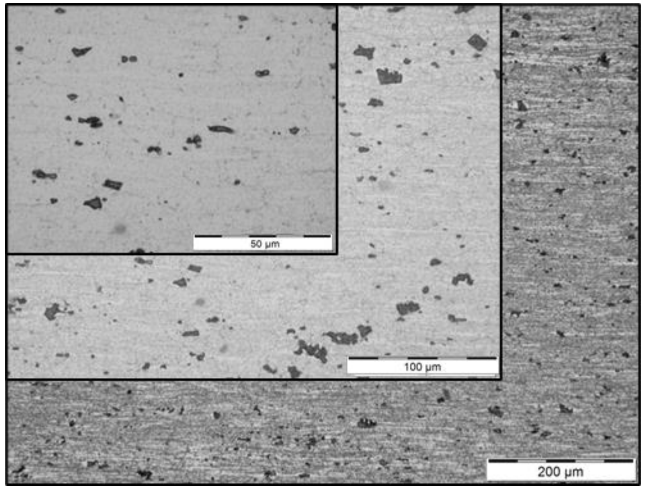
Base Material (BM)
Thermo-Mechanically Affected Zone (TMAZ)
Onion rings (OR)
Weld Nugget (WG)

Softening in the nugget zone: dissolution of hardening precipitates (Advancing size)

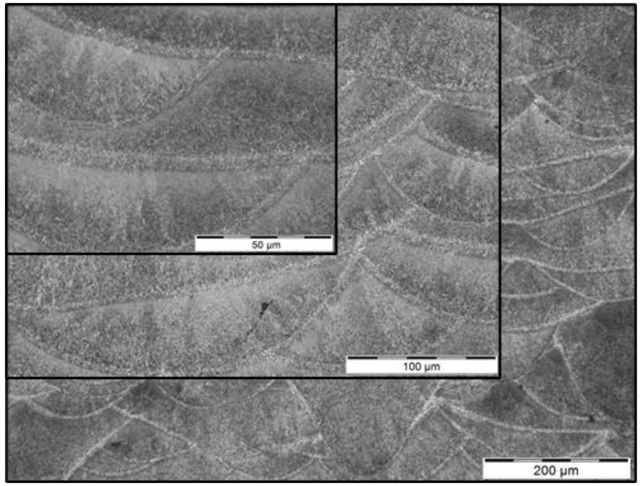
→ Welds without any macroscopic defect

Base Materials

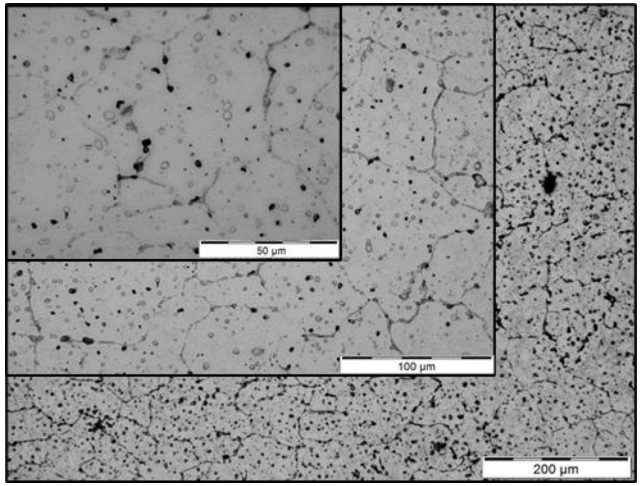
CONV 5083 Longitudinal



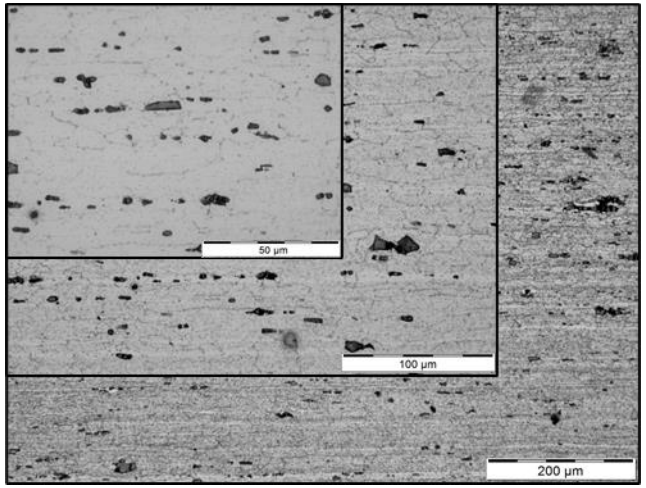
PBF-LB AlSi10Mg PBD



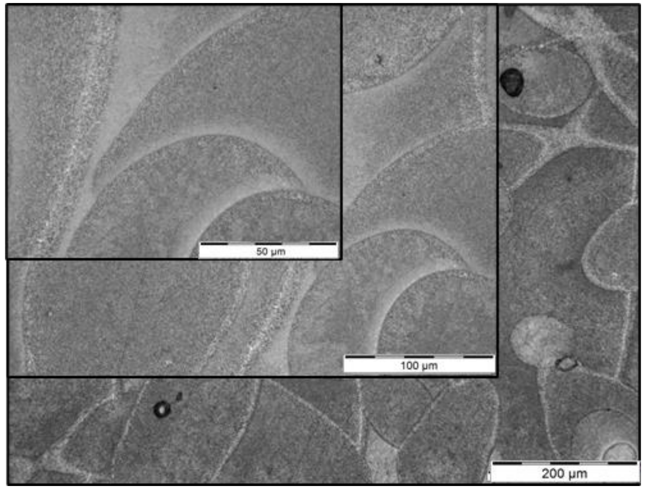
DED-Arc 5183 PBD



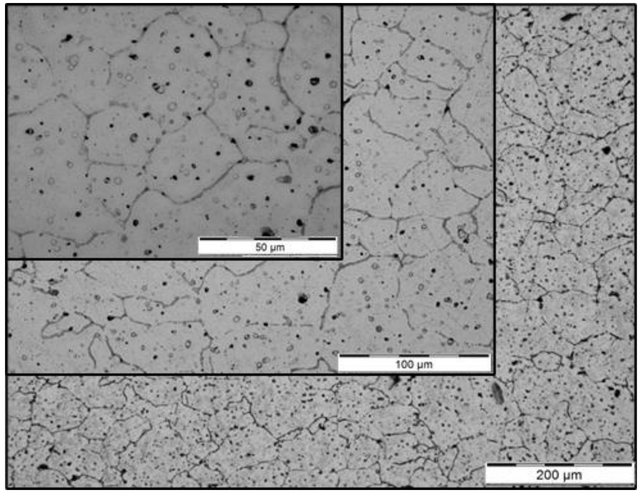
CONV 5083 Transversal



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

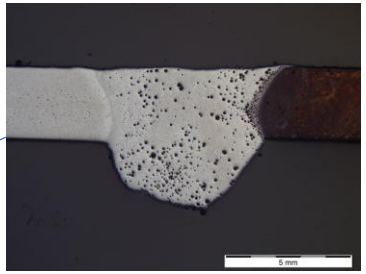
Evaluated Welding Processes and Conditions

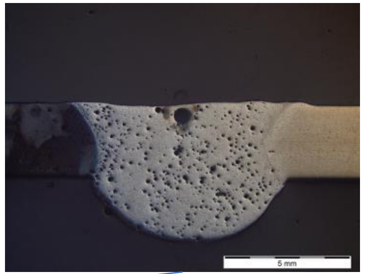
Fusion Welding Processes

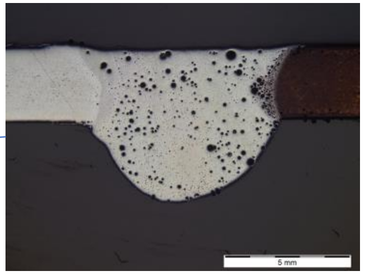
- GMAW Process:
  - Filler Metal Quality Influence
  - Heat Input Influence
  - Shielding Gas Composition Influence
  - Laser Cleaning Prior to Welding
- GTAW Process
- LBW Process:
  - Heat Input Influence
- PAW Process

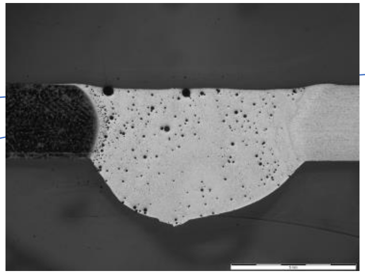
Solid-State Welding Processes

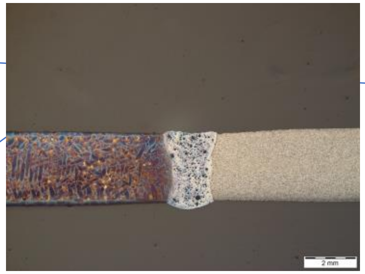
- FSW Process:
  - Heat Input Influence
- FRW Process

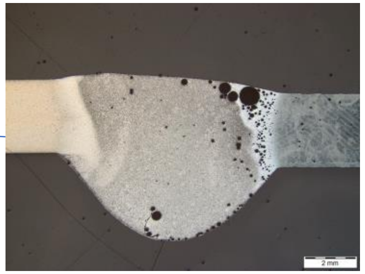


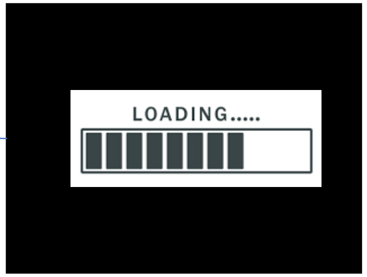


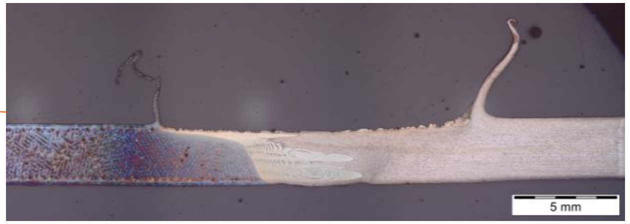












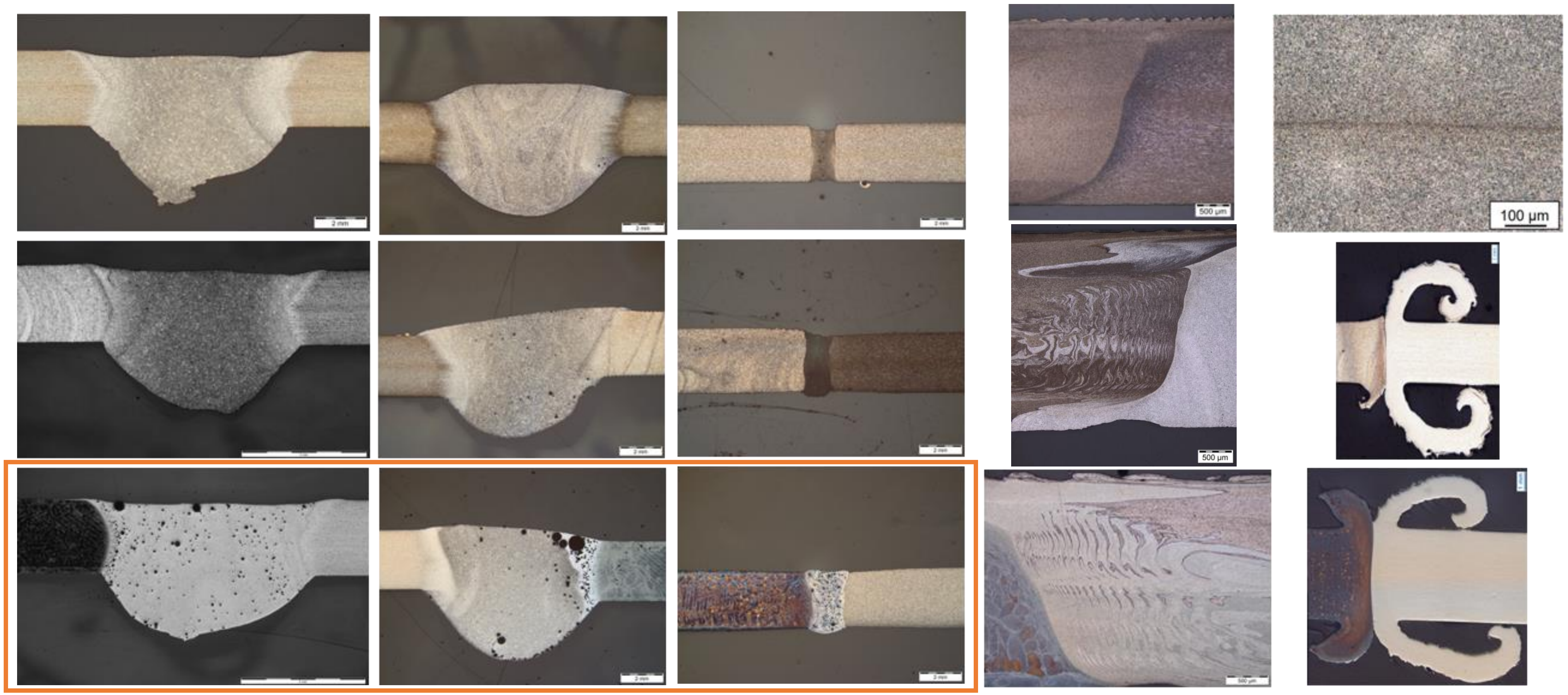
Evaluated Welding Processes and Conditions | Metallographic Examination

GMAW GTAW LBW FSW FRW

Conv 5083 / Conv 5083

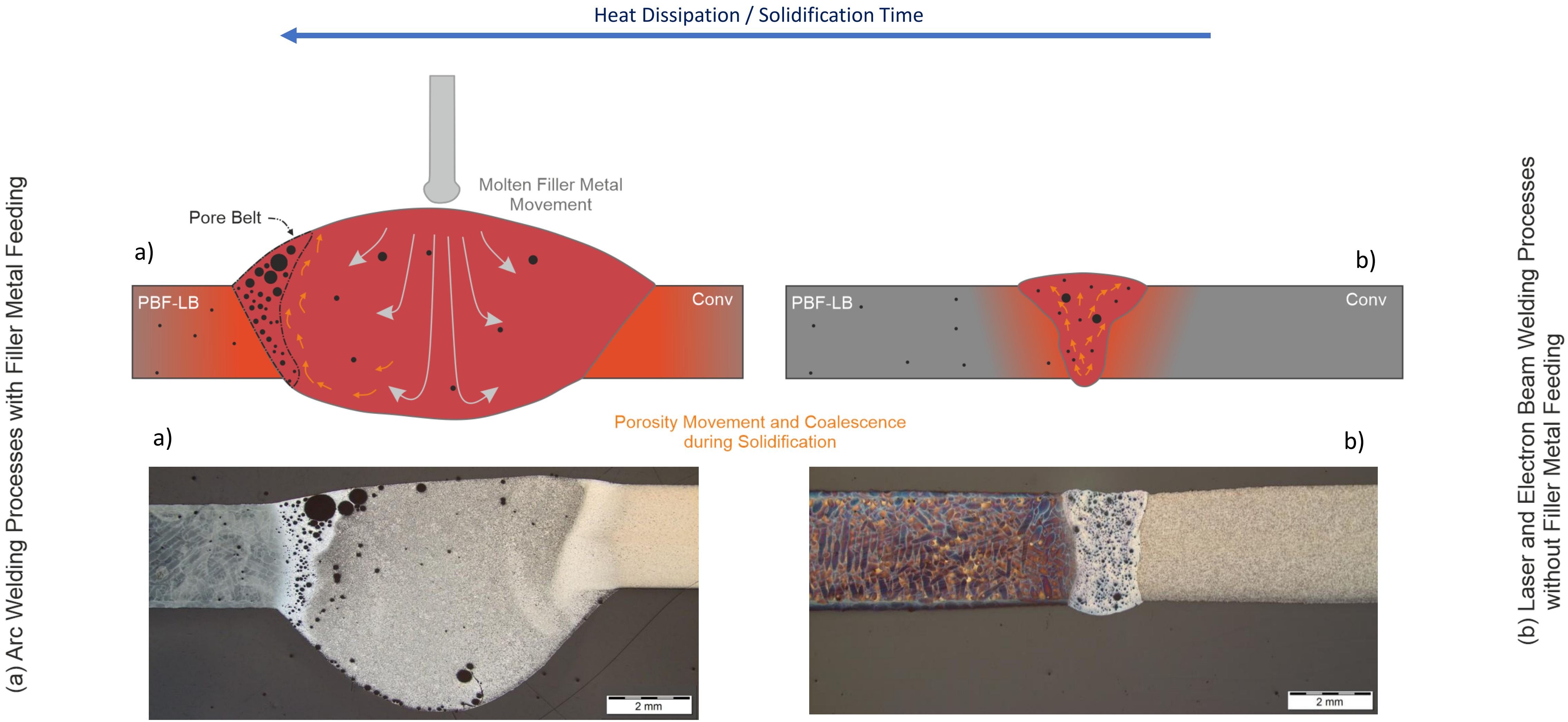
Conv 5083 / DED-Arc 5183

Conv 5083 / PBF-LB AlSi10Mg

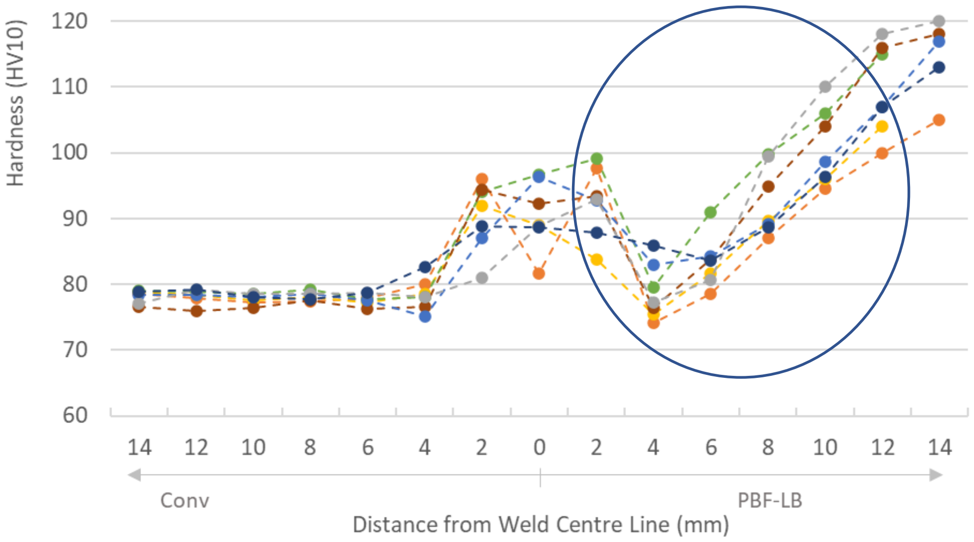


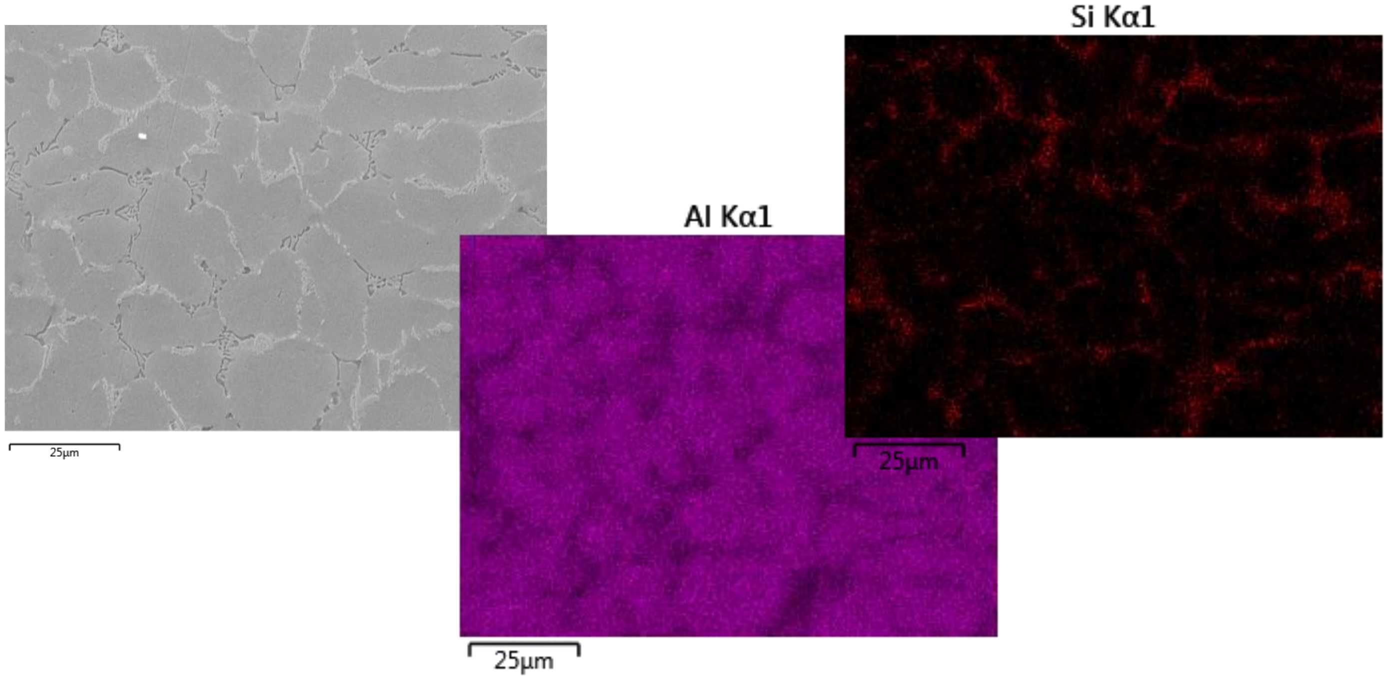
High Porosity Level

Evaluated Welding Processes and Conditions | Pore Belt Region



Evaluated Welding Processes and Conditions | Metallographic Examination - Fusion



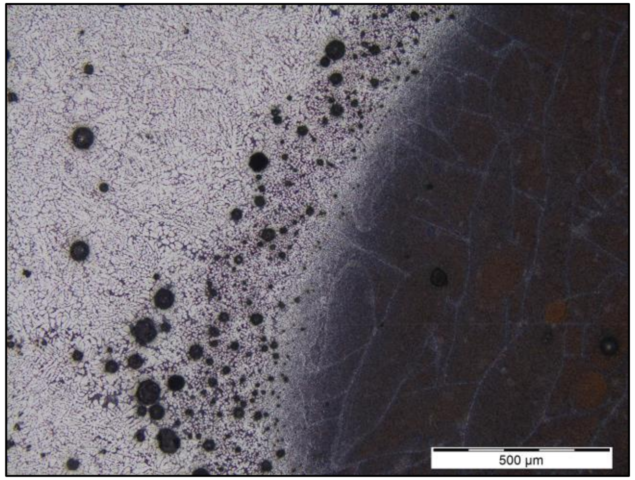


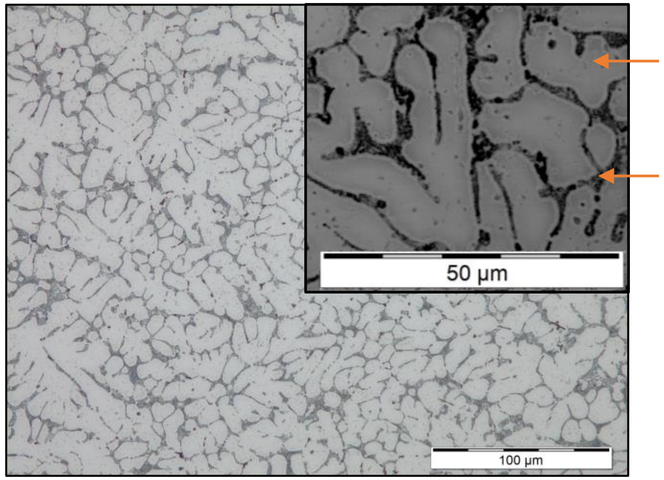
Hardening in WZ in the Conv-PBF-LB welds :

- α-Al cells surrounded by Si-rich eutectic phases

Softening in HAZ of Conv-PBF-LB welds :

- Pore belt region formation decreasing the hardness and strength
- Spheroidization of the silicon in the base material

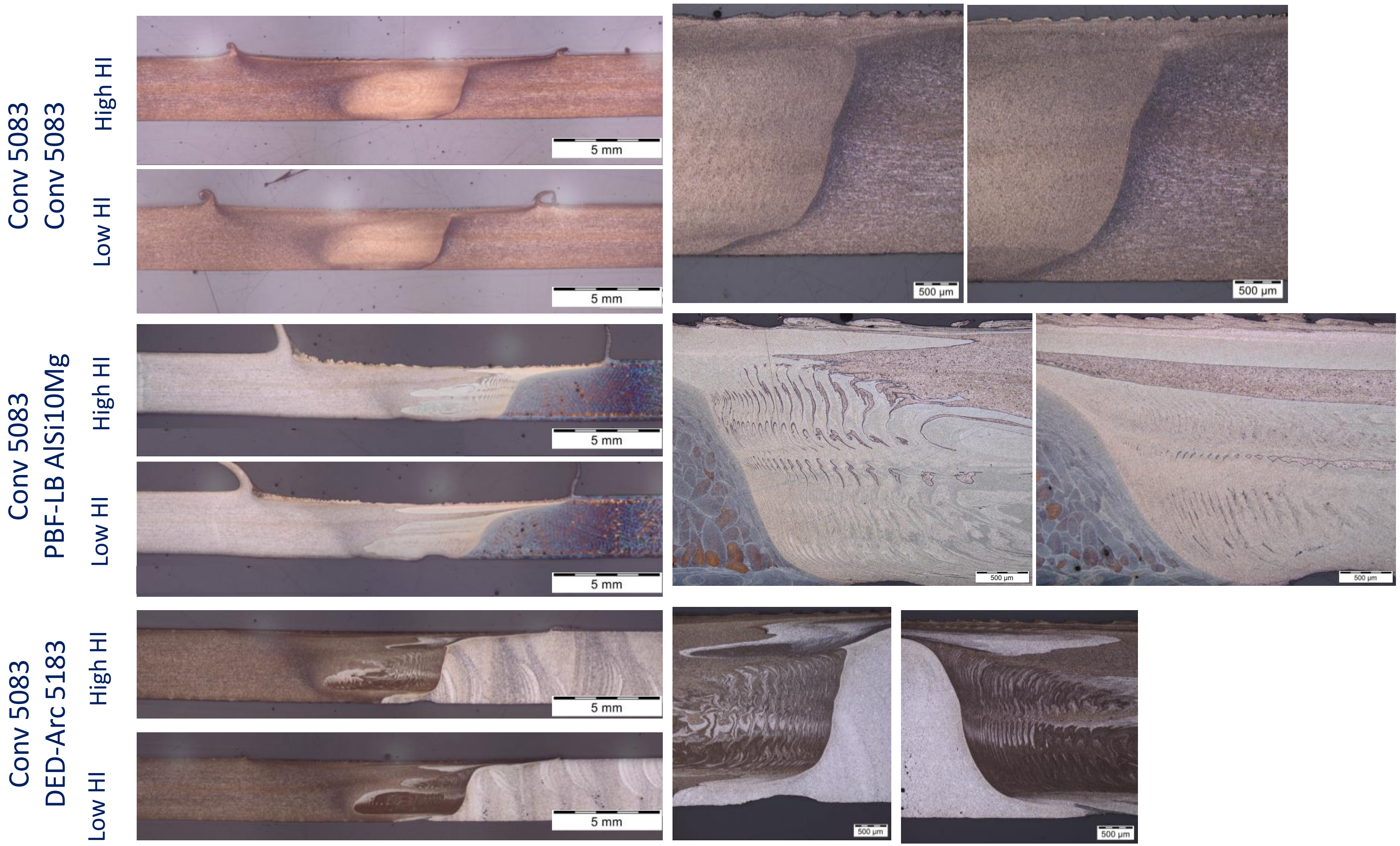




α-Al cells

Si-rich eutectic phases

Evaluated Welding Processes and Conditions | Metallographic Examination - FSW

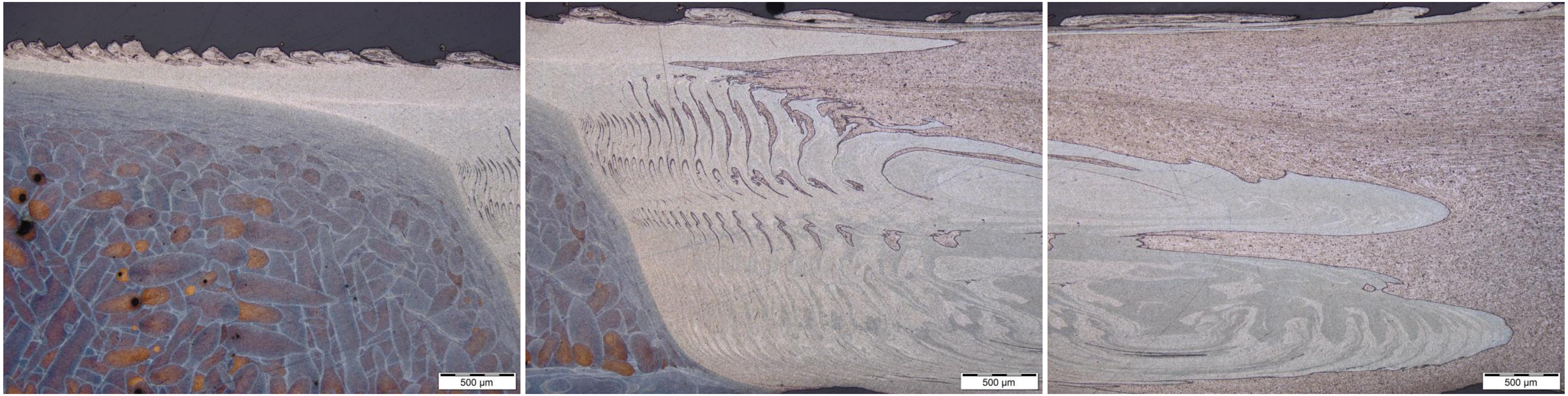


Four distinct regions:

Base Material (BM)
Thermo-Mechanically Affected Zone (TMAZ)
Onion rings (OR)
Weld Nugget (WG)

Although there are still opportunities for parameters optimization, the FSW process achieved defect-free welds for every materials combination

Evaluated Welding Processes and Conditions | Metallographic Examination - FSW



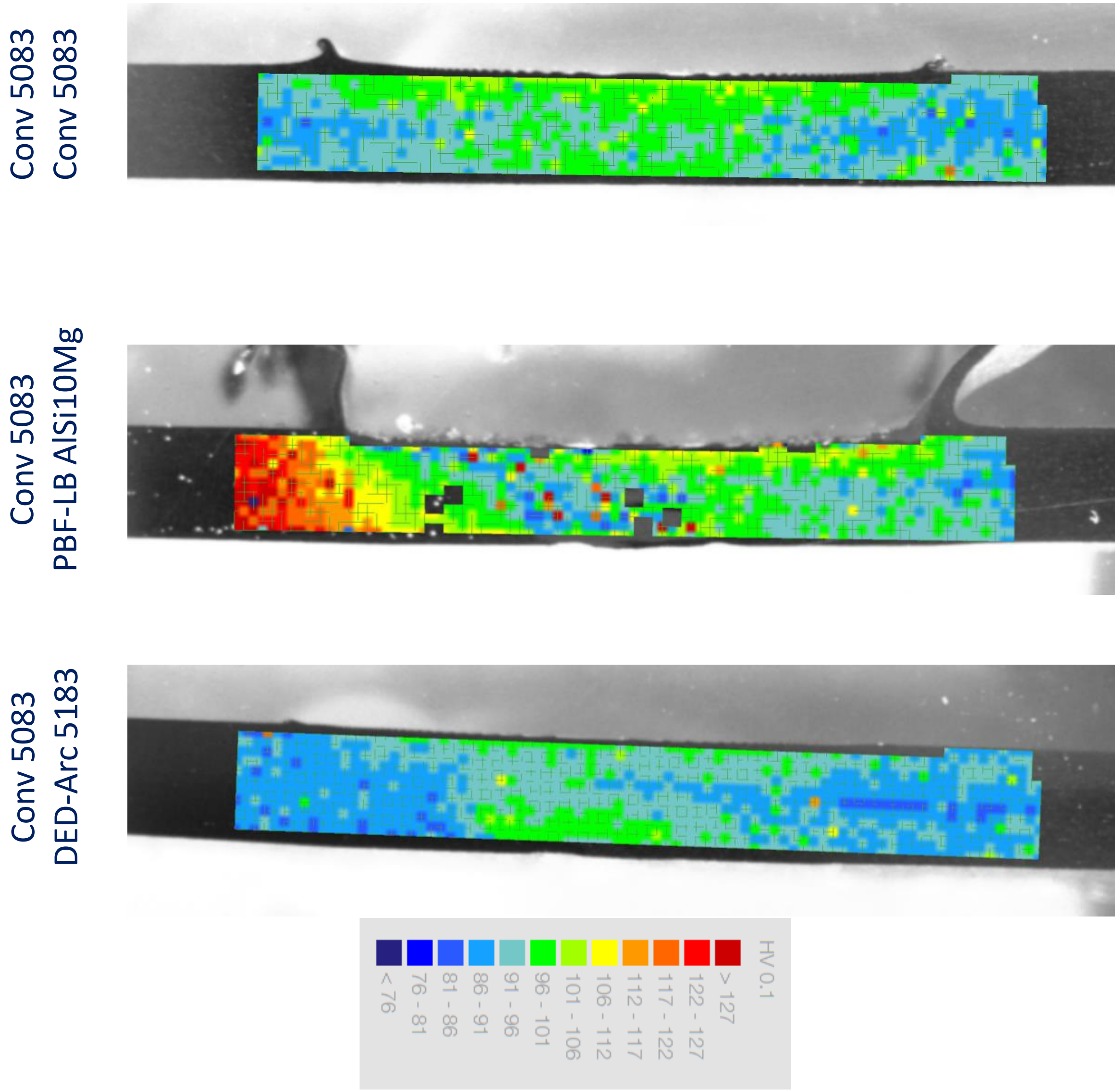
PBF-LB BM: High Porosity Level.

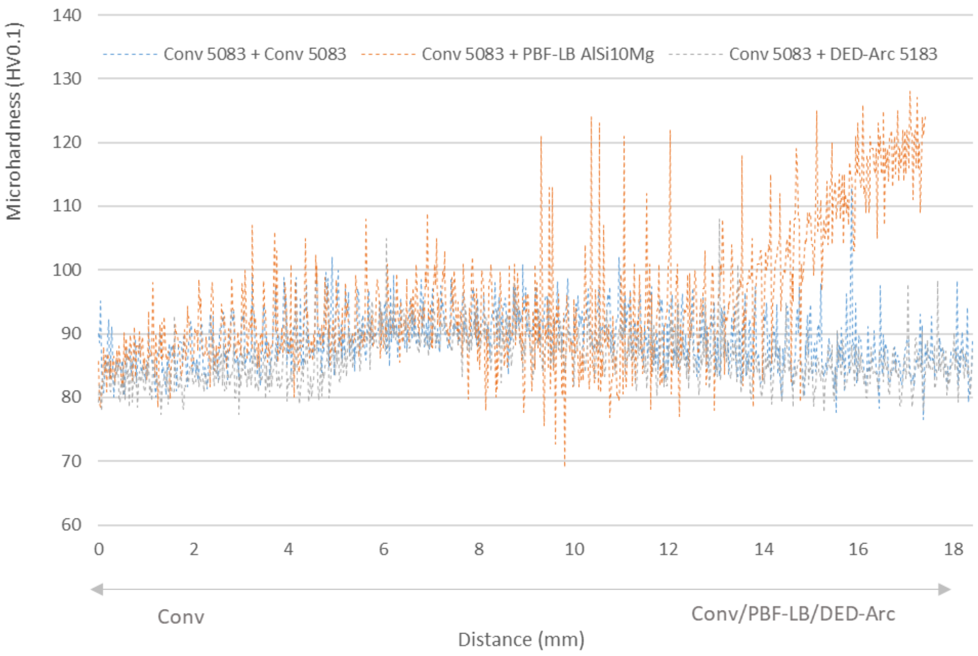
TMAZ: Highly deformed microstructure, subjected to elevated temperatures and deformation, with grains elongated in an upward-flowing pattern, compressed around the nugget due to the tool's forging action. In this region, recrystallization and grain coarsening are absent, likely because of insufficient deformation strain.

OR: More pronounced presence on the advancing side, due to the expectedly greater plastic deformation on the advancing size during the welding process.

WN: Fine grains resulting from the significant plastic deformation, friction heating, and subsequent dynamic recrystallization.

Evaluated Welding Processes and Conditions | Metallographic Examination - FSW

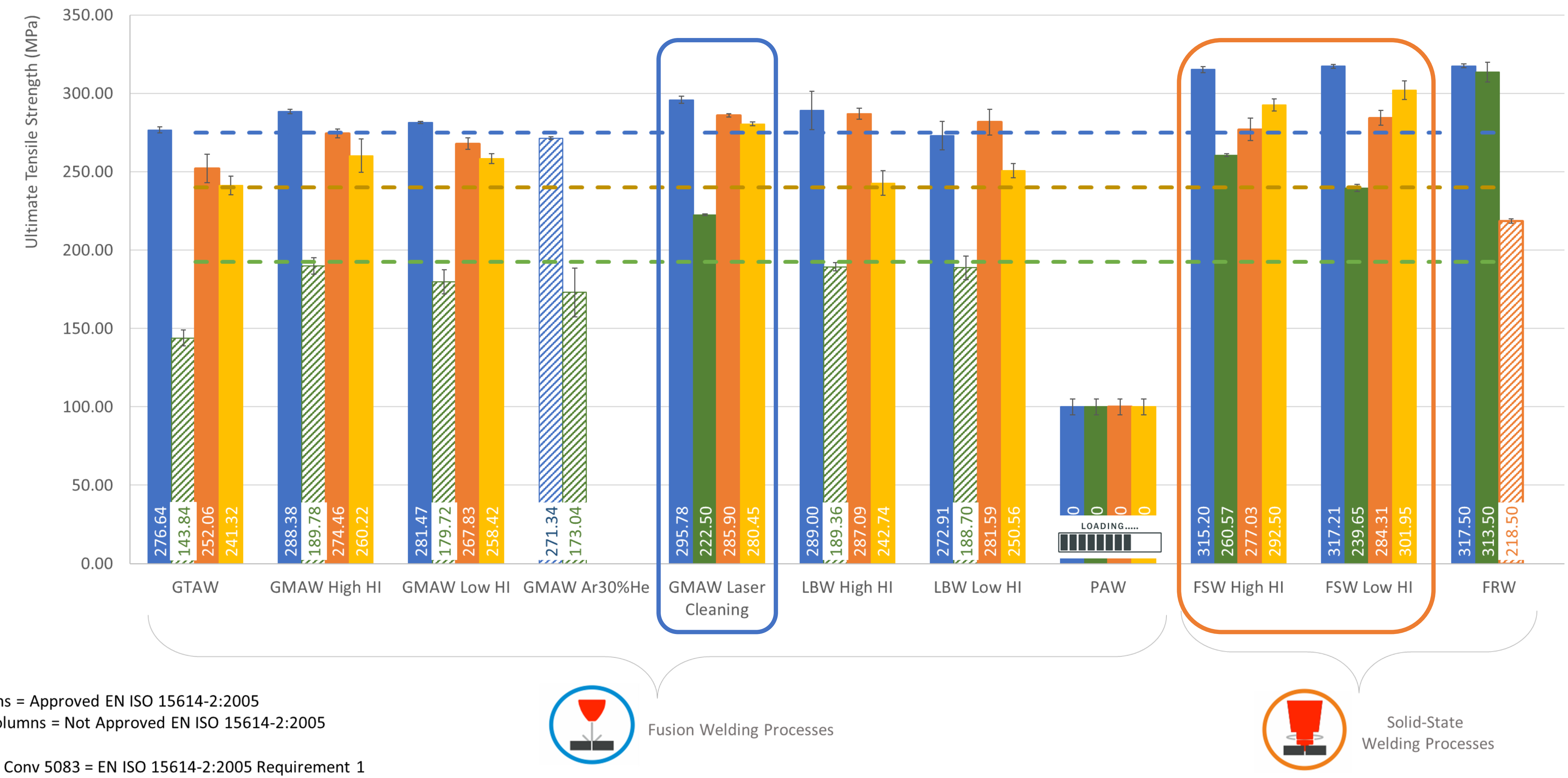




(Conv 5083 + PBF-LB AlSi10Mg)

The dissolution of the fine Si-network and coarsening of Si-particles induced by FSW are seen to be responsible for the reduction of hardness.

Evaluated Welding Processes and Conditions | Tensile Testing



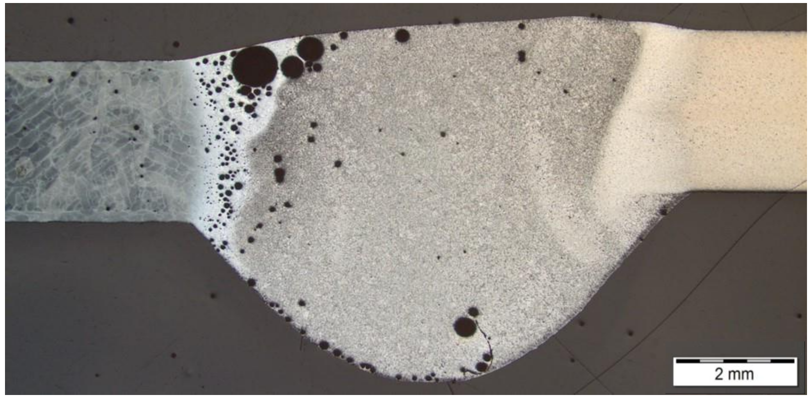
Solid Columns = Approved EN ISO 15614-2:2005
Non-solid Columns = Not Approved EN ISO 15614-2:2005

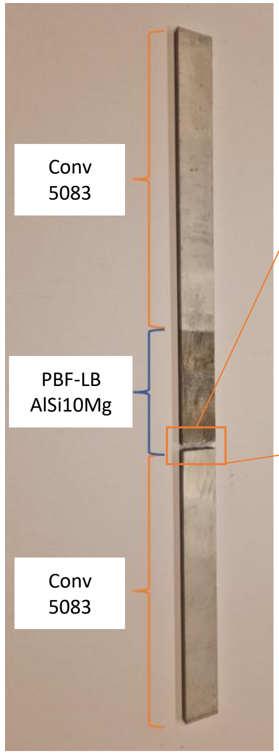
Conv 5083 + Conv 5083 = EN ISO 15614-2:2005 Requirement 1
Conv 5083 + PBF-LB AlSi10Mg = EN ISO 15614-2:2005 Requirement 2
Conv 5083 + DED-Arc 5183 = EN ISO 15614-2:2005 Requirement 3

Evaluated Welding Processes and Conditions | Bend Testing

Welding Process	Material A	Material B	Bend Testing Result
GMAW	Conv 5083	Conv 5083	Approved
	Conv 5083	PBF-LB ALSi10Mg	Not Approved
	Conv 5083	DED-Arc	Approved
GTAW	Conv 5083	Conv 5083	Approved
	Conv 5083	PBF-LB ALSi10Mg	Not Approved
	Conv 5083	DED-Arc	Approved
LBW	Conv 5083	Conv 5083	Approved
	Conv 5083	PBF-LB ALSi10Mg	Not Approved
	Conv 5083	DED-Arc	Approved
PAW	Conv 5083	Conv 5083	Approved
	Conv 5083	PBF-LB ALSi10Mg	Not Approved
	Conv 5083	DED-Arc	Approved
FSW	Conv 5083	Conv 5083	Approved
	Conv 5083	PBF-LB ALSi10Mg	Approved
	Conv 5083	DED-Arc	Approved
FRW	Conv 5083	Conv 5083	Approved
	Conv 5083	PBF-LB ALSi10Mg	Approved
	Conv 5083	DED-Arc	Approved

EN ISO 15614-1





Main factor for strength and ductility reduction:

High porosity level in HAZ near the PBF-LB part (Pore Belt Region)

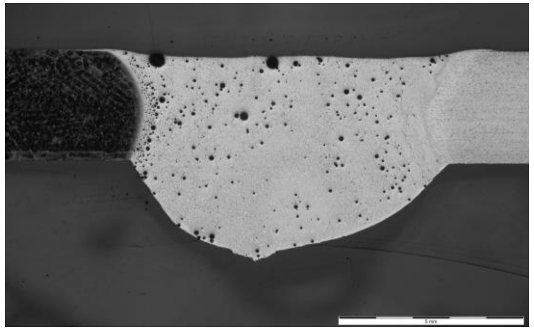
Conclusion and Final Remarks

- Different thermal cycles
- Different filler material form (wire/powder)
- Different microstructure
- Different mechanical (material) properties

Fusion Welding Processes

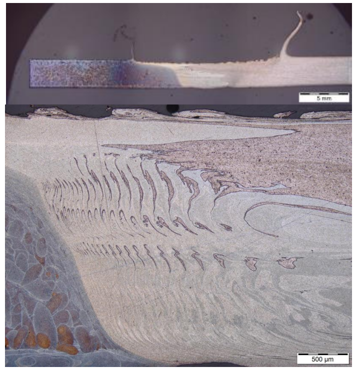
Solid-State Welding Processes

Welding of PBF-LB Al Alloy Parts



Arc Welding / LBW

FRW

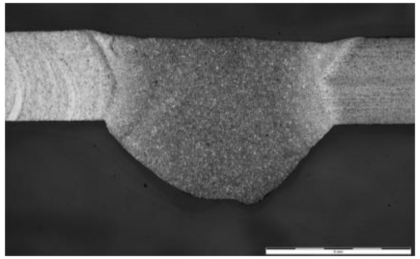


FSW

Weldability

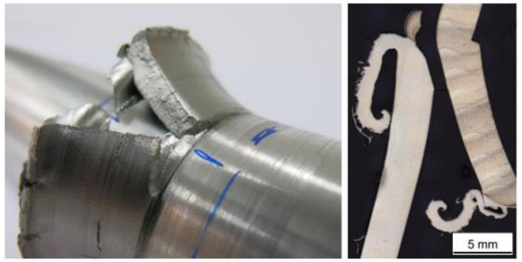
Welding of DED-Arc Al Alloy Parts

FSW



Arc Welding / LBW

FRW

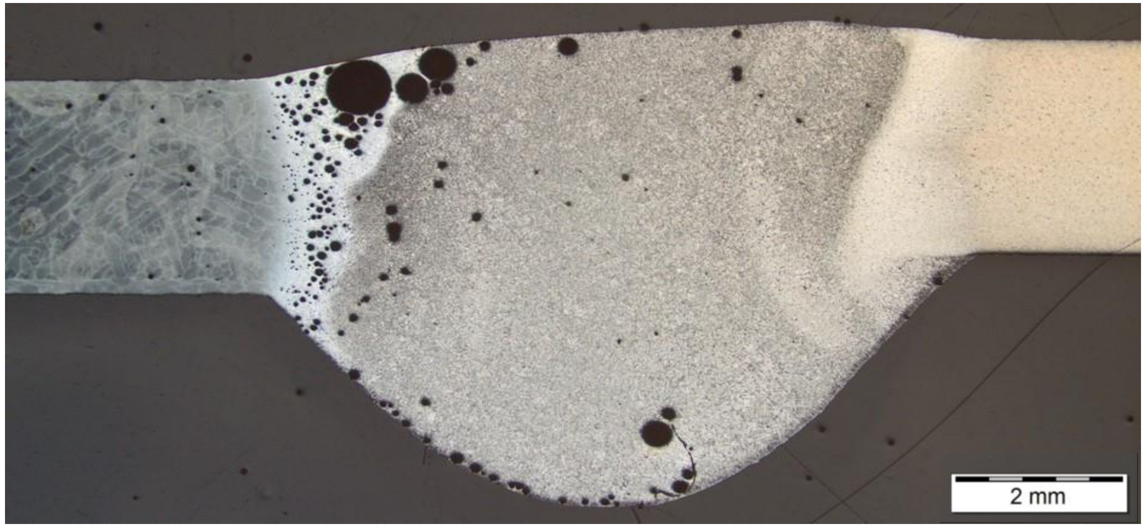


*Low weldability observed only during FRW
High mechanical properties achieved by FSW

Highest Weldability/Welding Quality for all Materials Combinations: FSW

Next Steps and Suggestions

- Plasma Arc Welding (PAW) experiments
- Mapping hardness (high porosity level samples?)
- Microstructure evolution via SEM analysis
- Computer Tomography analysis (Pore Belt Region)
- Tensile testing with DIC (elongation analysis)



ANY OTHER IDEAS?

Thank you for your attention!

Ing. Rafael Nunes
WAAM and Welding R&D

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rafael.nunes@bil-ibs.be

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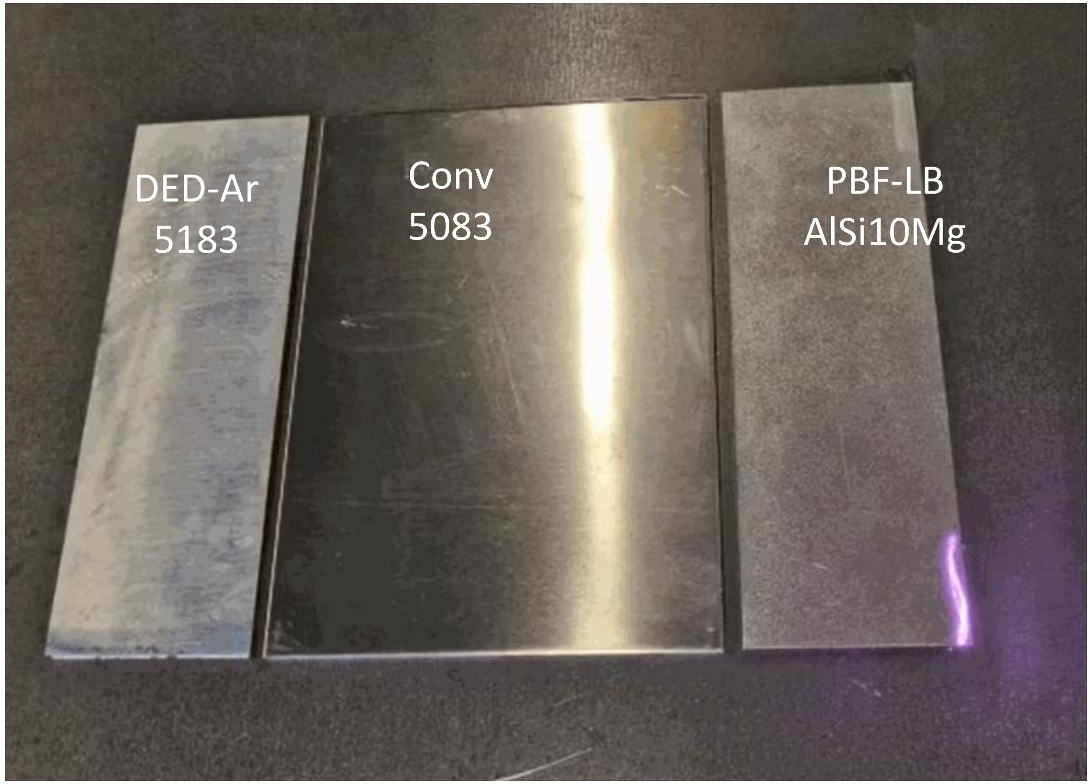
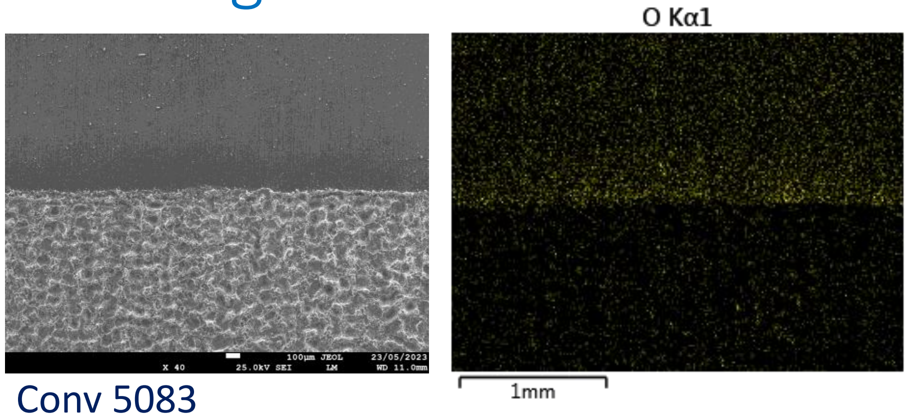
info@bil-ibs.be | www.bil-ibs.be

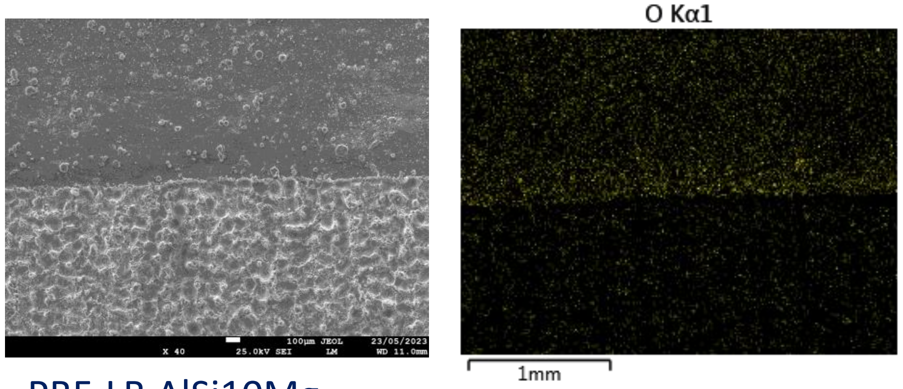
Weldability of AM Al Alloys | Laser Cleaning Prior to Welding

Siginificant reduction in the Oxygen Content (Al_2O_3 Oxyde Layer) in the 3 base materials:

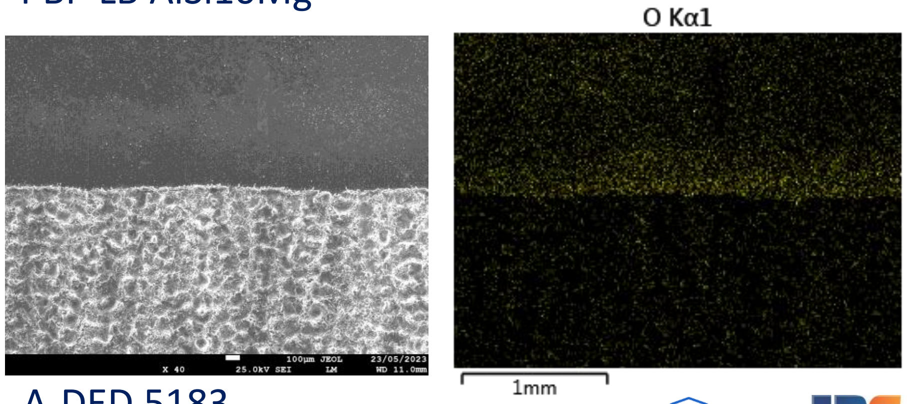




Conv 5083



PBF-LB AlSi10Mg



A-DED 5183

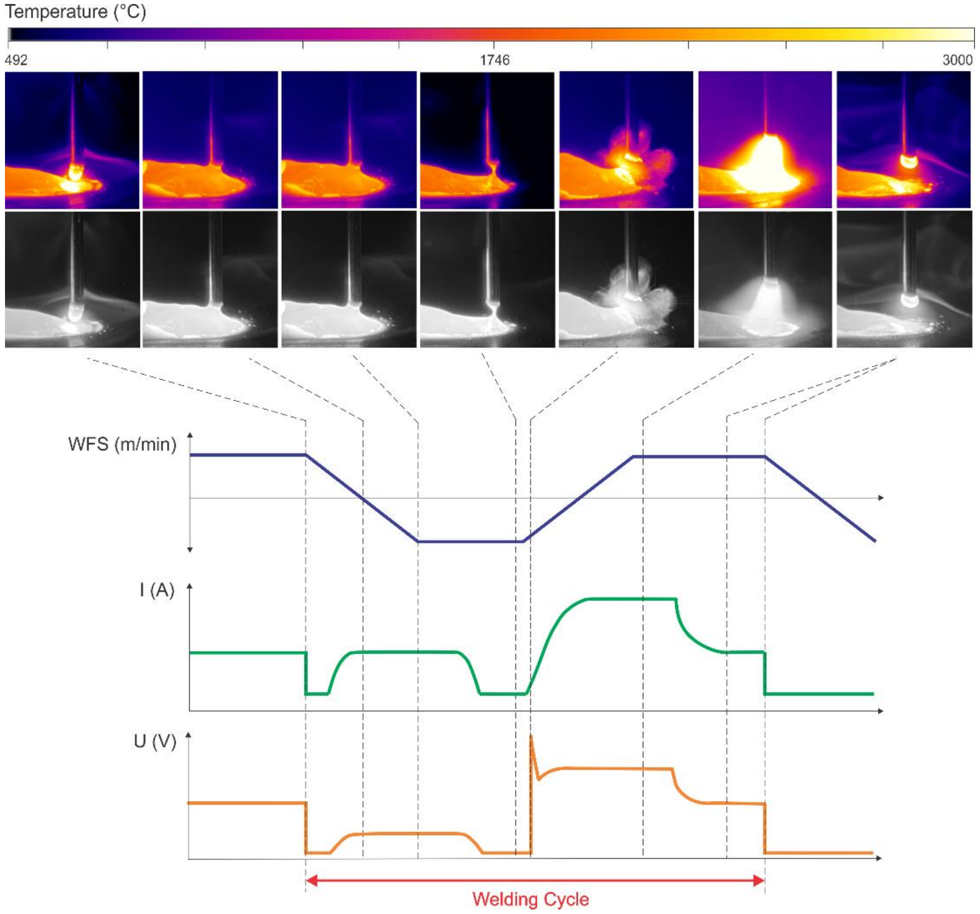
*No literature available showing the use of laser cleaning prior to the welding of AMed Al parts

*SEM analysis performed 1 day after the Laser cleaning

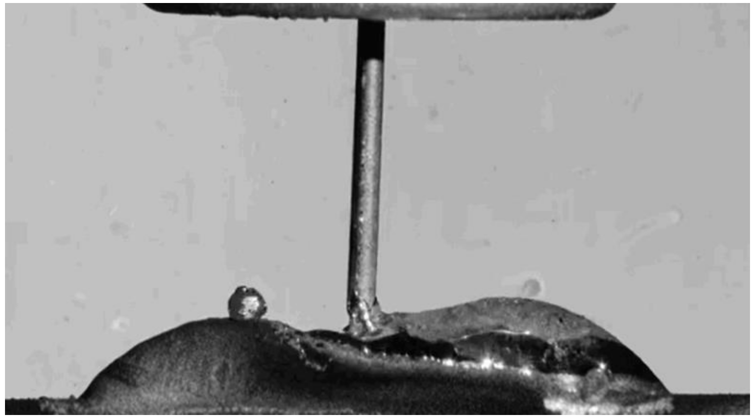
CMT Process: Cold Metal Transfer

“CMT process can deliver extremely low heat input and an extremely stable arc when compared to conventional MIG/MAG welding”

Fronius International GmbH (https://www.fronius.com/en/welding-technology/world-of-welding/fronius-welding-processes/cmt)



Cavitar Ltd – Visualization of a CMT Process
https://www.youtube.com/watch?v=sEaV3wfx8Hw



Dynamic Wire Feeding + Dedicated Current/Voltage Waveform for Specific Material

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

Enhancing Performance of Welded Additively Manufactured Aluminium Alloy Components Through Friction Stir Welding

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