The WAALU project is founded by Wallonie Recherche SPW – DG06, under Grant Number 02110224

The COAMWELD project is founded by VLAIO, under Grant Number HBC.2020.2994

Improving the Weldability and WAAM-Manufacturability of Aluminium Alloys by Laser Cleaning

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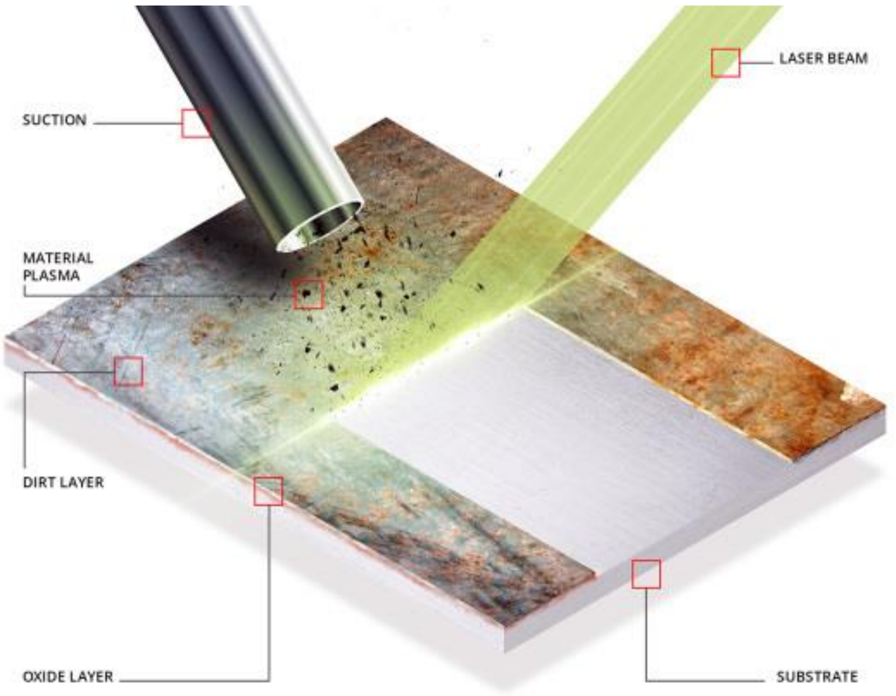
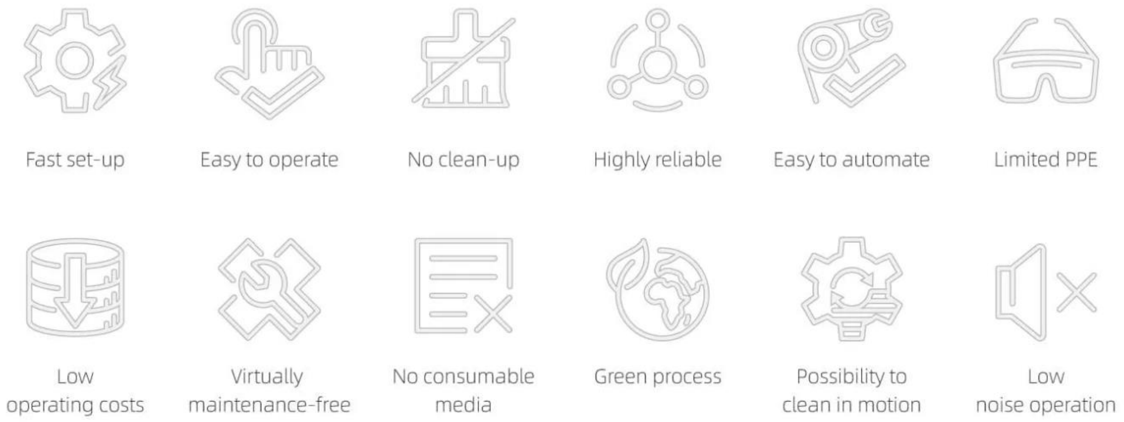
How Laser Cleaning Works?

Laser cleaning removes contaminants by vaporizing them into dust and fumes through laser ablation. When the laser beam hits the surface, part of its energy is absorbed by the metal surface, and the rest is reflected.

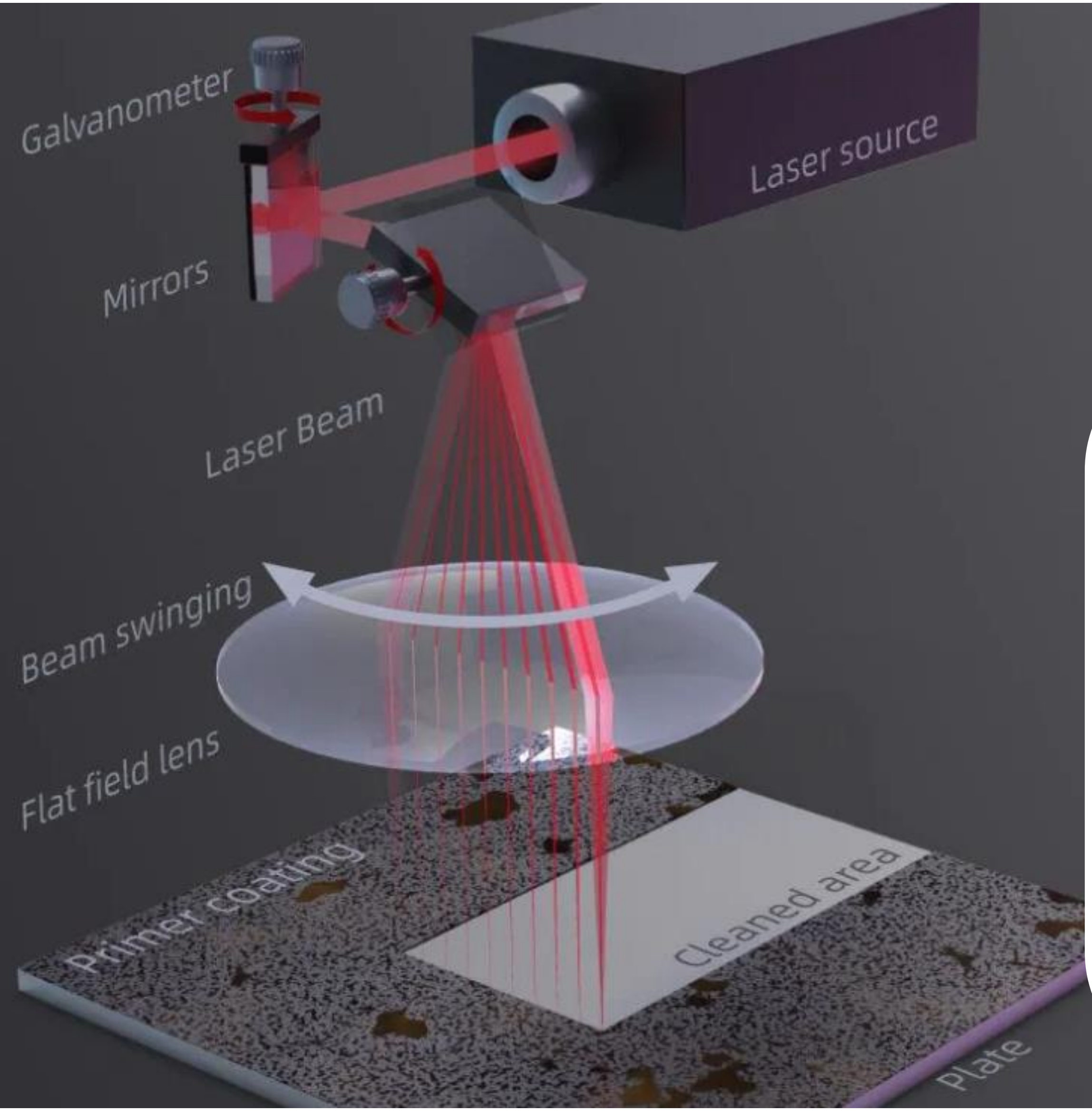


Examples of laser cleaning on metallic components (www.hq-star.com)



Main benefits of laser cleaning technology

How Laser Cleaning Works?

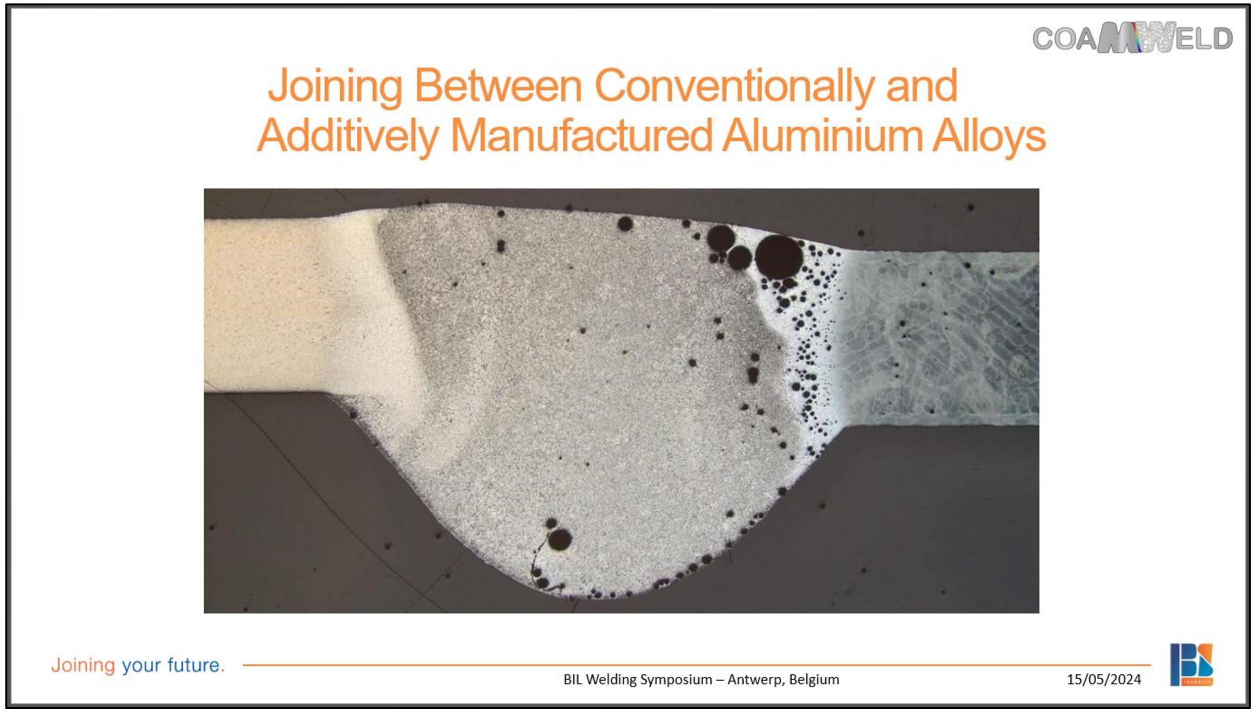


Multiple Scanning Modes

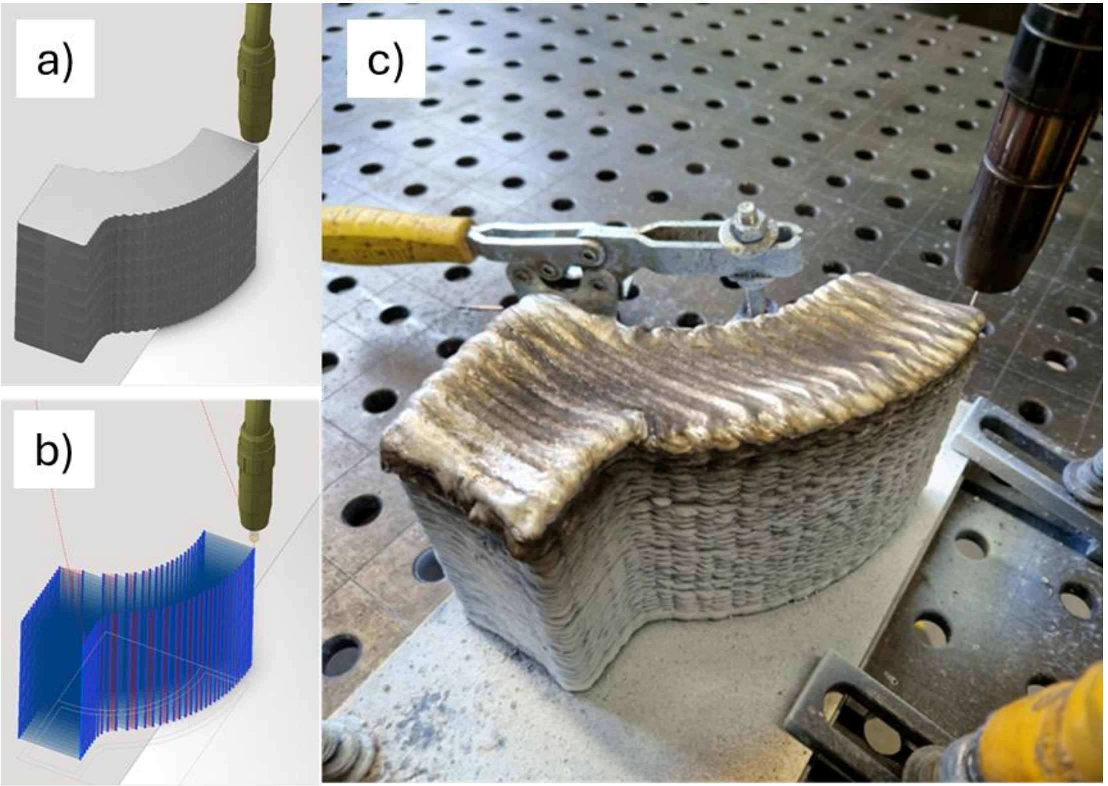
Main aspects of selected laser cleaning device (P-Laser QF-100):

- Typical AVG power: 95 – 100 – 105 W
- Typical Wavelength: 1055 – 1064 – 1075 nm
- Typical Pulse duration: 80 – 100 – 180 ns
- Typical Pulse Frequency: 5 – 100 – 500 kHz
- Focal Diameter: 75 – 85 µm

Improving the Weldability and WAAM-Manufacturability of Aluminium Alloys by Laser Cleaning



Additive Manufacturing of Aluminium Alloys (ER5183, ER2219, ER7075) by Wire Arc Additive Manufacturing



WAAM of Al Alloy Parts

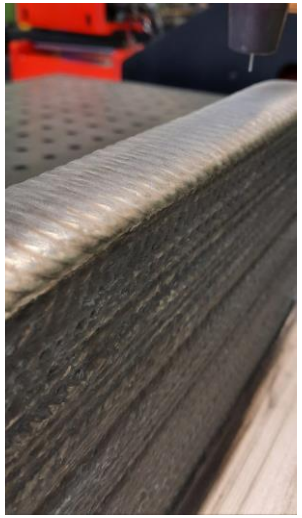
	Wall Numer	Final Dimensions	Filler Metal	Filler Metal Diameter (mm)	Shielding Gas	Deposition Path Strategy	Cleaning Method	Main Purpose / Comment
1	Wall 01	170 x 10 x 100 mm3	ER 5183	1.2	Ar	Straight Lines	No Cleaning	Basic Evaluation
	Wall 02	300 x 35 x 150 mm3	ER 5183	1.2	Ar	Weaving	No Cleaning	Basic Evaluation
2	Wall 03	300 x 35 x 150 mm3	ER 2219	1.2	Ar	Weaving	No Cleaning	Basic Evaluation
	Wall 04	300 x 35 x 150 mm3	ER 2219	1.2	Ar	Weaving	No Cleaning	PWHT Comparison
1	Wall 05	300 x 35 x 150 mm3	ER 5183	1.2	Ar 30% He	Weaving	No Cleaning	Shielding Gas Comparison
	Wall 06	300 x 35 x 150 mm3	ER 5183 (MIGAL)	1.2	Ar	Weaving	No Cleaning	Wire Quality Comparison
3	Wall 07	200 x 35 x 60 mm3	ER 5183	1.2	Ar	Weaving	Laser Cleaning	(With) Laser Cleaning Comparison
	Wall 08	200 x 35 x 60 mm3	ER 5183	1.2	Ar	Weaving	Laser Cleaning	(Without) Laser Cleaning Comparison
	Wall 09	200 x 35 x 60 mm3	ER 2219	1.2	Ar	Weaving	Laser Cleaning	(With) Laser Cleaning Comparison
	Wall 10	200 x 35 x 60 mm3	ER 2219	1.2	Ar	Weaving	Laser Cleaning	(Without) Laser Cleaning Comparison
4	Wall 11	60 x 10 x 50 mm3	ER 7075	1.6	Ar	Straight Lines	No Cleaning	Exploratory Test with ER 7075 1.6mm
	Wall 12	200 x 35 x 20 mm3	ER 7075	1.2	Ar	Weaving	No Cleaning	Exploratory Test with ER 7075 1.2mm
	Wall 13	140 x 12 x 45 mm3	ER 7075	1.6	Ar	Straight Lines	No Cleaning	Exploratory Test with ER 7075 1.6mm

1 Evaluation of Selected WAAM Parameters and Conditions | ER 5183

2 Post Welding Heat Treatment (PWTH) Optimization | ER 2219

3 Laser Cleaning During WAAM | ER 5183 and ER 2219

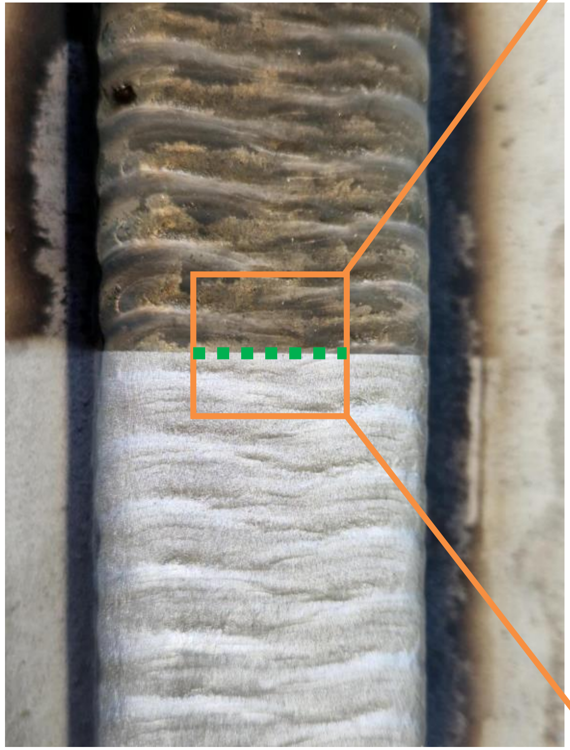
4 Exploratory Tests with 7xxx | ER 7075

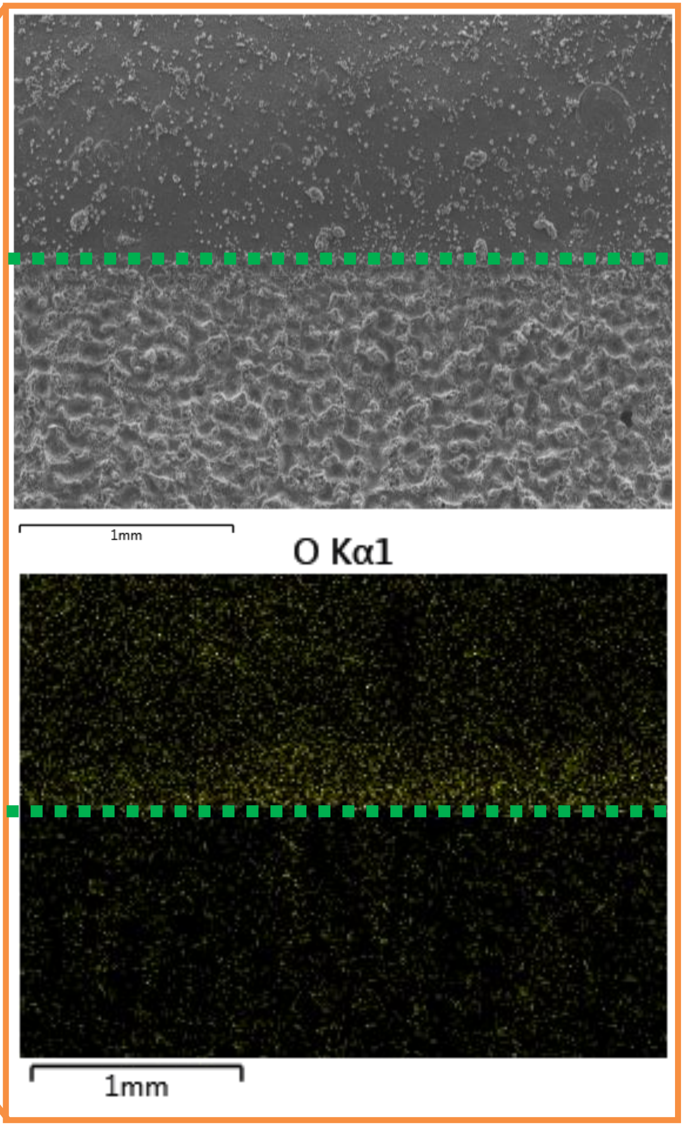


WAAM of Al Alloy Parts | Laser Cleaning

*SEM analysis performed 1 day after the Laser cleaning

Applicability of Cleaning Methods during printing



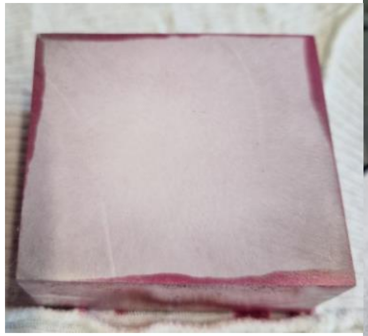


Performing of Laser cleaning between every layer:

- Approximately cleaning time: 3 min 30 s
- Dwell Time: 4 min

*No literature available showing the use of laser cleaning of aluminium alloys in WAAM manufacturing

Laser Cleaning During WAAM | ER 5183 and ER 2219



Wall 07

ER 5183
200 x 35 x 60 mm3
With Laser Cleaning between layers

Wall 08

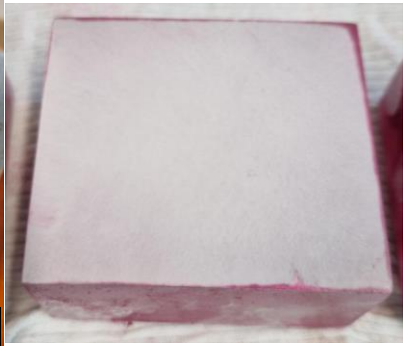
ER 5183
200 x 35 x 60 mm3
Without Laser Cleaning between layers

Wall 09

ER 2219
200 x 35 x 60 mm3
With Laser Cleaning between layers

Wall 10

ER 2219
200 x 35 x 60 mm3
Without Laser Cleaning between layers

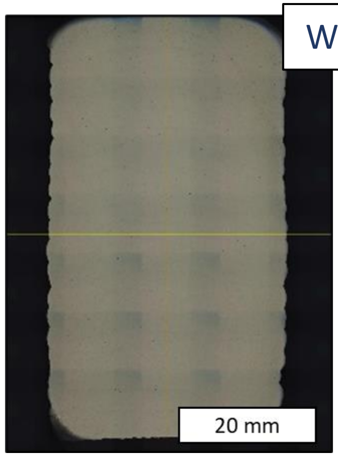


Laser Cleaning During WAAM |ER 5183 and ER 2219

Metallographic Examination

Wall 07

ER5183 with laser cleaning



ER5183 without laser cleaning

Wall 08

EN ISO 10042:2015
Quality Level B

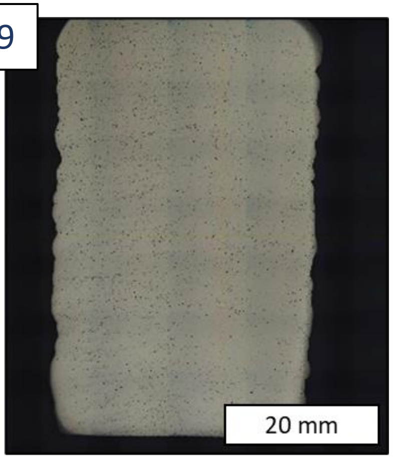
Porosity level:

Wall 07 – With Laser Cleaning: 0.17 %

Wall 08 – Without Laser Cleaning: 0.06 %

ER2219 with laser cleaning

Wall 09



Porosity level :

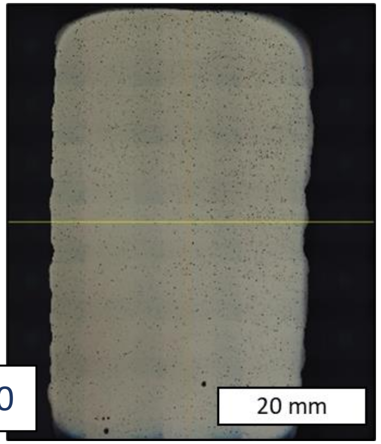
Wall 09 – With Laser Cleaning: 2.98 %

Wall 10 – Without Laser Cleaning: 2.79 %

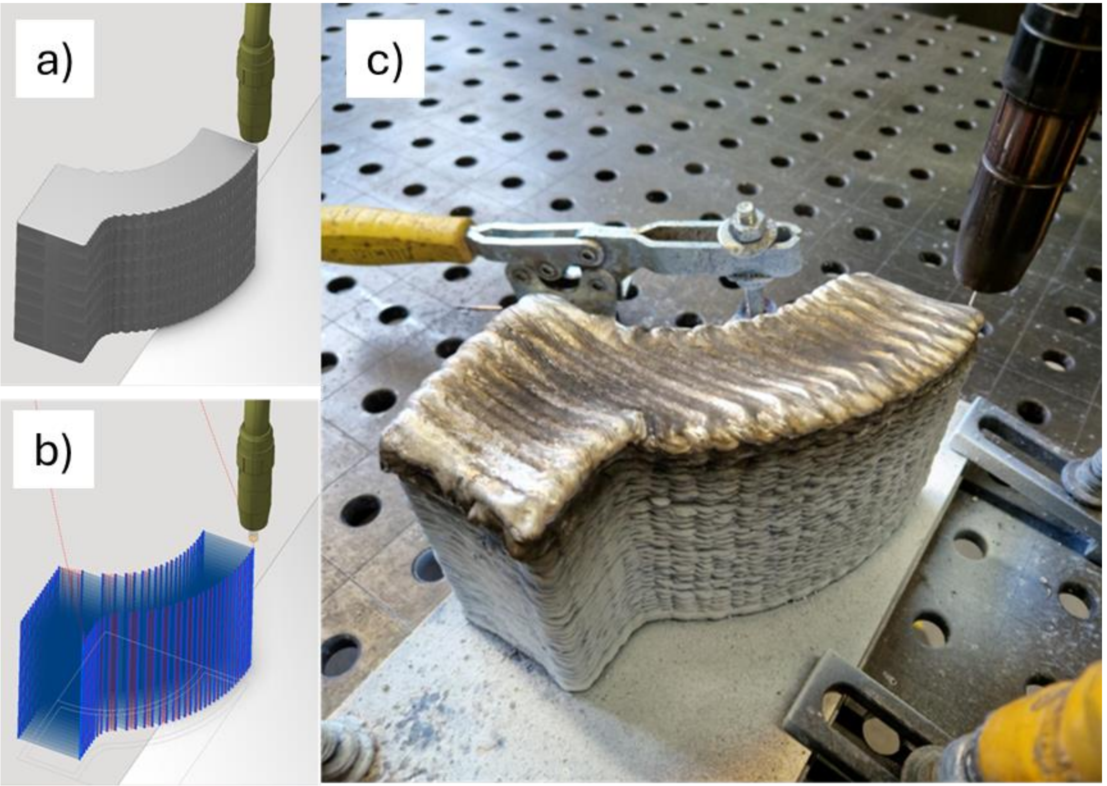
EN ISO 10042:2015
Quality Level C

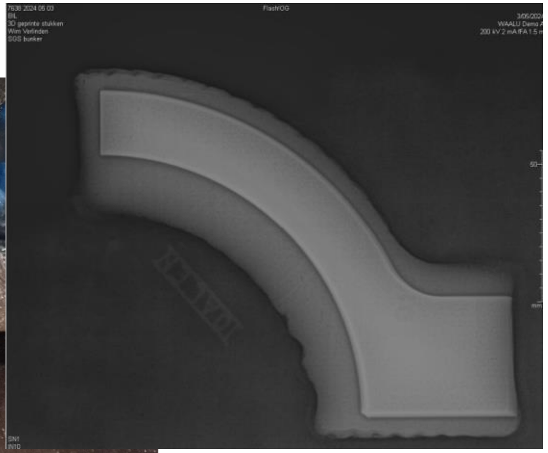
ER2219 without laser cleaning

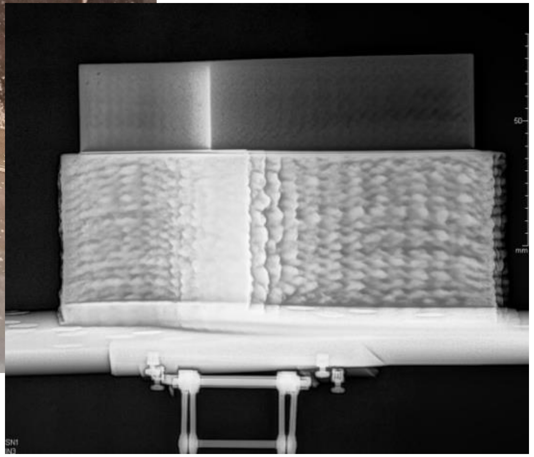
Wall 10



WAAM of Al Alloys | Demonstrator Manufacturing





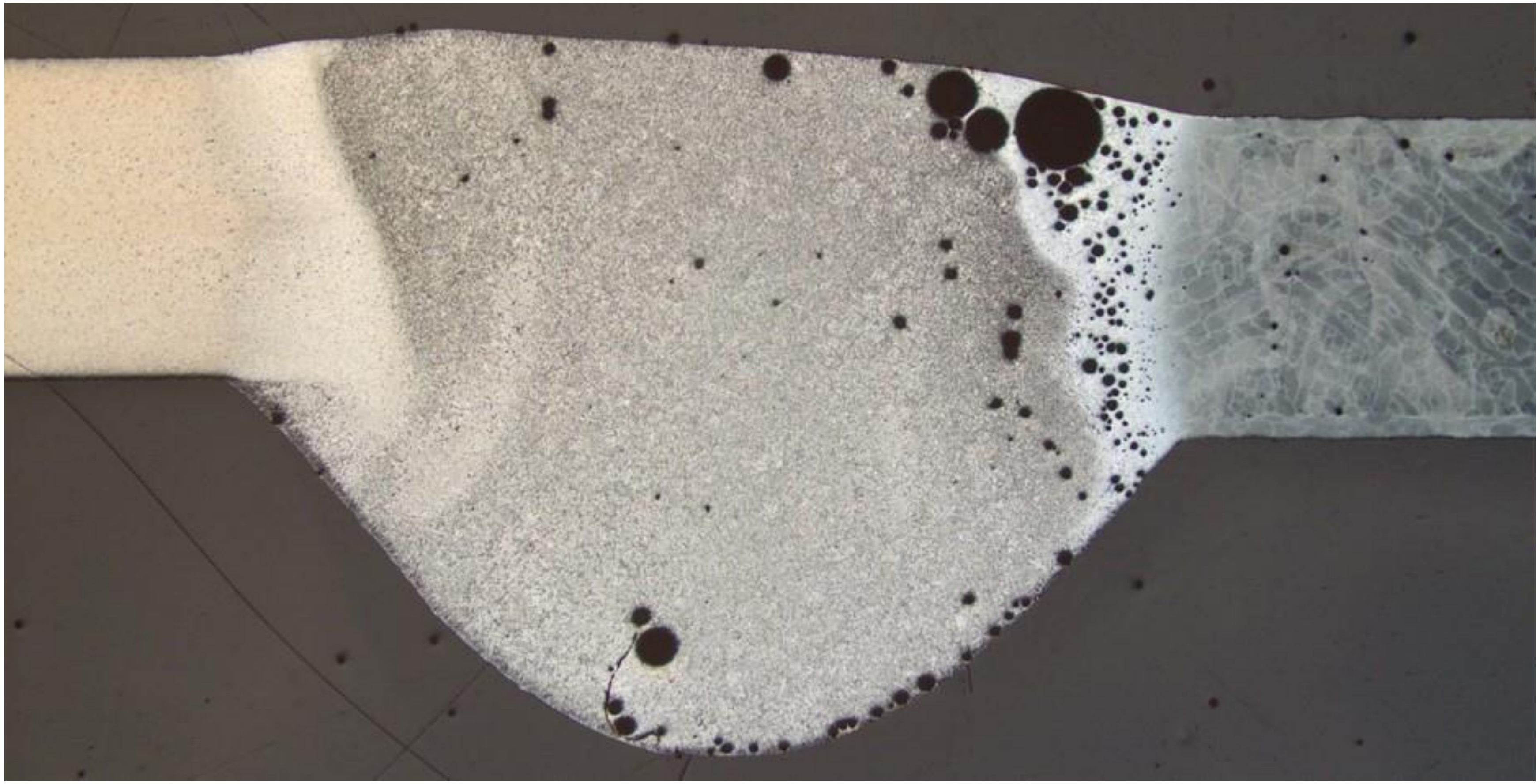


Exploratory demonstrator manufacturing with ER 5183 Al-alloy

Next steps:

1. X-Ray evaluation
2. Computed tomography evaluation
3. Mechanical testing (after PWTH for ER2219)
4. Laser cleaning during WAAM manufacturing of ER 7075 alloy

Joining Between Conventionally and Additively Manufactured Aluminium Alloys



Current Status of the Art | Weldability of AM-ed Al Alloy Parts

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

19 articles (49 %) evaluating fusion welding processes

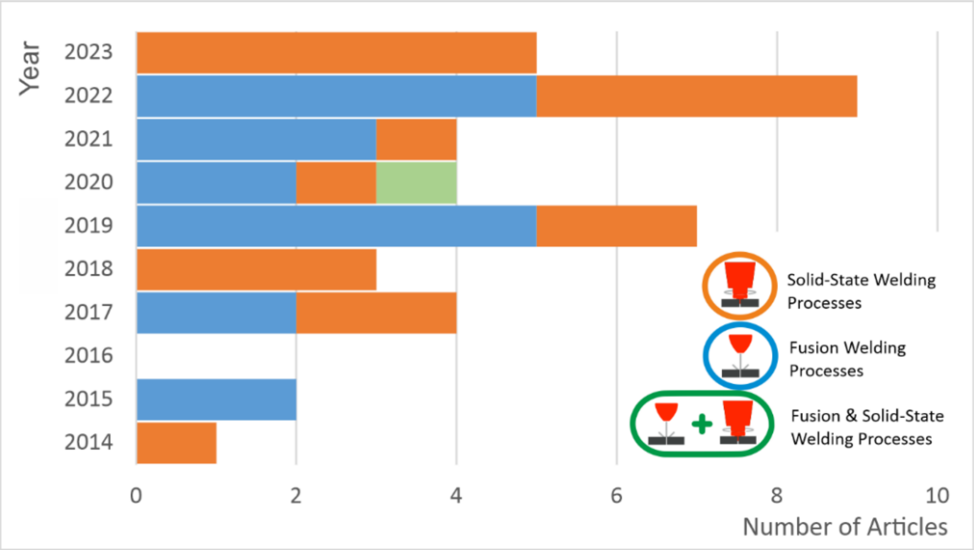
- 18 articles evaluating PBF-LB parts and 1 article evaluating DED-Arc (DED-Arc) parts
- 14 articles evaluating LBW
- 4 article evaluating EBW
- 3 articles evaluating GTAW

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

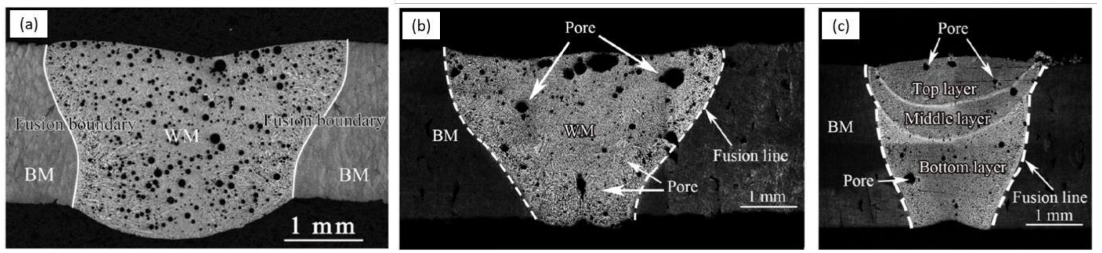

metals

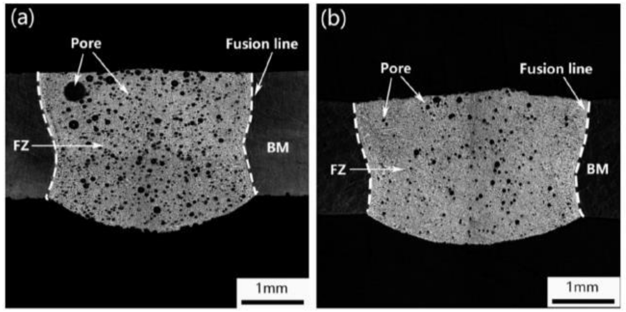
Review

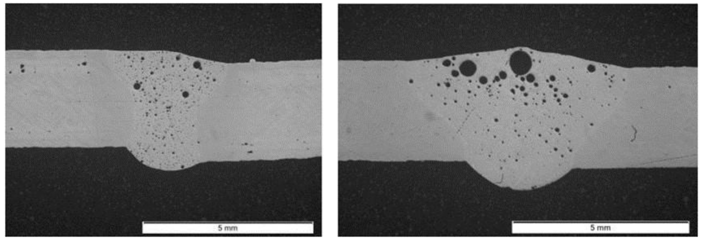
A Review on the Weldability of Additively Manufactured Aluminium Parts by Fusion and Solid-State Welding Processes

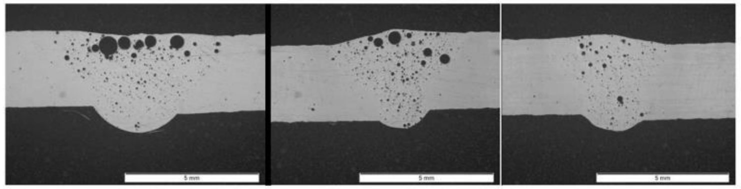
R. Nunes *et al.* **A Review on the Weldability of Additively Manufactured Aluminium Parts by Fusion And Solid-State Welding Processes**. Metals. Vol 13(10), 2023.
https://doi.org/10.3390/met13101724

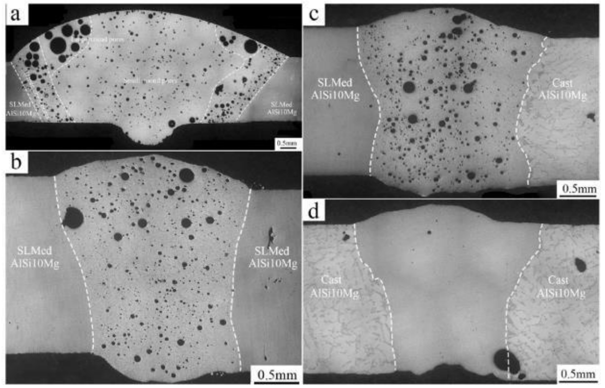
Current Status of the Art | Weldability of AM-ed Al Alloy Parts

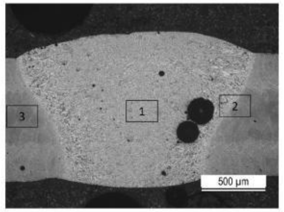


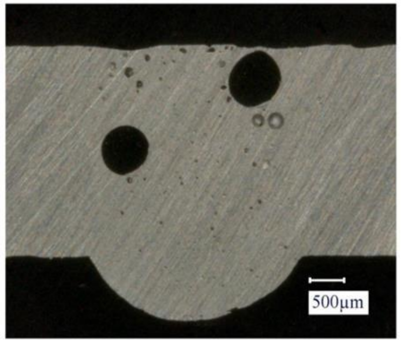


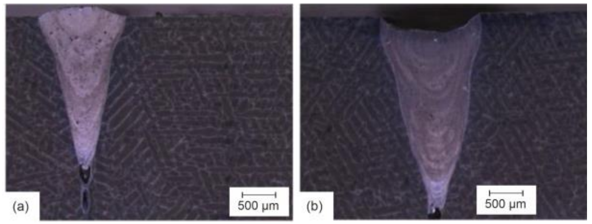












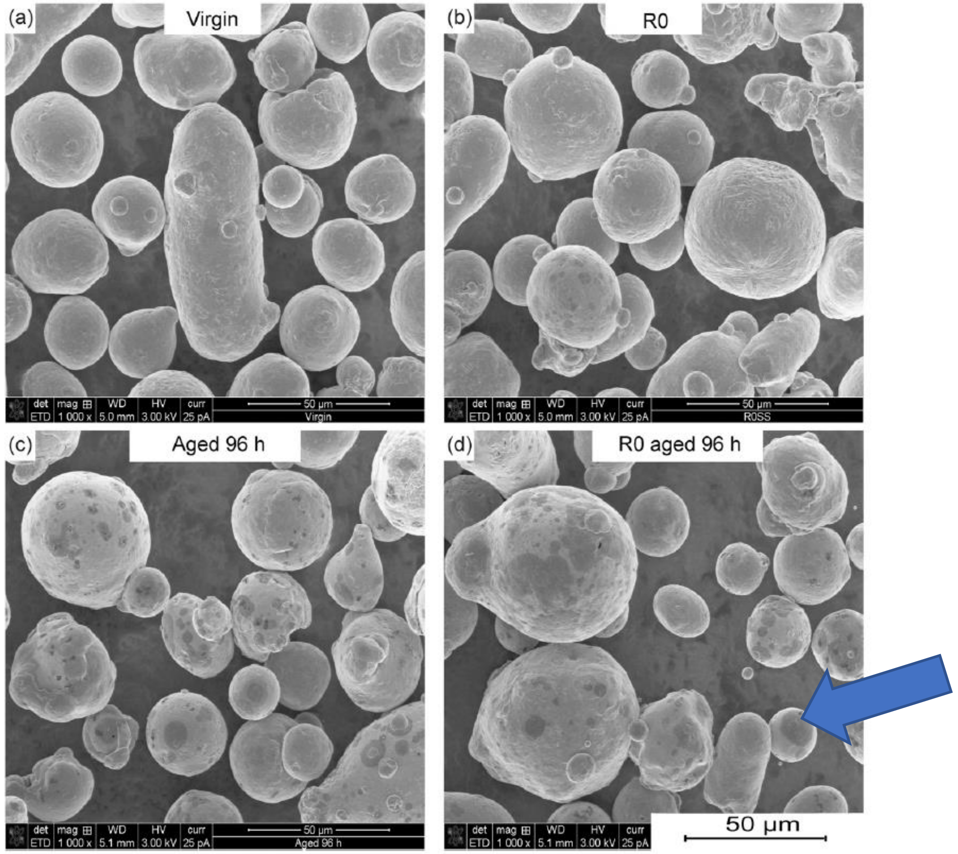
Unlikely the porosity can be entirely avoided by optimization of welding parameters,
Other fusion welding processes are likely to suffer from porosity issues.

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

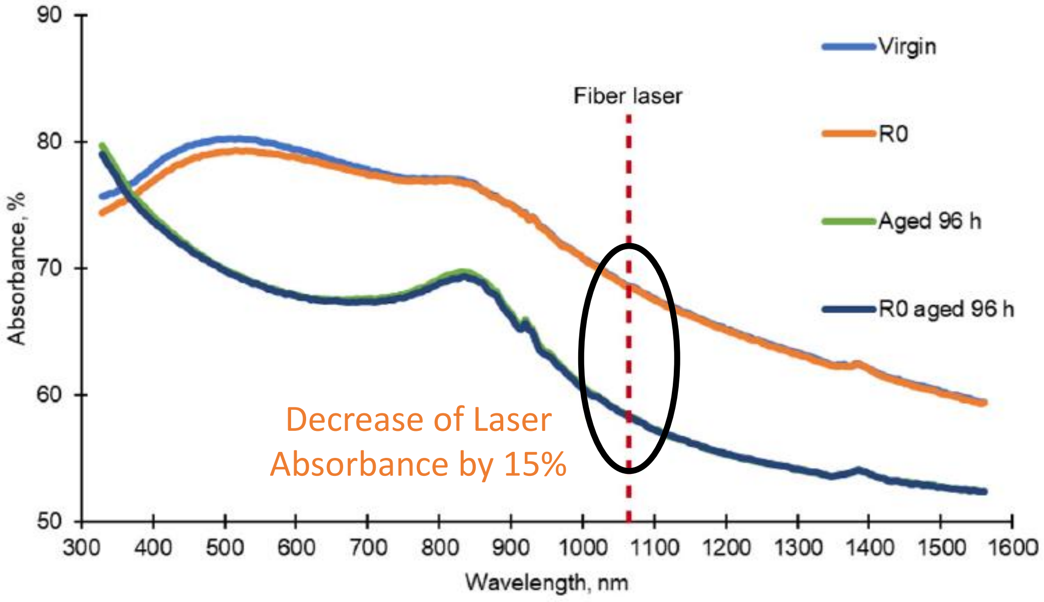
- Higher surface area to volume ratio compared to wire filler material
- Most commercial equipment control is based on O_2 content (not by creating a vacuum and then filling it with Ar)
- Common to recycle powder in the PBF-LB process.

Current Status of the Art | Weldability of AM-ed Al Alloy Parts

Particle Morphology, Porosity and Surface Oxidation



Morphology and surface oxidation condition of new and recycled AlSi10Mg powder

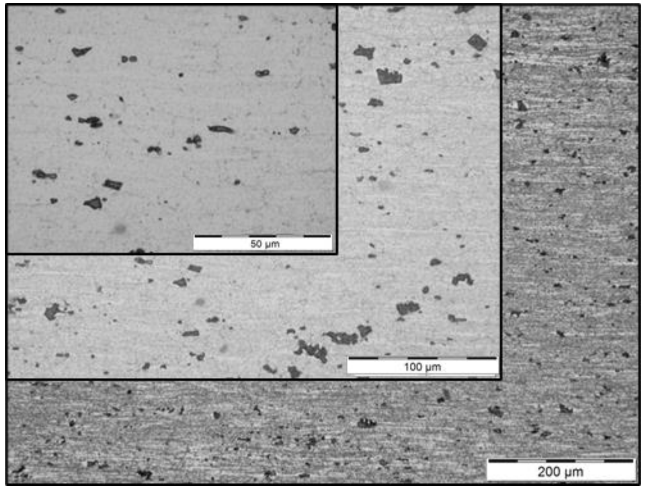


Powder state	Average laser light absorbance [%]
Virgin	68.55 (±0.10)
R0	68.48 (±0.09)
Aged 96 h	58.23 (±0.13)
R0 aged 96 h	58.13 (±0.09)

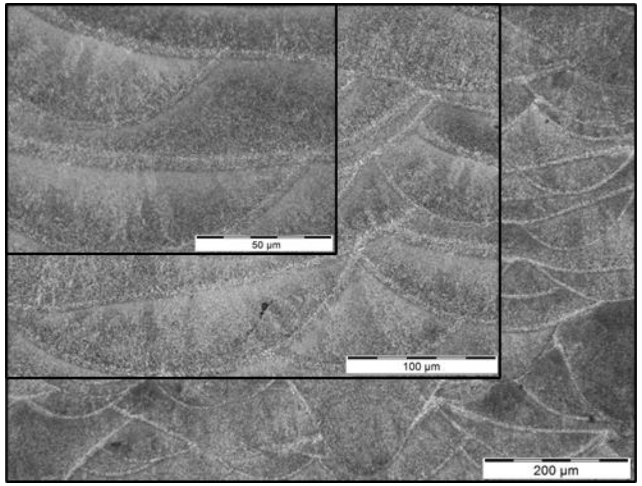
Fedina, T. *et al.* Influence of AlSi10Mg Powder Aging on the Material Degradation and its Processing in Laser Powder Fusion. Powder Technology 412 (2022) https://doi.org/10.1016/j.powtec.2022.118024

Base Materials

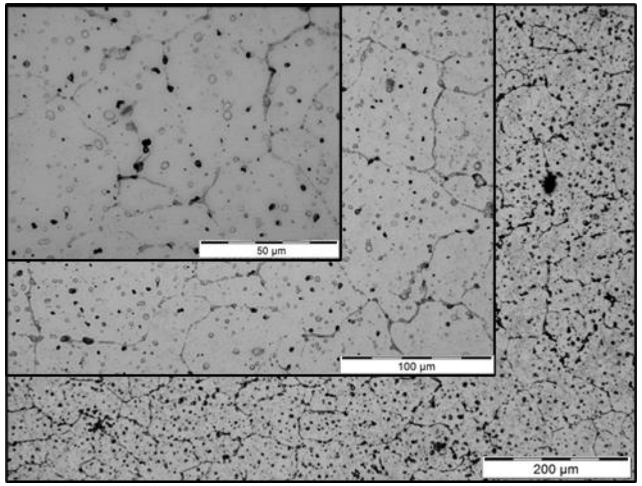
CONV 5083 Longitudinal



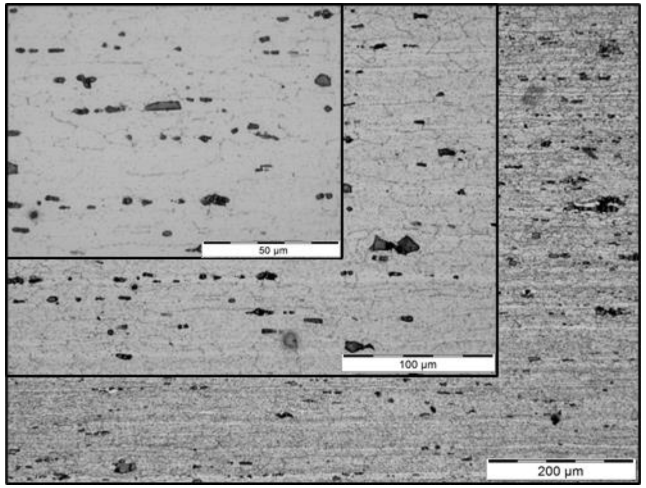
PBF-LB AlSi10Mg PBD



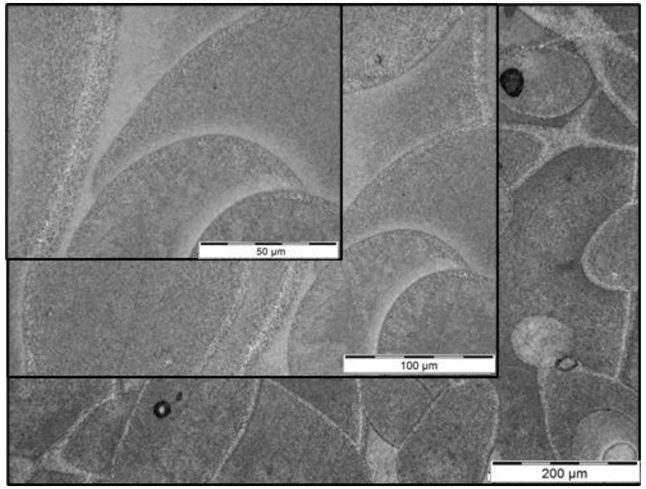
DED-Arc 5183 PBD



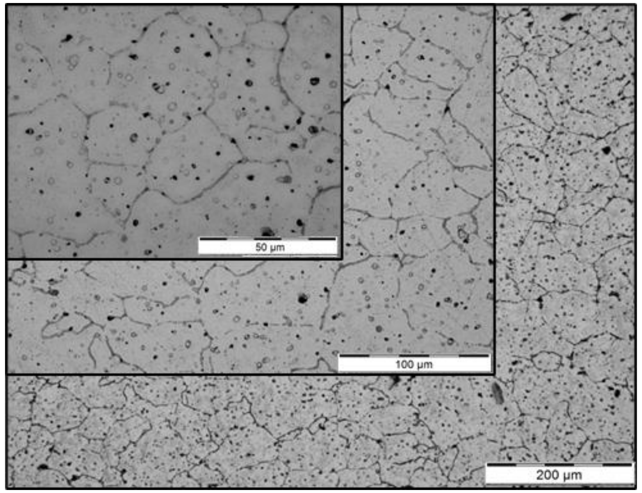
CONV 5083 Transversal



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

Metallographic Examination

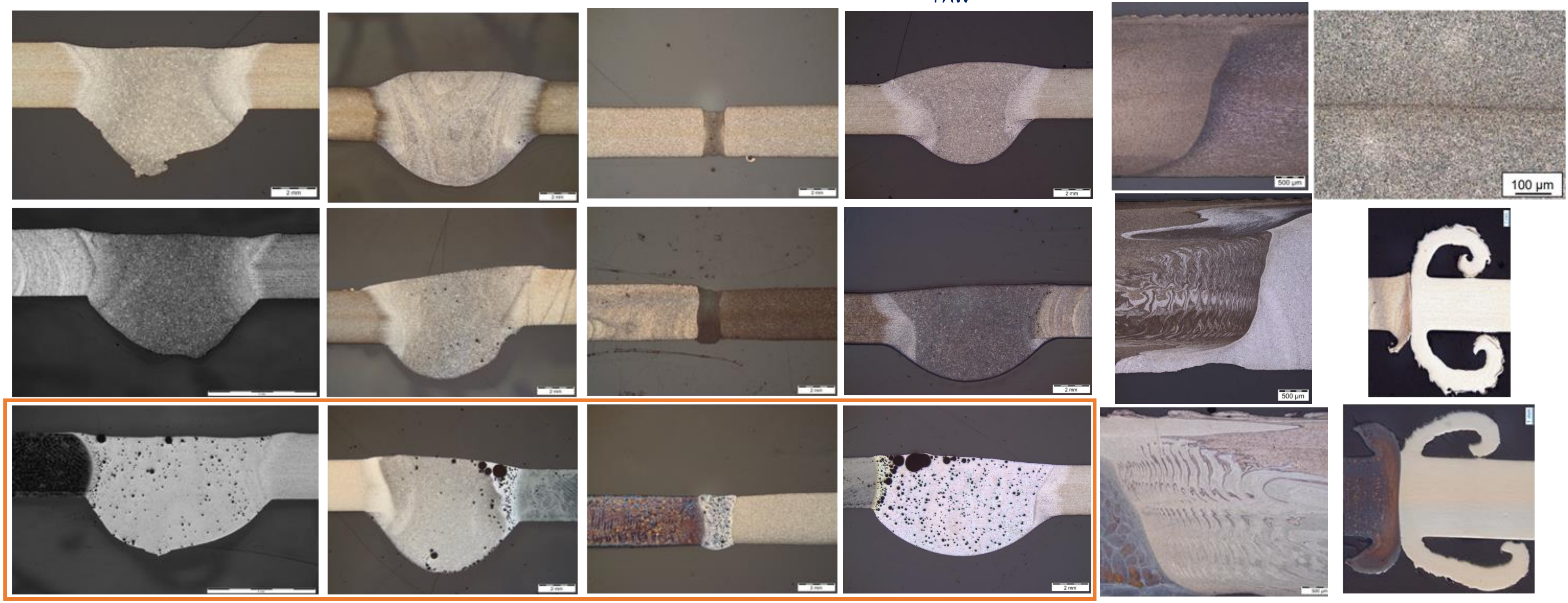
COAMWELD

GMAW | GTAW | LBW | PAW | FSW | FRW

Conv 5083 / Conv 5083

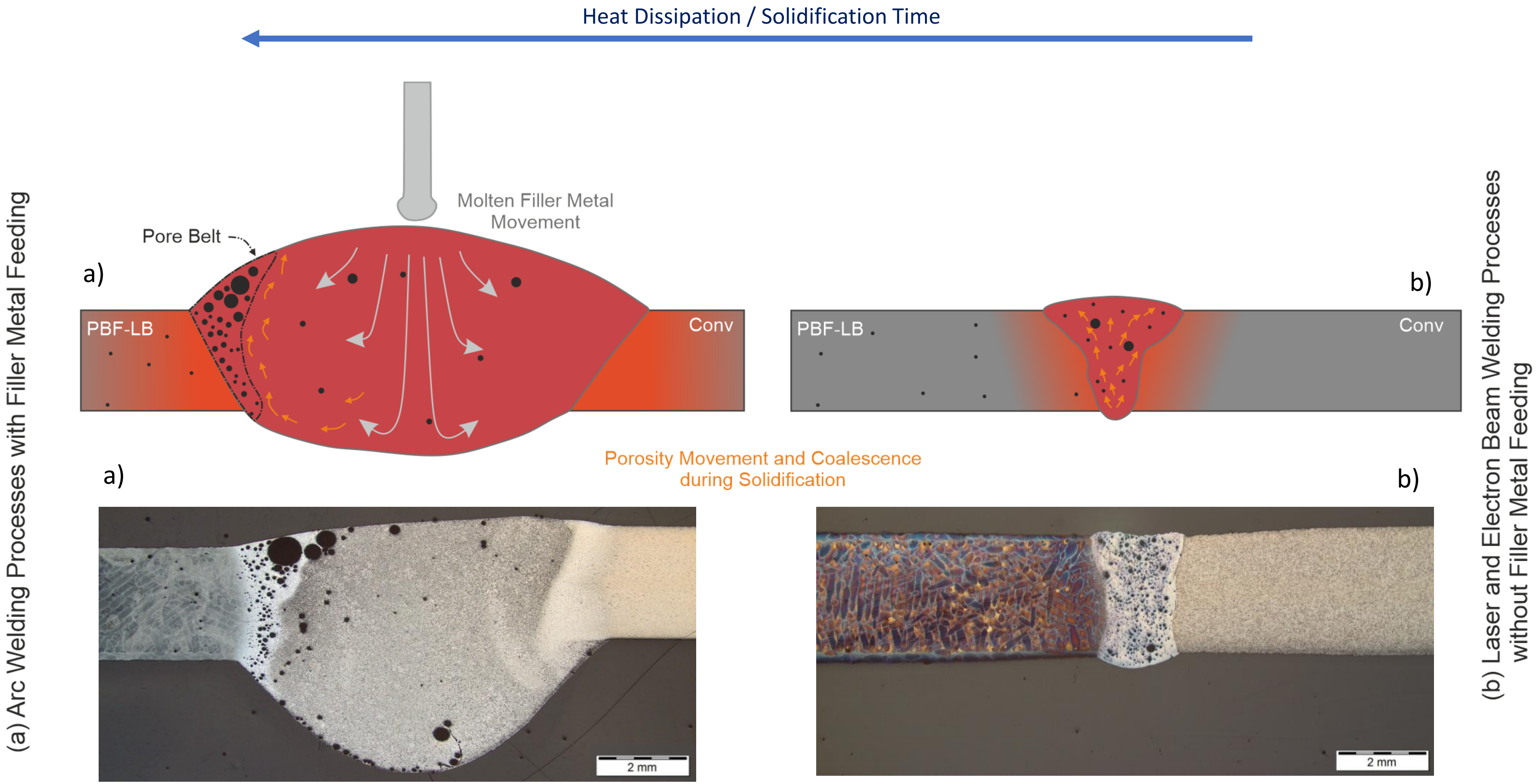
Conv 5083 / WAAM ER 5183

Conv 5083 / PBF-LB AlSi10Mg



High Porosity Level

Evaluated Welding Processes and Conditions | Pore Belt Region



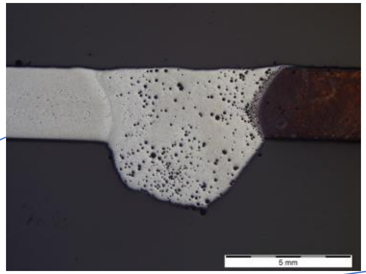
Evaluated Welding Processes and Conditions

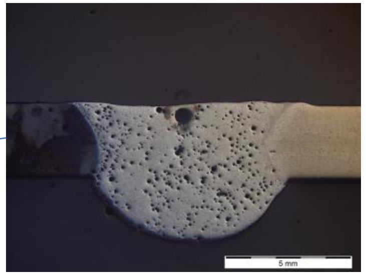
Fusion Welding Processes

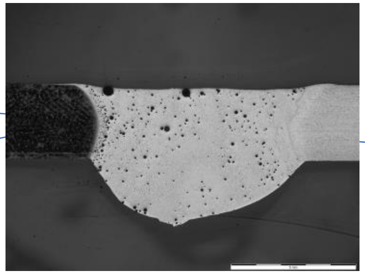
- GMAW Process:
  - Filler Metal Quality Influence
  - Heat Input Influence
  - Shielding Gas Composition Influence
  - Laser Cleaning Prior to Welding
- GTAW Process
- PAW Process
- LBW Process:
  - Heat Input Influence

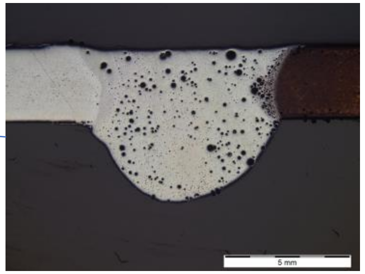
Solid-State Welding Processes

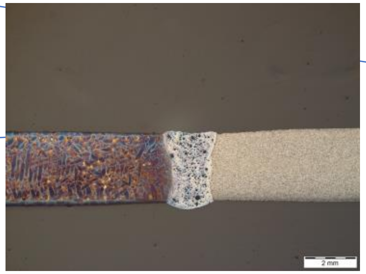
- FSW Process:
  - Heat Input Influence
- FRW Process

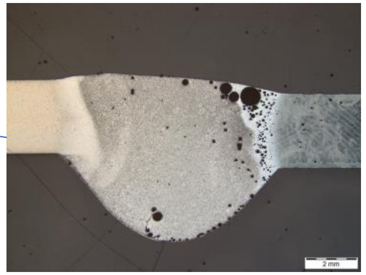


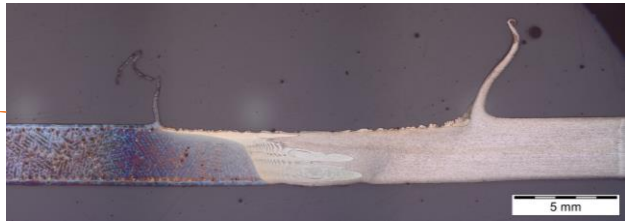






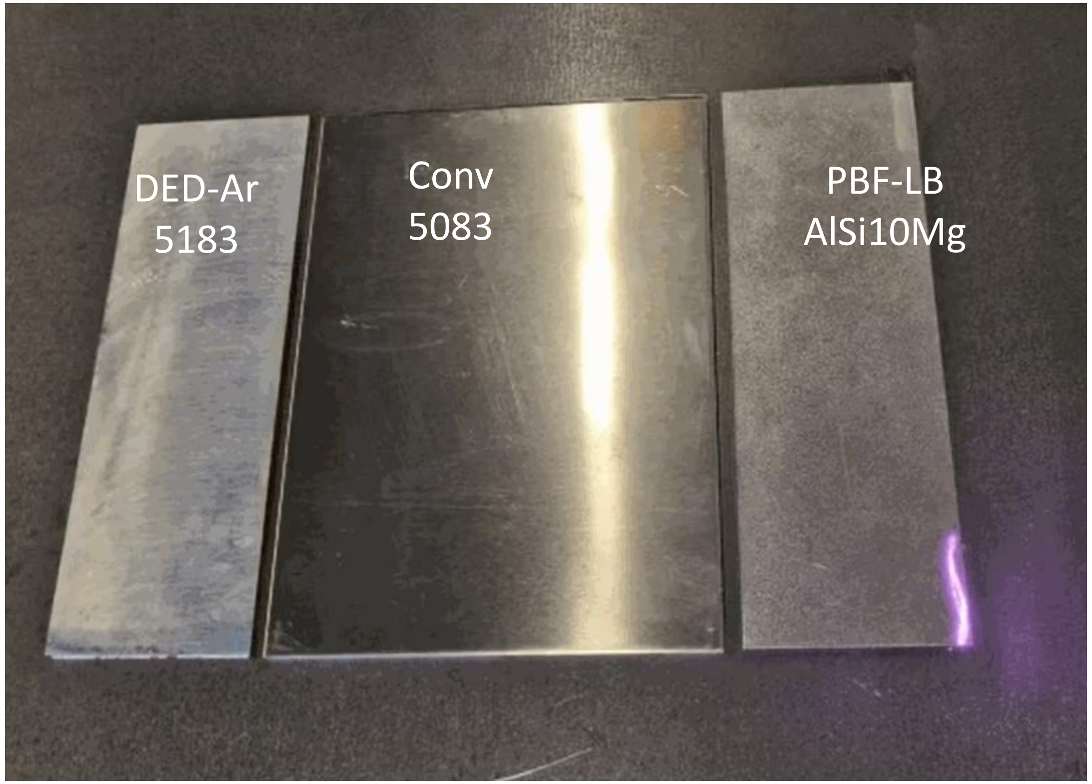




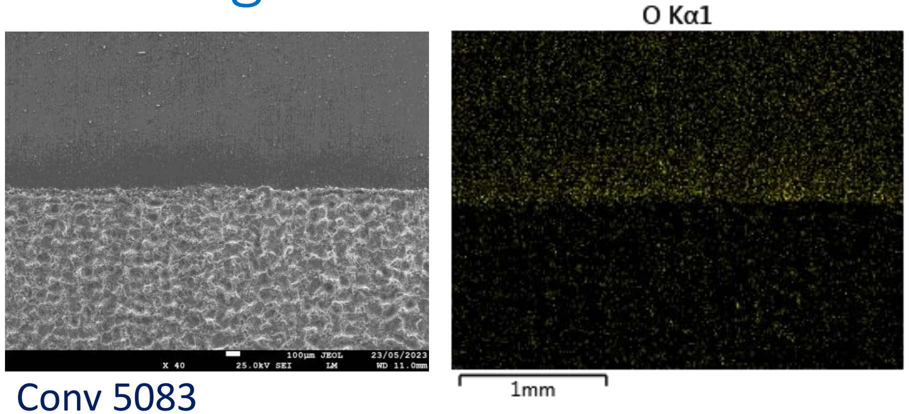


Weldability of AM Al Alloys | Laser Cleaning Prior to Welding

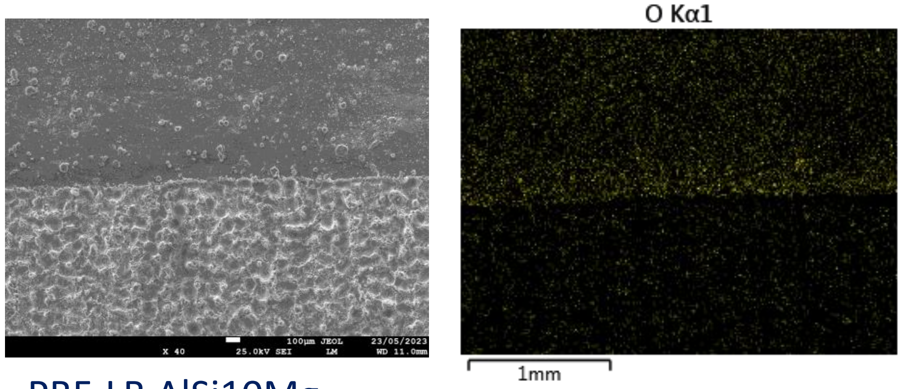
➡ Siginificant reduction in the Oxygen Content (Al_2O_3 Oxyde Layer) in the 3 base materials:



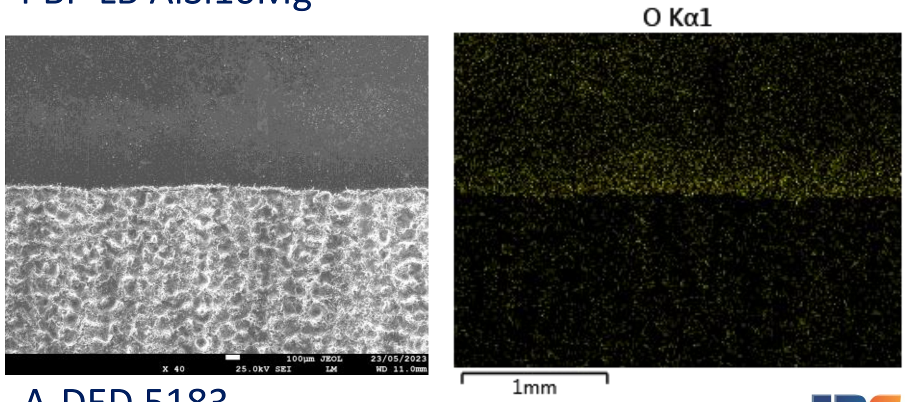
*No literature available showing the use of laser cleaning prior to the welding of AM-ed Al parts



Conv 5083



PBF-LB AlSi10Mg



A-DED 5183

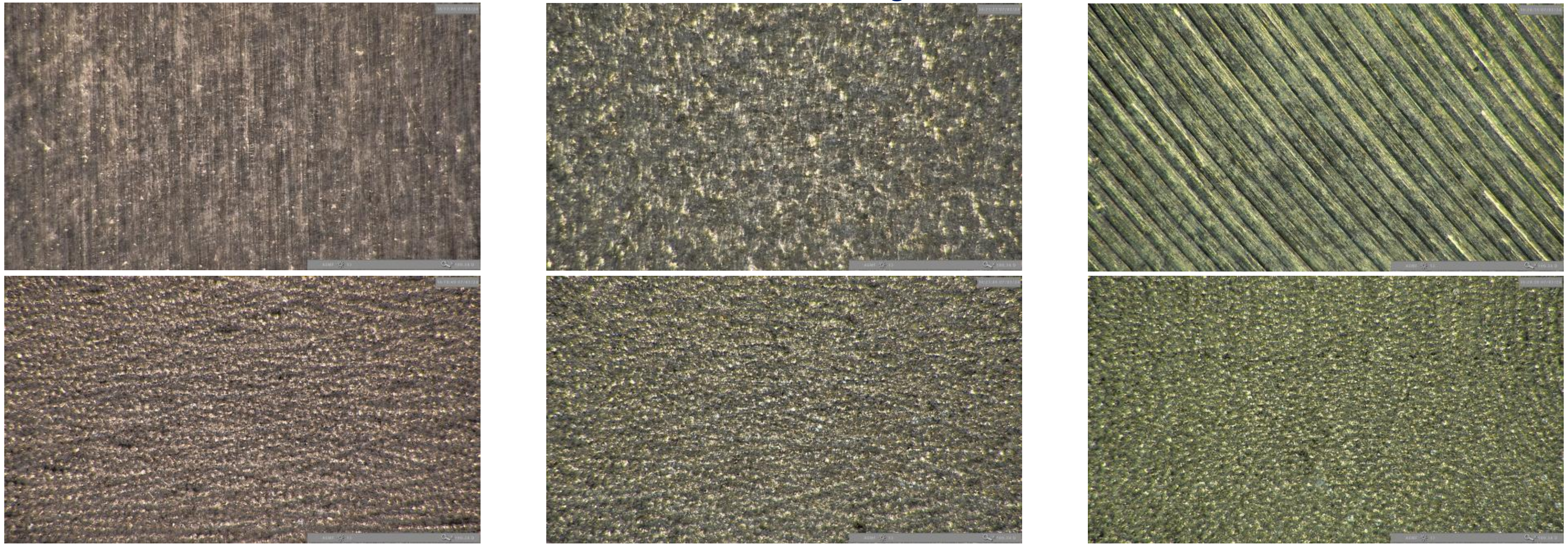
*SEM analysis performed 1 day after the Laser cleaning

Weldability of AM Al Alloys | Laser Cleaning Prior to Welding

Conv 5083 | PBF-LB AlSi10Mg | A-DED 5183

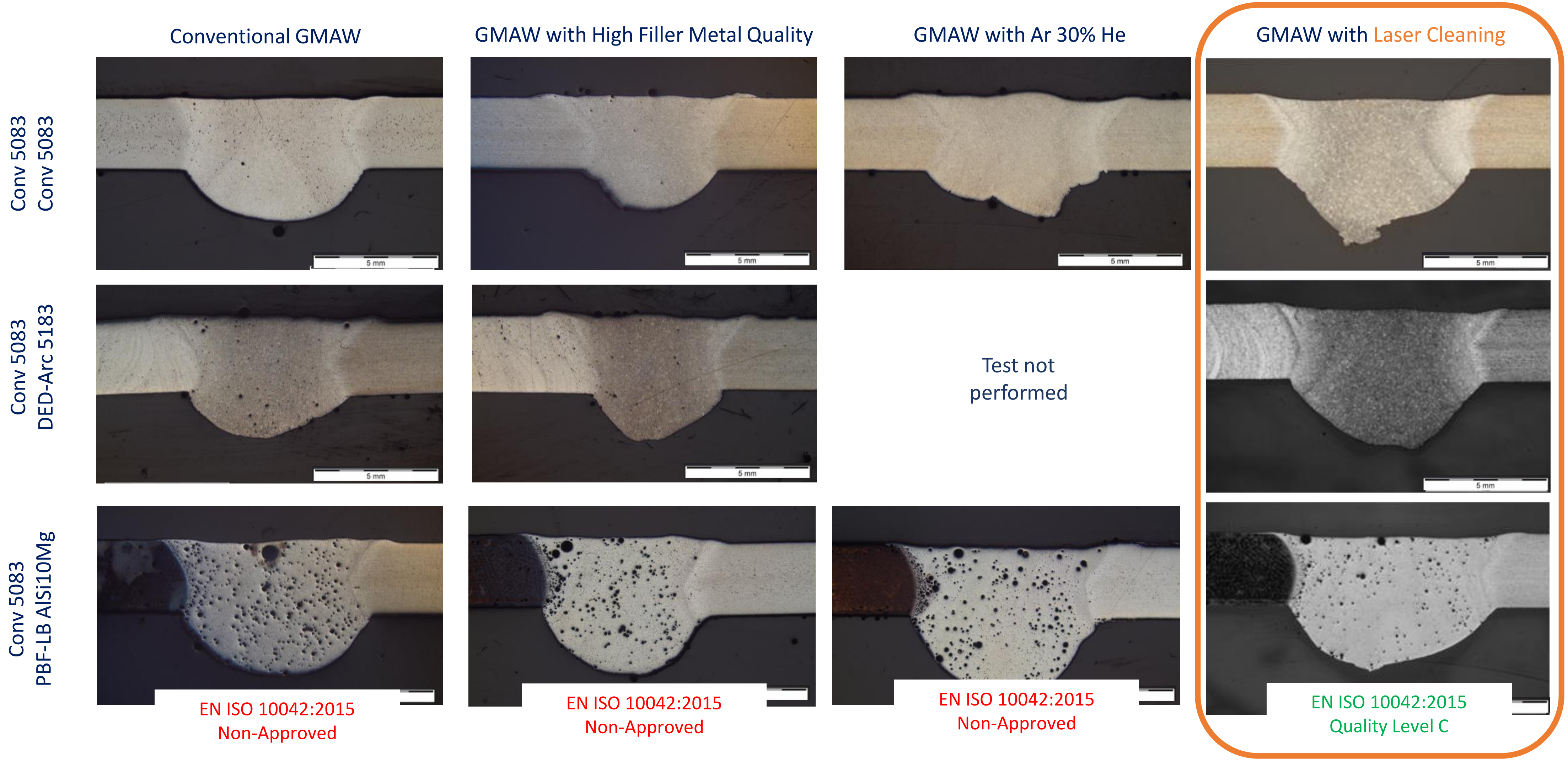
Before Laser Cleaning

After Laser Cleaning



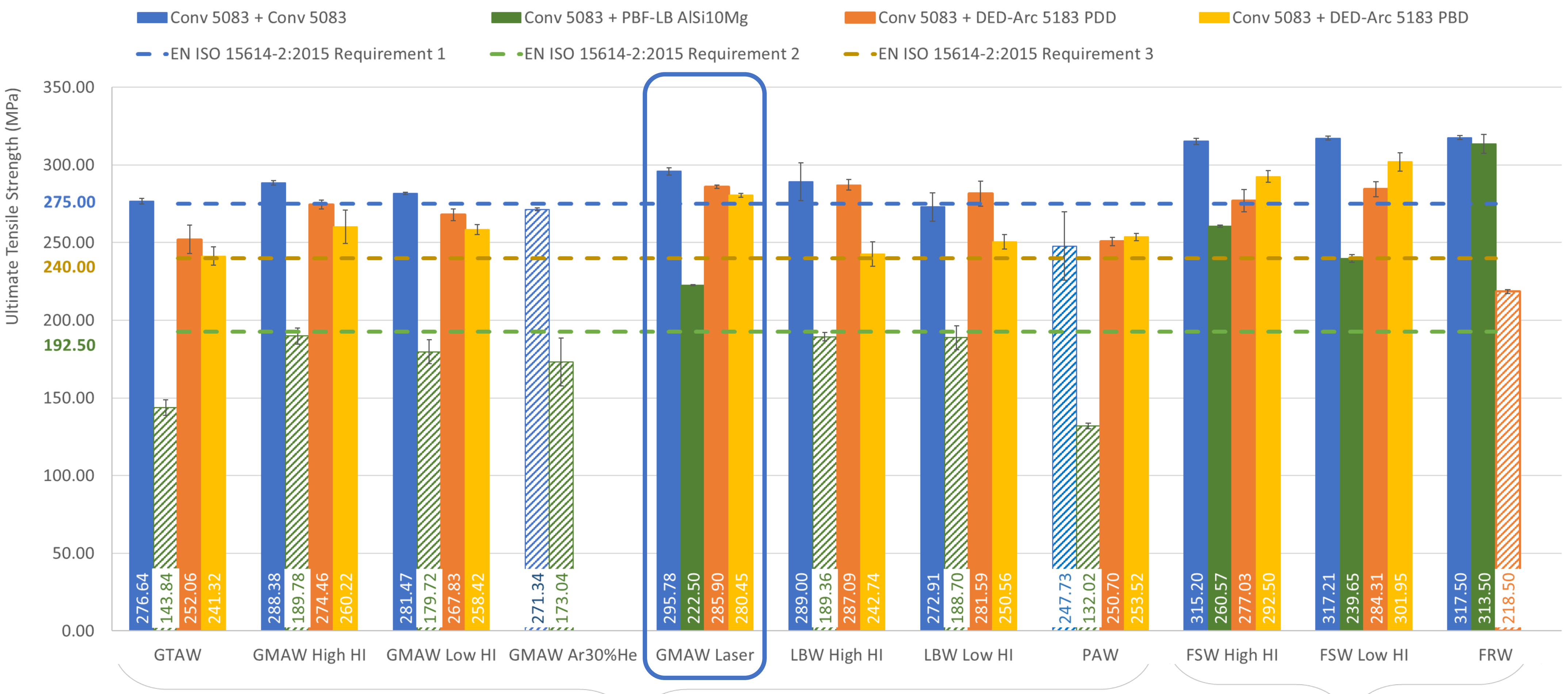
Material	Before Laser Cleaning Ra (µm)		Before Laser Cleaning Rz (µm)		After Laser Cleaning Ra (µm)		After Laser Cleaning Rz (µm)	
Conventional EN AW 5083	0.269	**0.271**	1.980	**1.997**	3.902	**4.129**	29.300	**31.100**
	0.261		1.930		4.137		31.600	
	0.284		2.080		4.348		32.400	
PBF-LB AlSi10Mg	7.011	**6.576**	49.300	**46.167**	7.561	**7.495**	49.800	**51.167**
	6.074		41.700		7.888		55.500	
	6.643		47.500		7.037		48.200	
DED-Arc ER5183	2.118	**2.109**	13.200	**12.600**	5.362	**6.337**	32.800	**40.000**
	2.111		12.500		6.670		41.900	
	2.099		12.100		6.979		45.300	

Conclusion and Final Remarks



Weldability (porosity level & tensile strength) improvement of all material combinations by laser cleaning prior to the GMAW welding

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

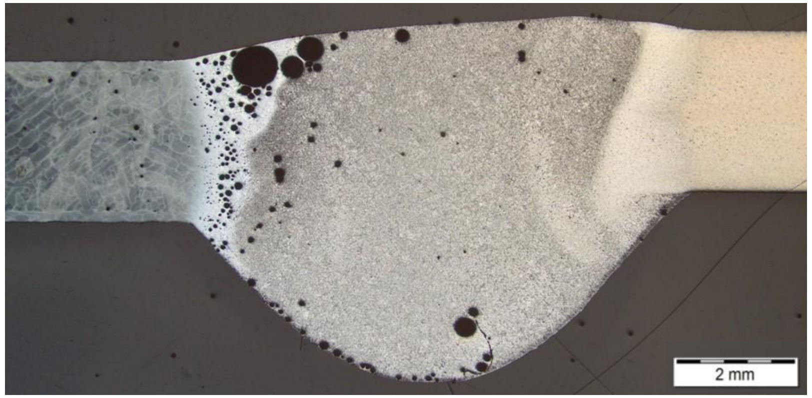
Fusion Welding Processes

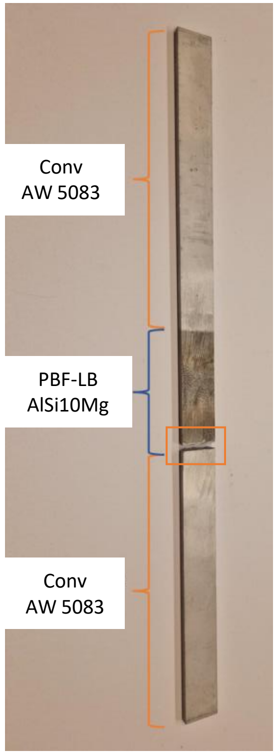
Solid-State
Welding Processes

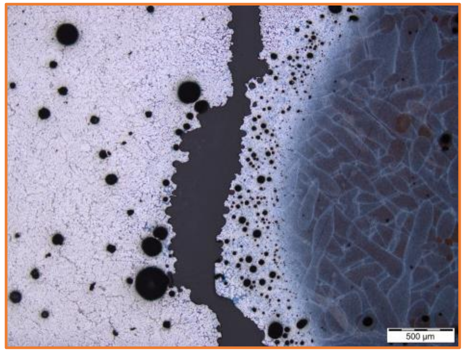
Evaluated Welding Processes and Conditions | Bend Testing

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

COAMWELD

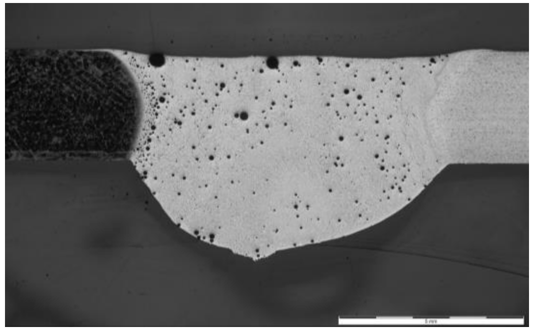
- Different thermal cycles
- Different filler metal form (wire/powder)
- Different microstructure
- Different mechanical (material) properties

Fusion Welding Processes

Solid-State Welding Processes

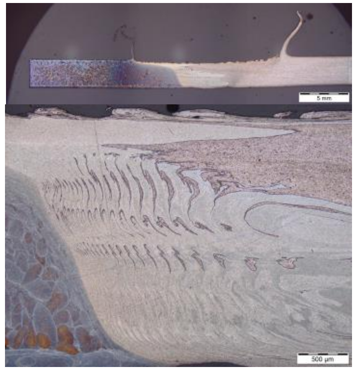
Weldability

Welding of PBF-LB Al Alloy Parts



Arc Welding / LBW

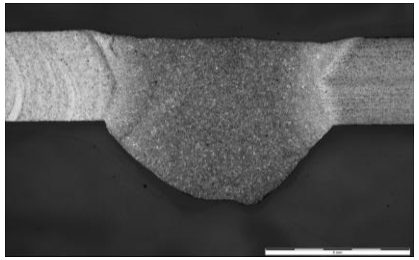
FRW



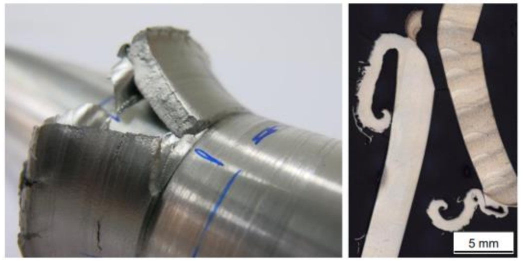
FSW

Welding of DED-Arc Al Alloy Parts

FSW



Arc Welding / LBW



FRW

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

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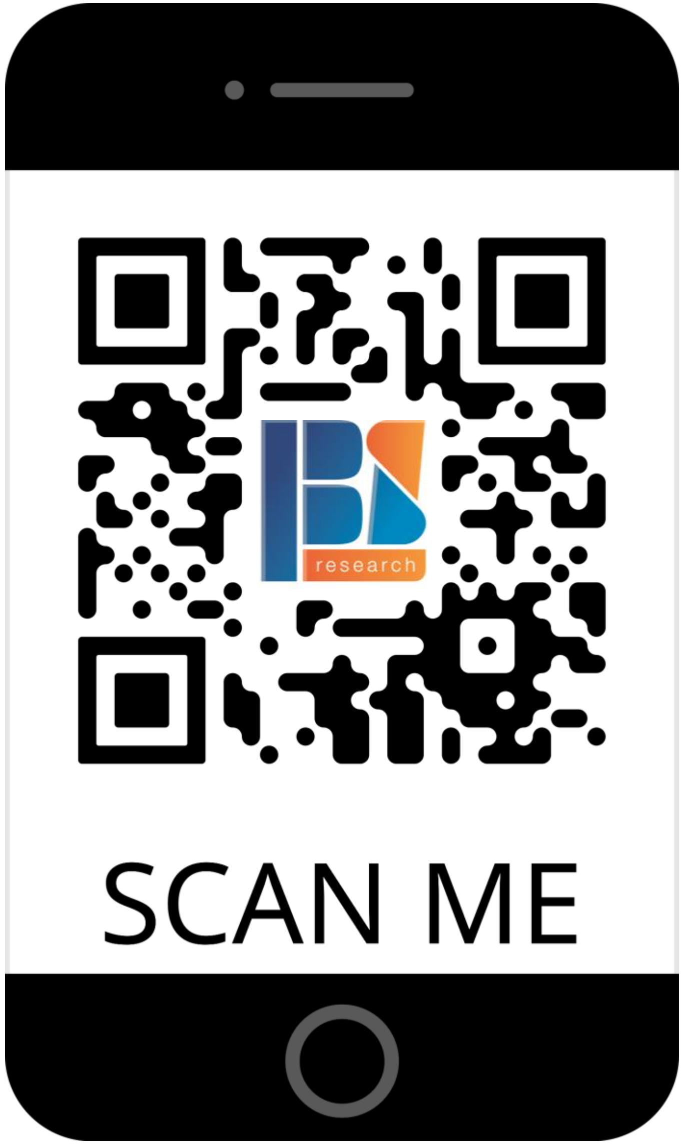
Your Input Matters: We value your questions and ideas. Let's collaborate to advance our understanding.

Get Meeting Details: If you'd like to join, scan the QR-code, and we'll send you the information.



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Thank you for your attention!

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