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

Rafael Nunes [1,2,3], Koen Faes [1], Wim Verlinde [1], Wim De Waele [2], Matthieu Lezaack [3], Aude Simar [3]

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GHENT UNIVERSITY

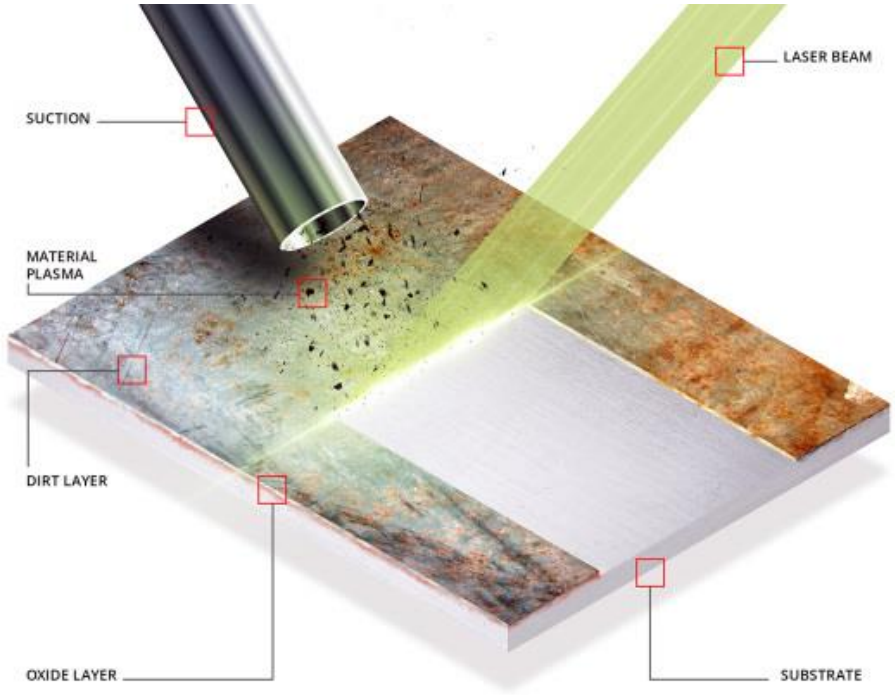
Joining your future.

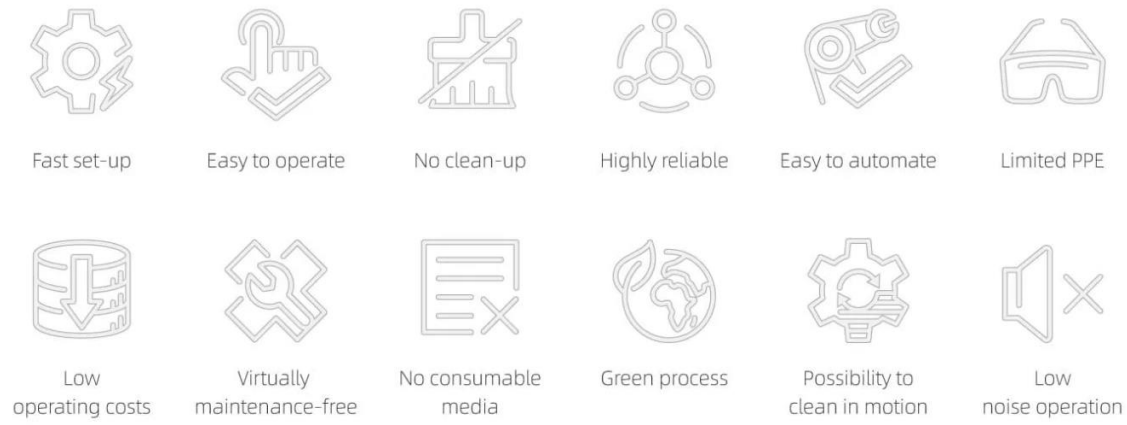
How Laser Cleaning Works?

P-Laser
INDUSTRIAL LASER CLEANING

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.

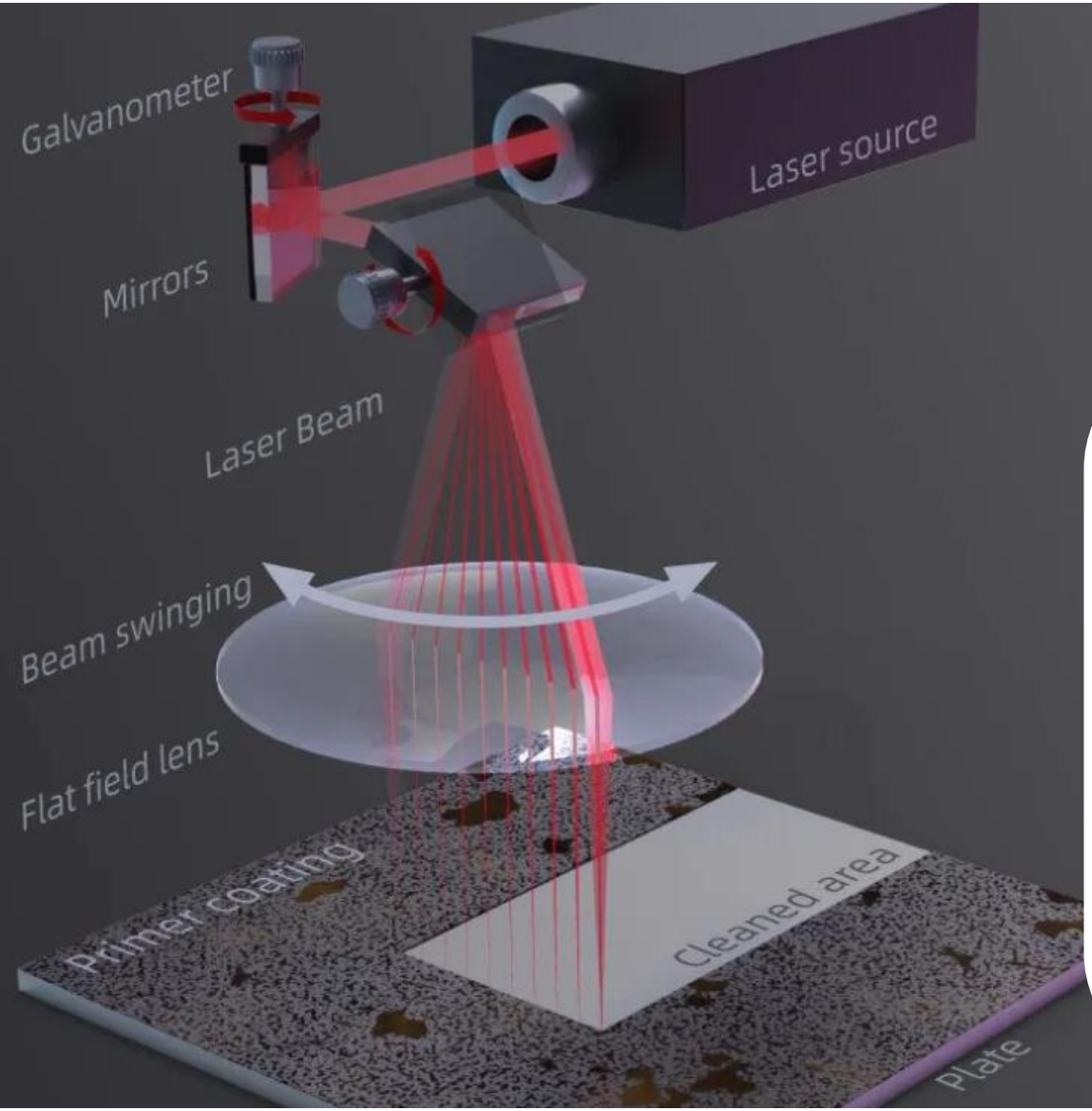
Examples of laser cleaning on metallic components (www.hg-star.com)





Main benefits of laser cleaning technology

How Laser Cleaning Works?



P-Laser
INDUSTRIAL LASER CLEANING

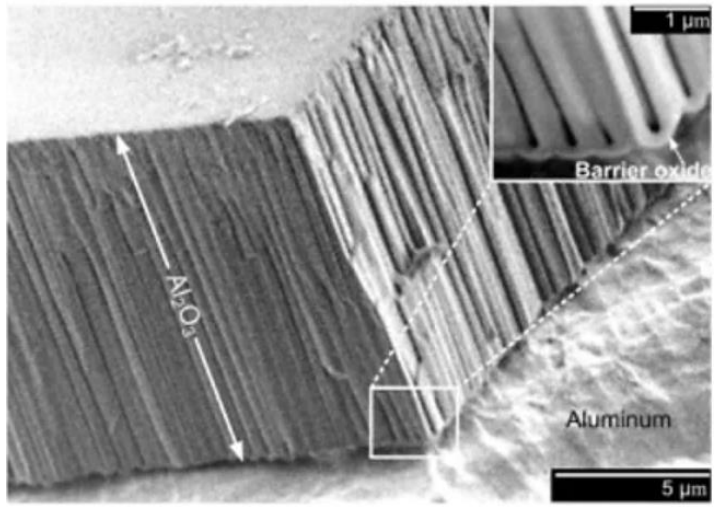
Multiple Scanning Modes

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

Challenges in the Welding and WAAM Manufacturing of Al Alloys

- High thermal conductivity
- High coefficient of thermal expansion
- High solubility of Hydrogen in liquid Aluminium
- Presence of oxide layer Al_2O_3

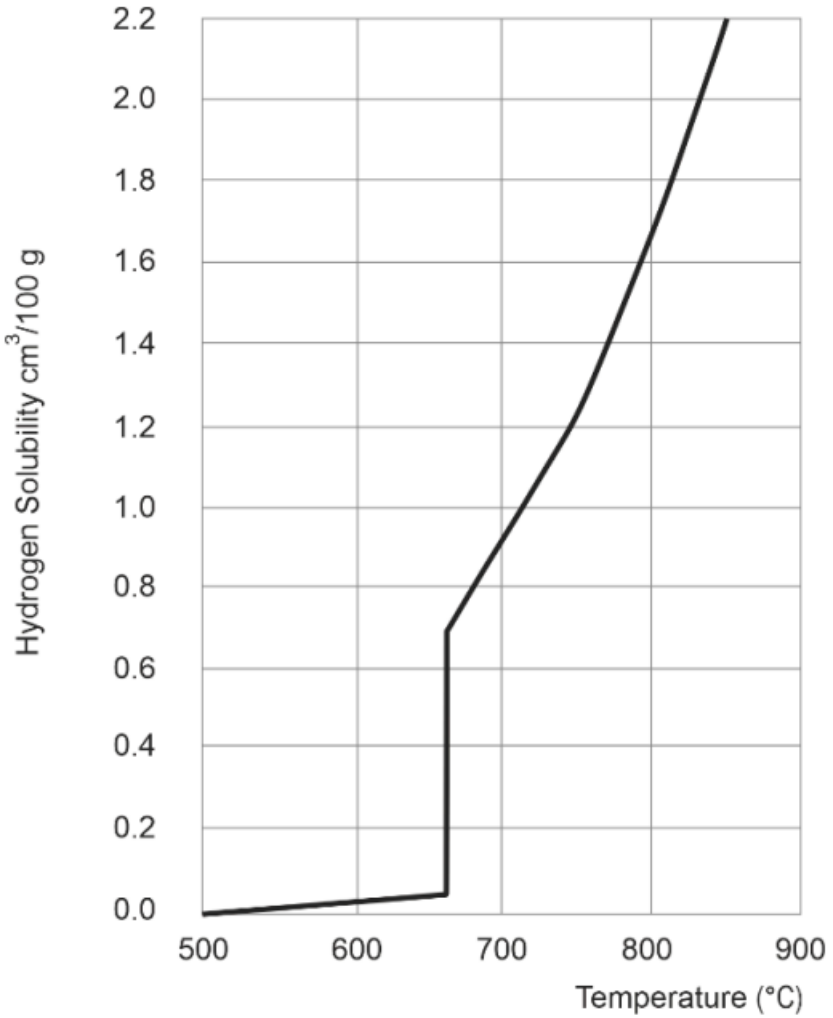


Haboudou *et al.* Materials Science and Engineering. 2003

Melting point:

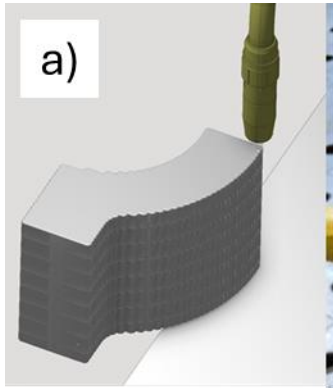
Al: 660 °C

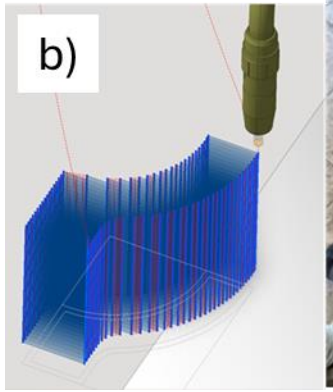
Al_2O_3: 2072 °C

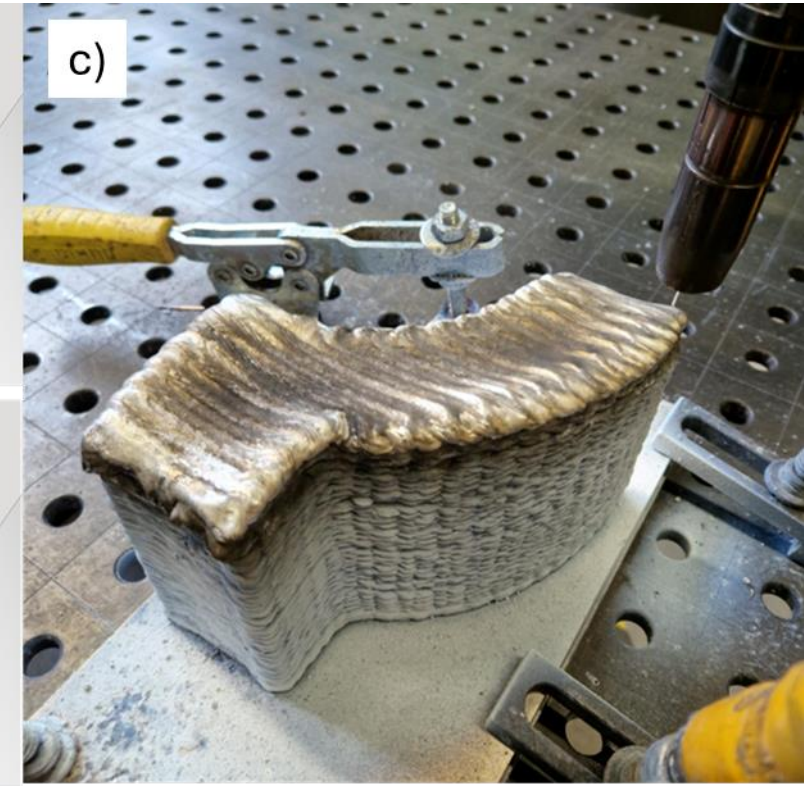


Belyaev *et al.* J. Eng. Appl. Sci. 2017

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



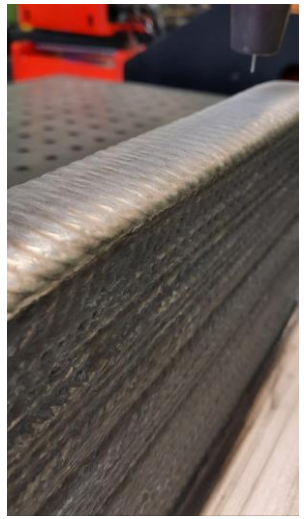




WAAM of Al Alloy Parts

	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
	Wall 07	200 x 35 x 60 mm3	ER 5183	1.2	Ar	Weaving	Laser Cleaning	(With) Laser Cleaning Comparison
3	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
	Wall 11	60 x 10 x 50 mm3	ER 7075	1.6	Ar	Straight Lines	No Cleaning	Exploratory Test with ER 7075 1.6mm
4	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

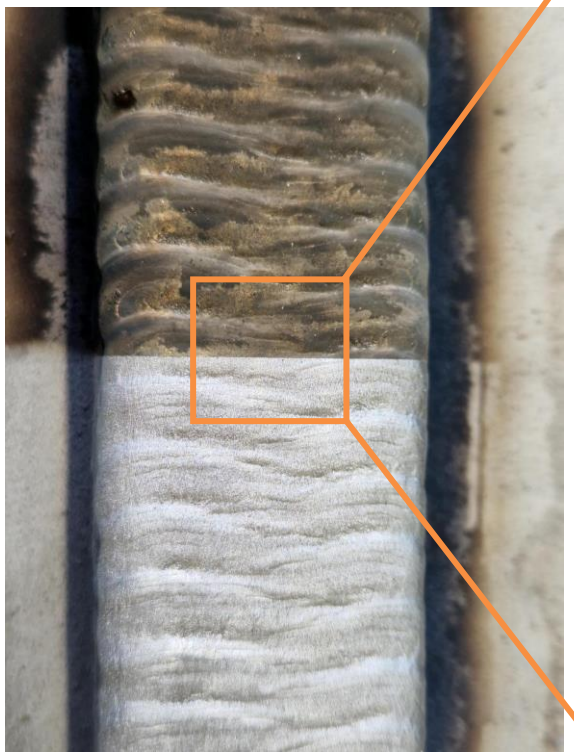
1. Evaluation of Selected WAAM Parameters and Conditions | ER 5183
2. Post Welding Heat Treatment (PWTH) Optimization | ER 2219
3. Laser Cleaning During WAAM| ER 5183 and ER 2219
4. Exploratory Tests with 7xxx | ER 7075

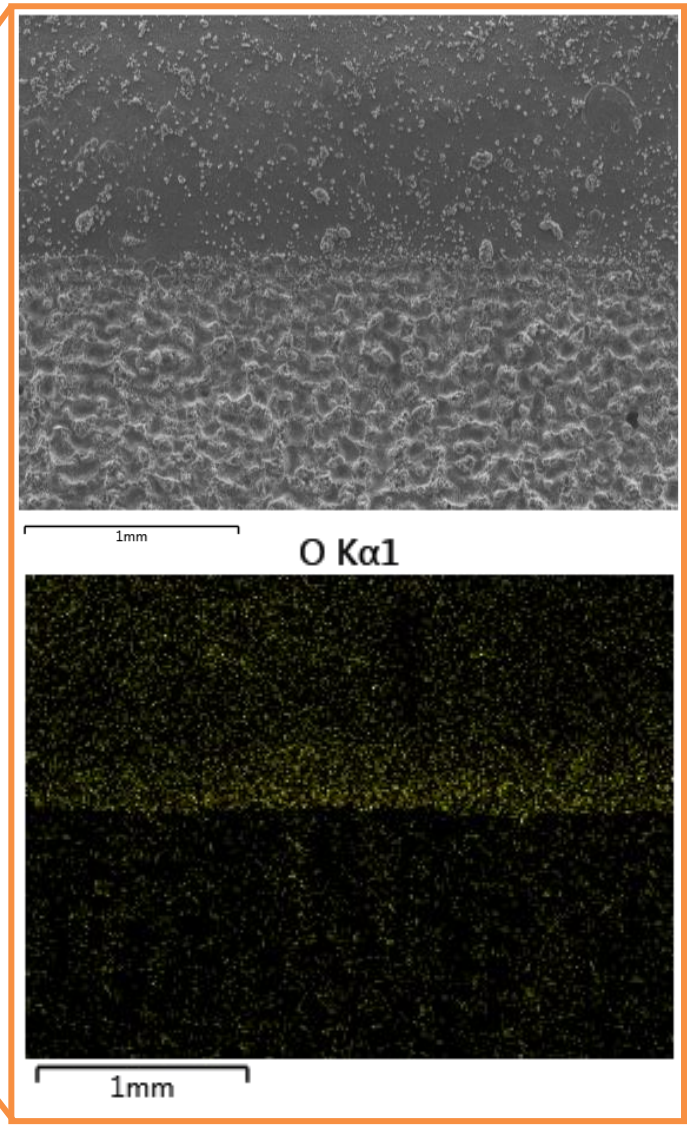


WAAM of Al Alloy Parts | Laser Cleaning

*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

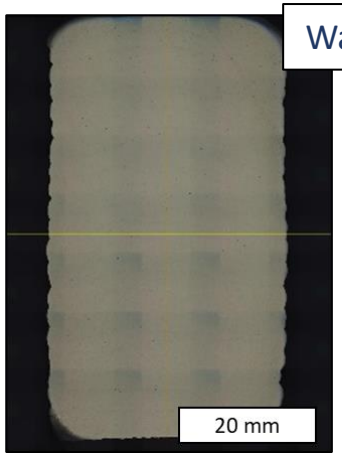
*No literature available showing the use of laser cleaning of aluminium alloys in WAAM manufacturing

Laser Cleaning During WAAM | ER 5183 and ER 2219

Metallographic Examination

Wall 07

ER5183 with laser cleaning



Wall 08

ER5183 without laser cleaning

EN ISO 10042:2015
Quality Level B

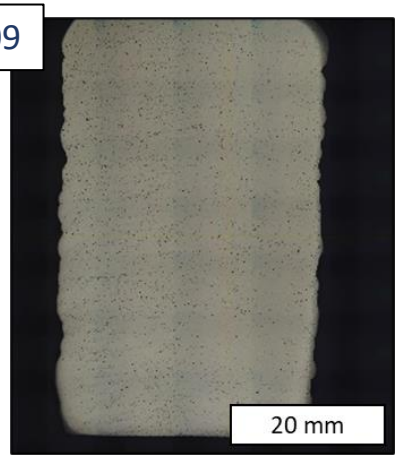
Porosity level:

Wall 07 – With Laser Cleaning: 0.17 %

Wall 08 – Without Laser Cleaning: 0.06 %

ER2219 with laser cleaning

Wall 09



Porosity level :

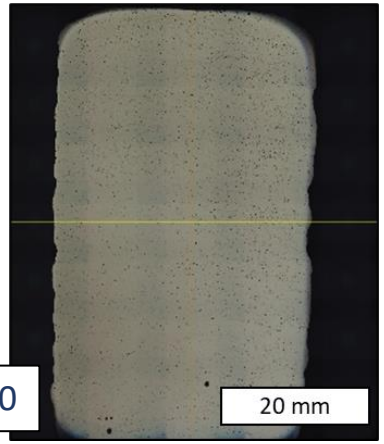
Wall 09 – With Laser Cleaning: 2.98 %

Wall 10 – Without Laser Cleaning: 2.79 %

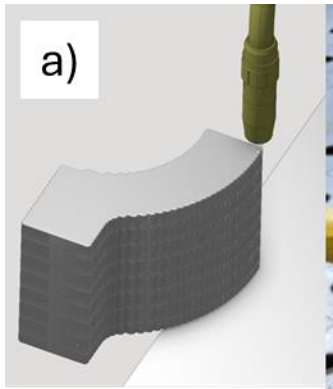
EN ISO 10042:2015
Quality Level C

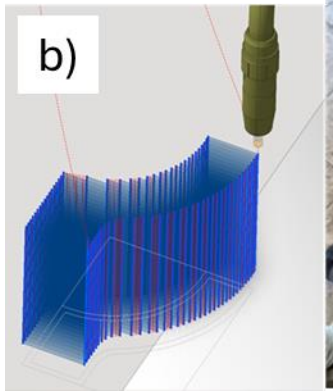
ER2219 without laser cleaning

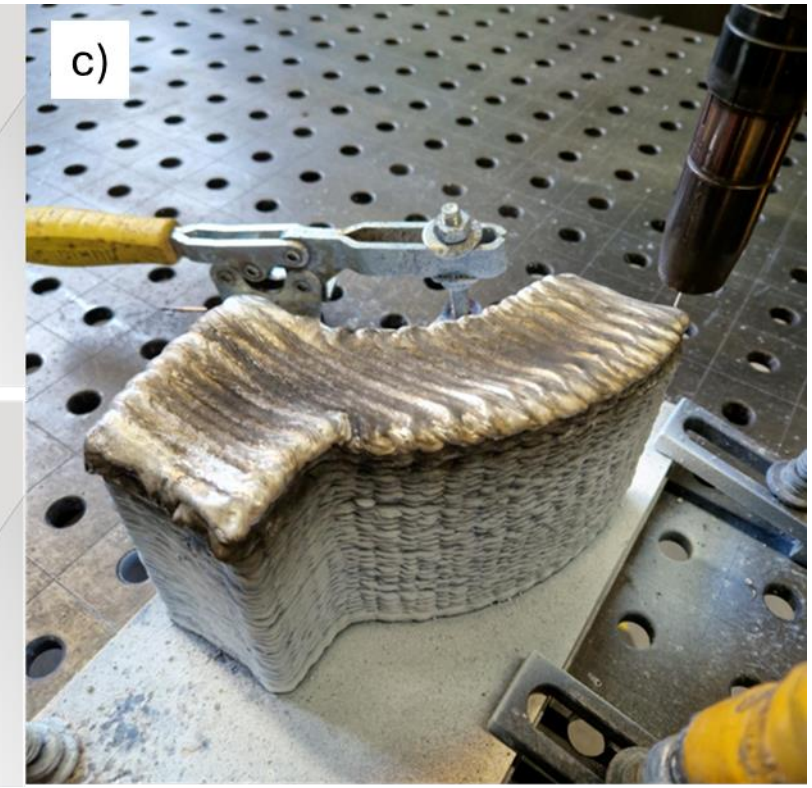
Wall 10

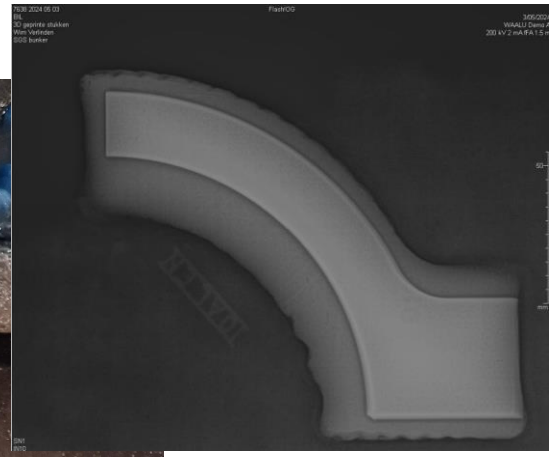


WAAM of Al Alloys| Demonstrator Manufacturing







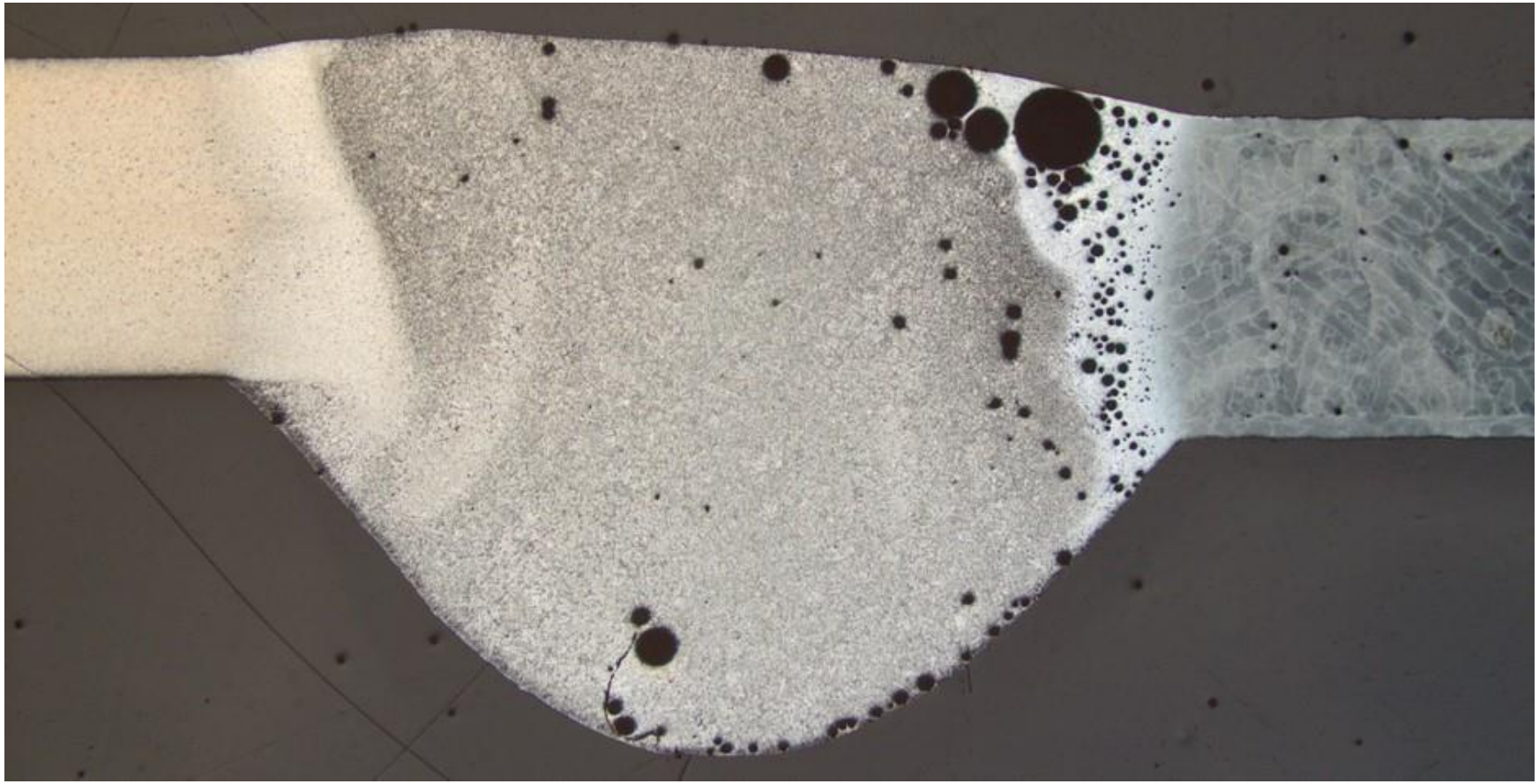


Exploratory demonstrator manufacturing with ER 5183 Al-alloy

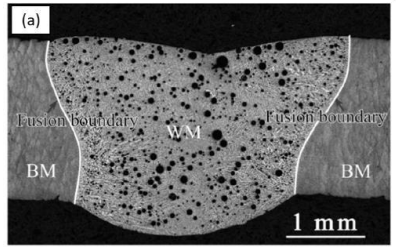
Next steps:

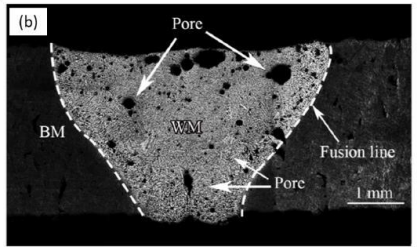
1. X-Ray evaluation
2. Computed tomography evaluation
3. Mechanical testing (after PWTH for ER2219)
4. Laser cleaning during WAAM manufacturing of ER 7075 alloy

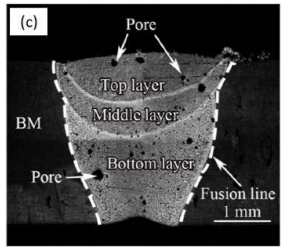
Joining Between Conventionally and Additively Manufactured Aluminium Alloys



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







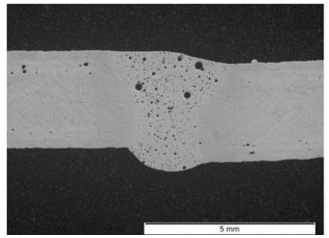
metals

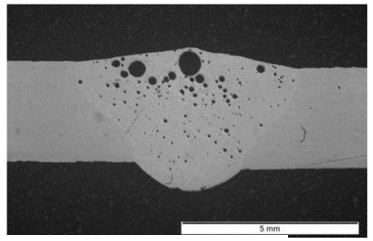
MDPI

Review

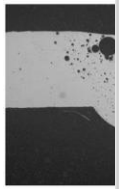
A Review on the Weldability of Additively Manufactured Aluminium Parts by Fusion and Solid-State Welding Processes

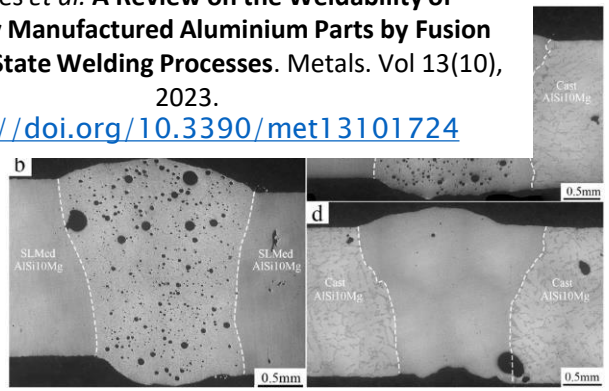
Rafael Nunes [1,2,3,*], Koen Faes [1], Wim De Waele [2], Aude Simar [3], Wim Verlinde [1], Matthieu Lezaack [3], Wout Sneyers [2] and Julius Arnhold [4]

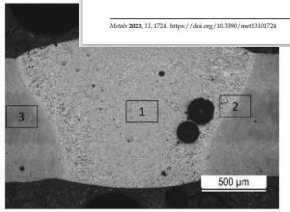


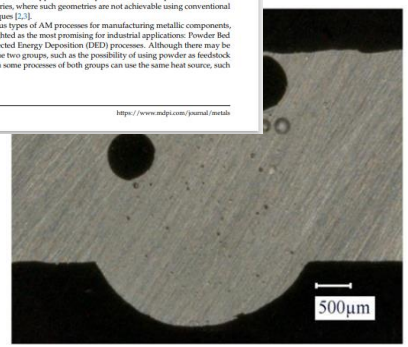


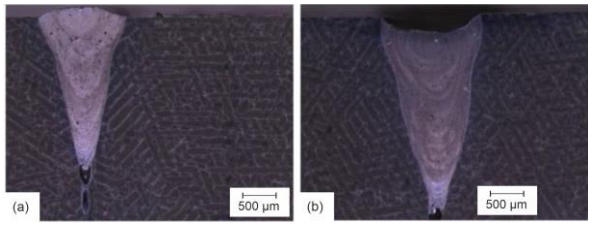
R. Nunes *et al.* **A Review on the Weldability of Additively Manufactured Aluminium Parts by Fusion And Solid-State Welding Processes**. Metals. Vol 13(10), 2023.
https://doi.org/10.3390/met13101724











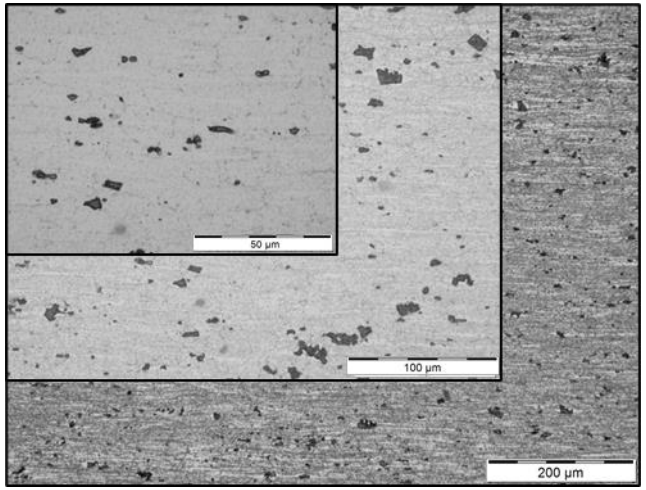
Unlikely the porosity can be entirely avoided by optimization of welding parameters,
Other fusion welding processes are likely to suffer from porosity issues.

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

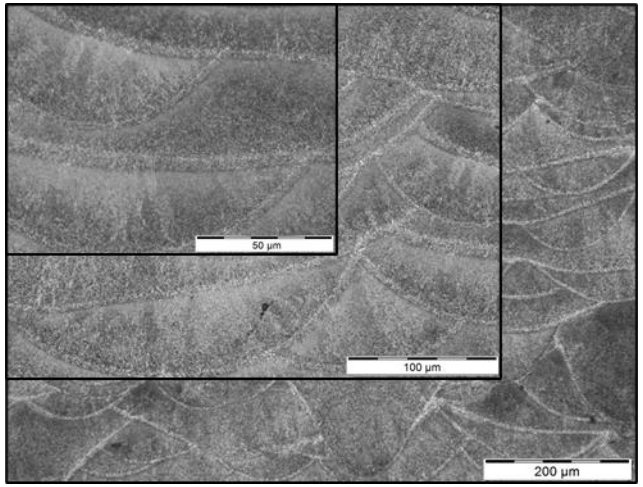
- Higher surface area to volume ratio compared to wire filler material
- Most powder have included porosity
- Most commercial equipment control is based on O_2 content (not by creating a vacuum and then filling it with Ar)
- Common to recycle powder in the PBF-LB process.

Base Materials

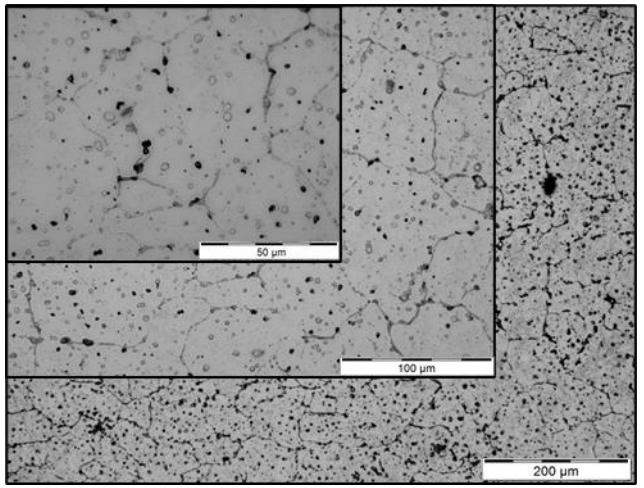
CONV 5083 Longitudinal



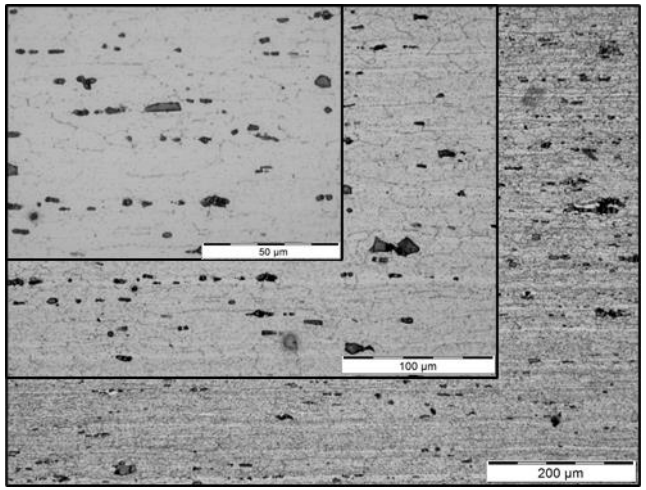
PBF-LB AlSi10Mg PBD



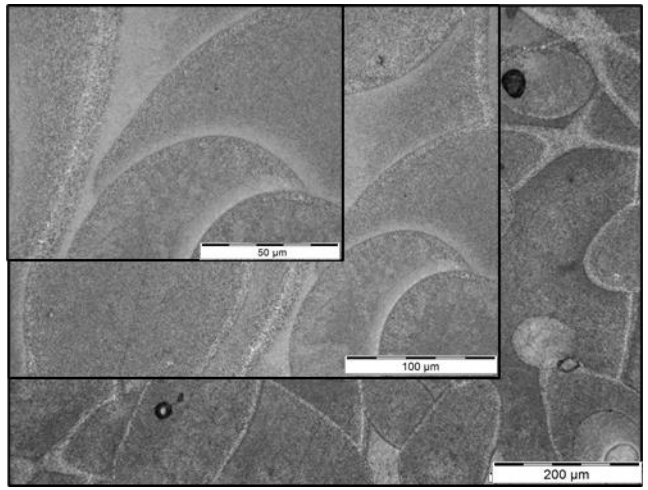
WAAM 5183 PBD



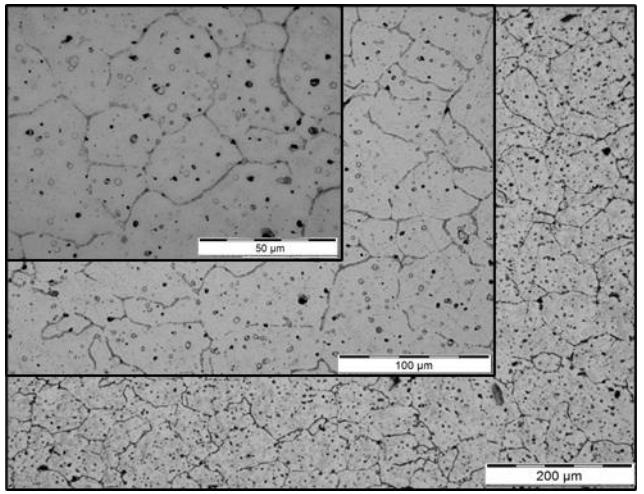
CONV 5083 Transversal



PBF-LB AlSi10Mg PDD



WAAM 5183 PDD

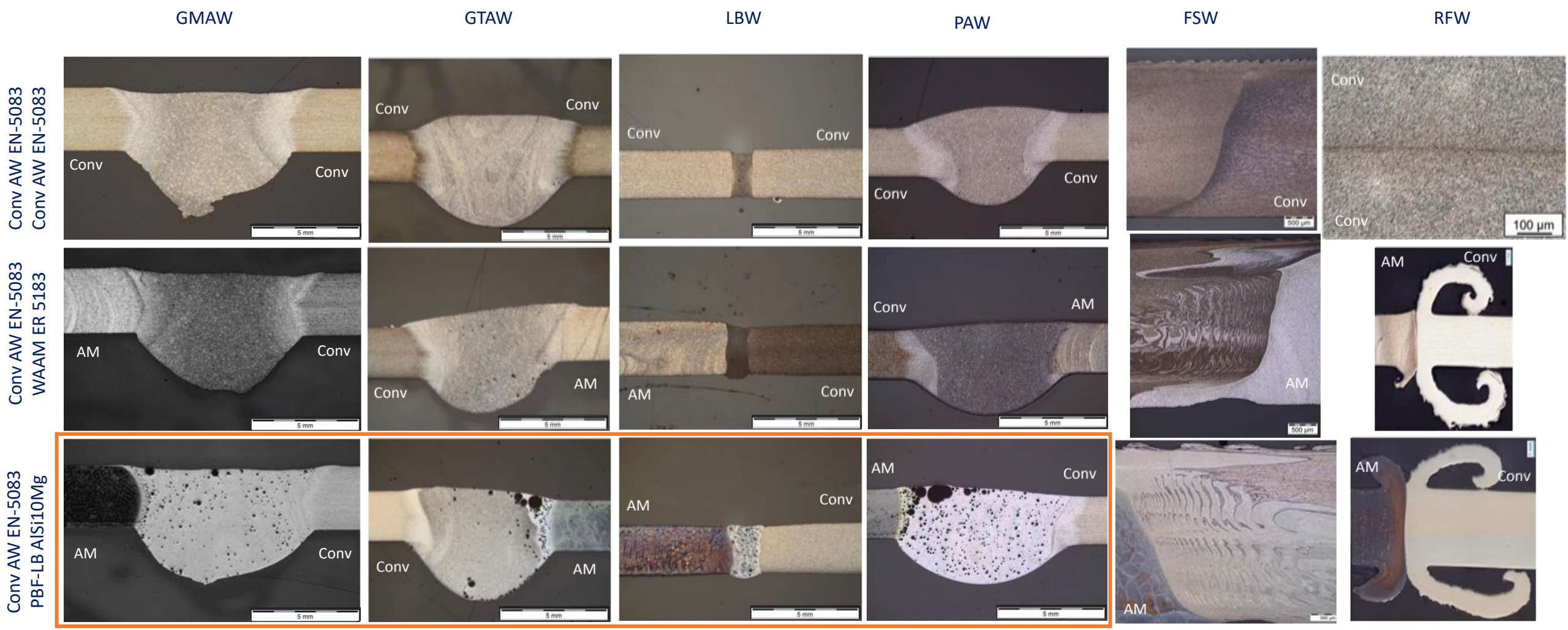


CONV UTS: 310.6 MPa

PBF-LB UTS: 435.6 MPa

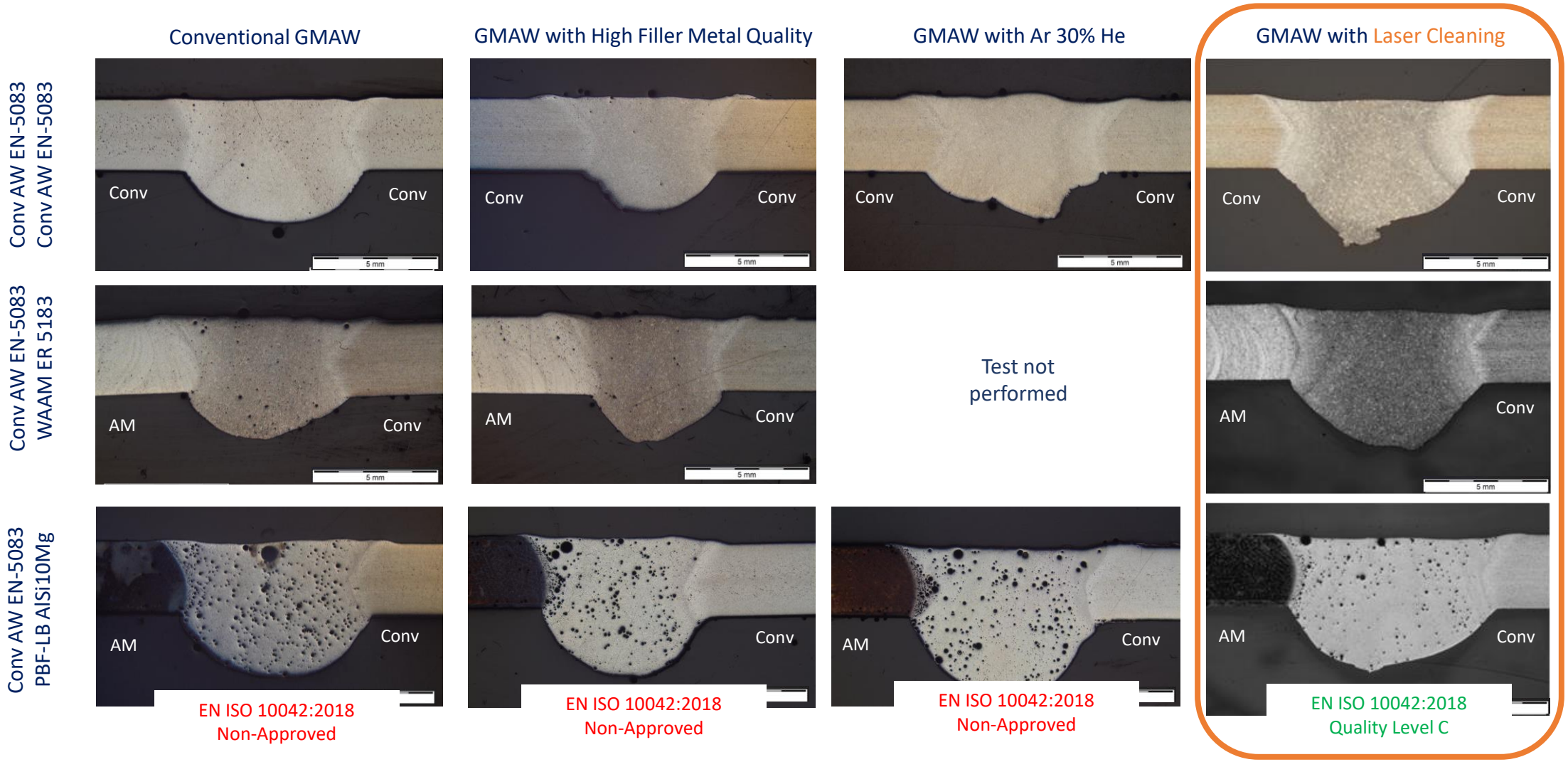
WAAM UTS: 288.4 MPa

Evaluated Welding Processes | Metallographic Examination



High Porosity Level

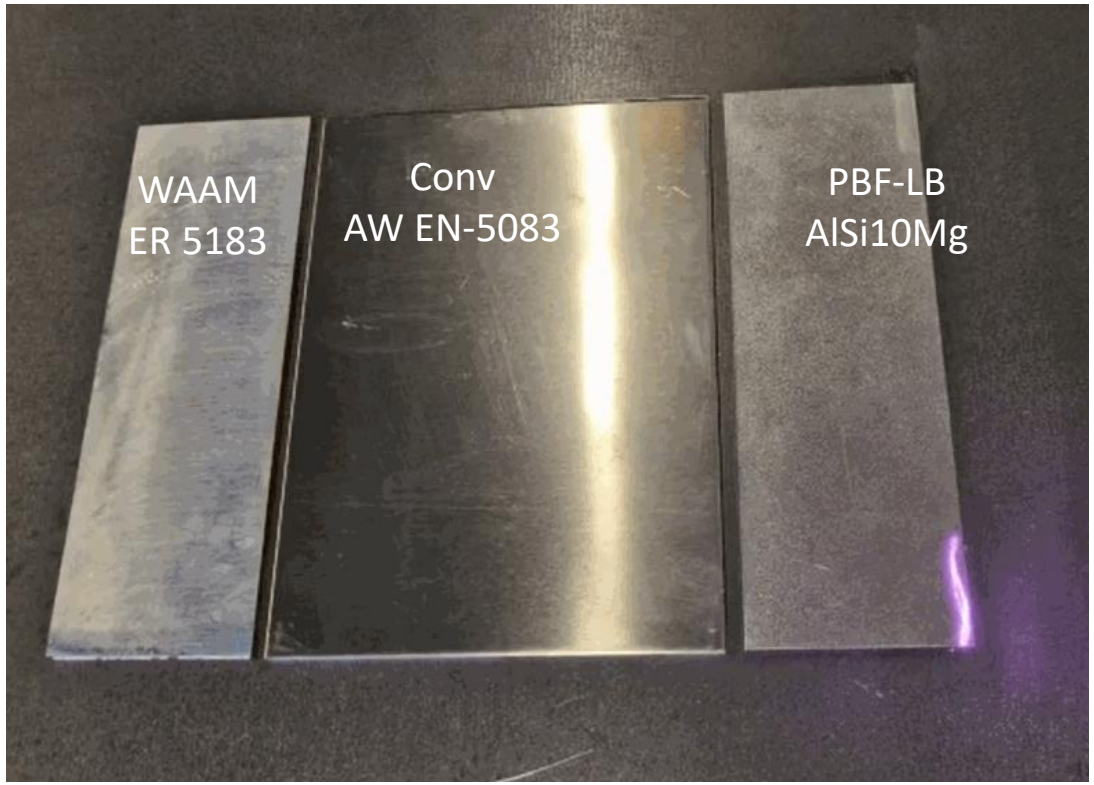
Evaluated Welding Processes | Metallographic Examination



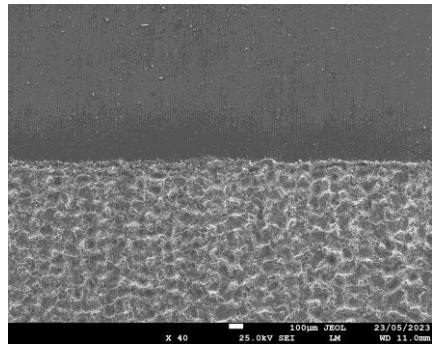
Weldability improvement of all material combinations by laser cleaning prior to the GMAW welding

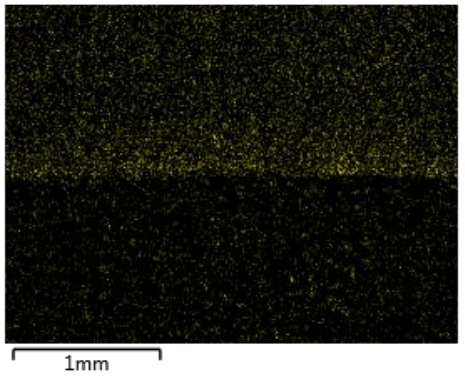
Weldability of AM Al Alloys | Laser Cleaning Prior to Welding

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

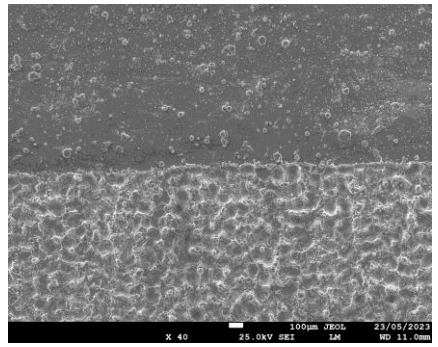


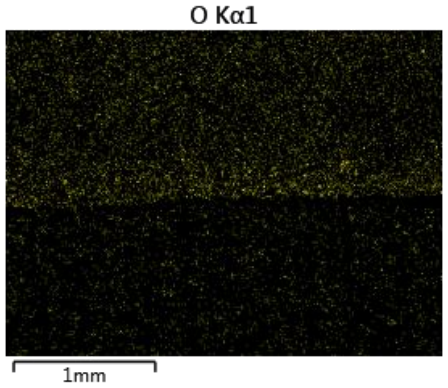
*No literature available showing the use of laser cleaning prior to the welding of AM-ed Al parts



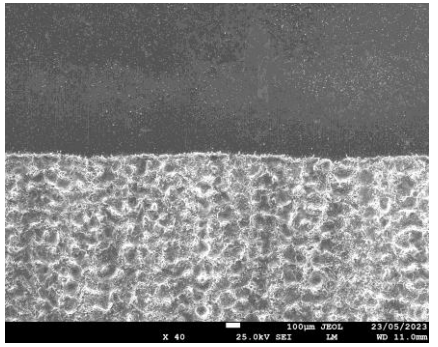


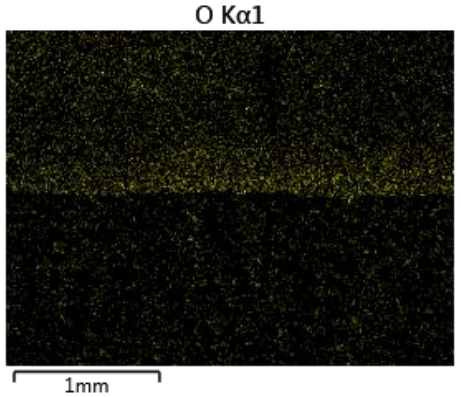
Conv AW EN-5083





PBF-LB AlSi10Mg

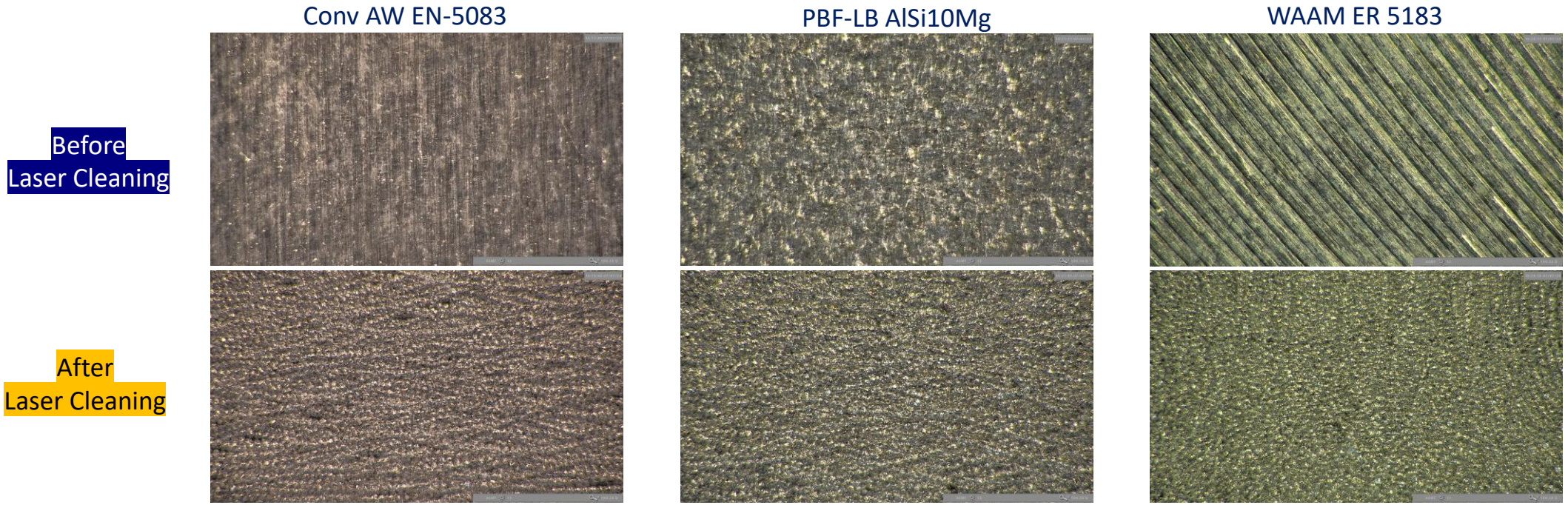




WAAM ER 5183

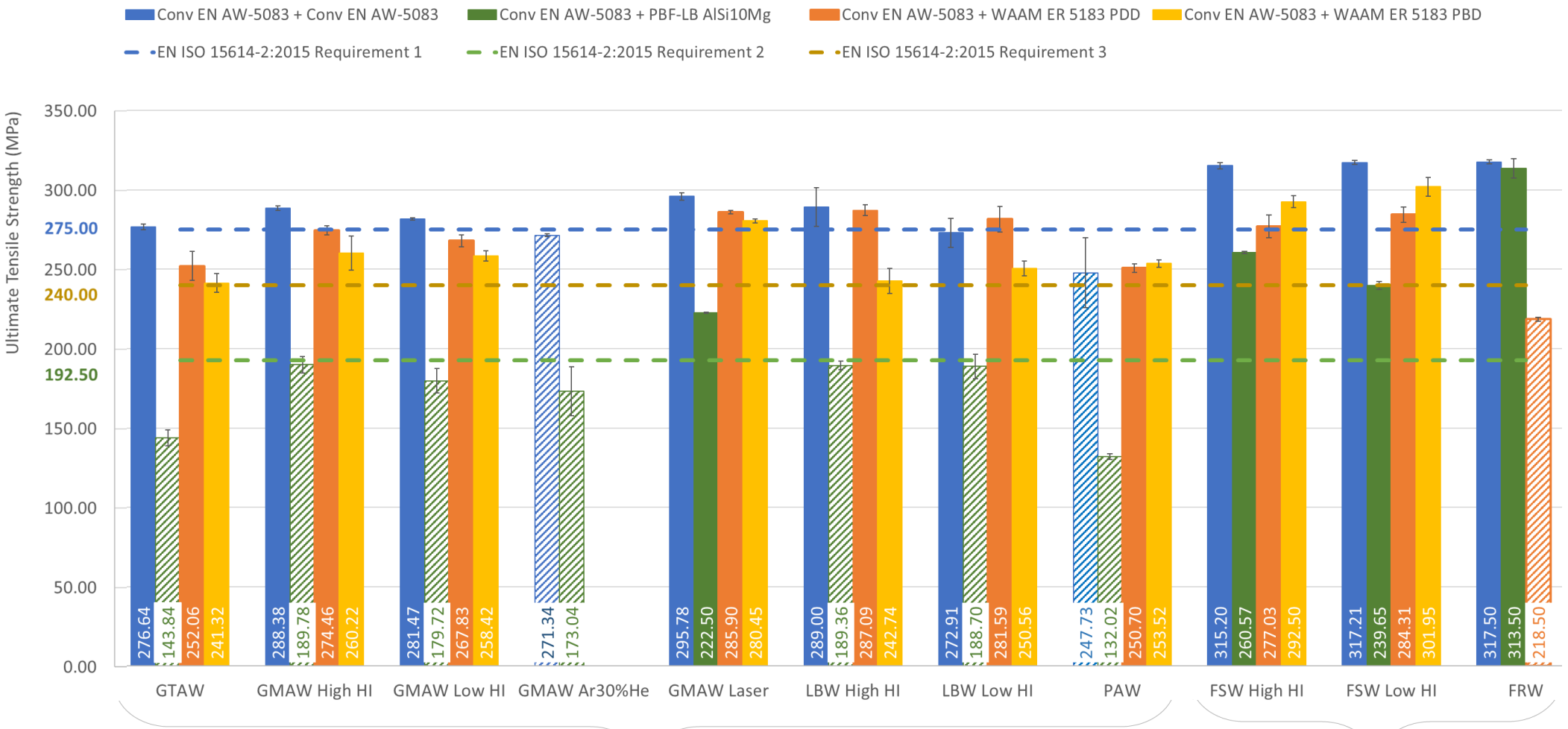
*SEM analysis performed 1 day after the Laser cleaning

Weldability of AM Al Alloys | Laser Cleaning Prior to Welding



Material	Before Laser Cleaning				After Laser Cleaning			
	Ra (µm)		Rz (µm)		Ra (µm)		Rz (µm)	
Conventional AW EN-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	
WAAM ER 5183	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	

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

Joining your future.

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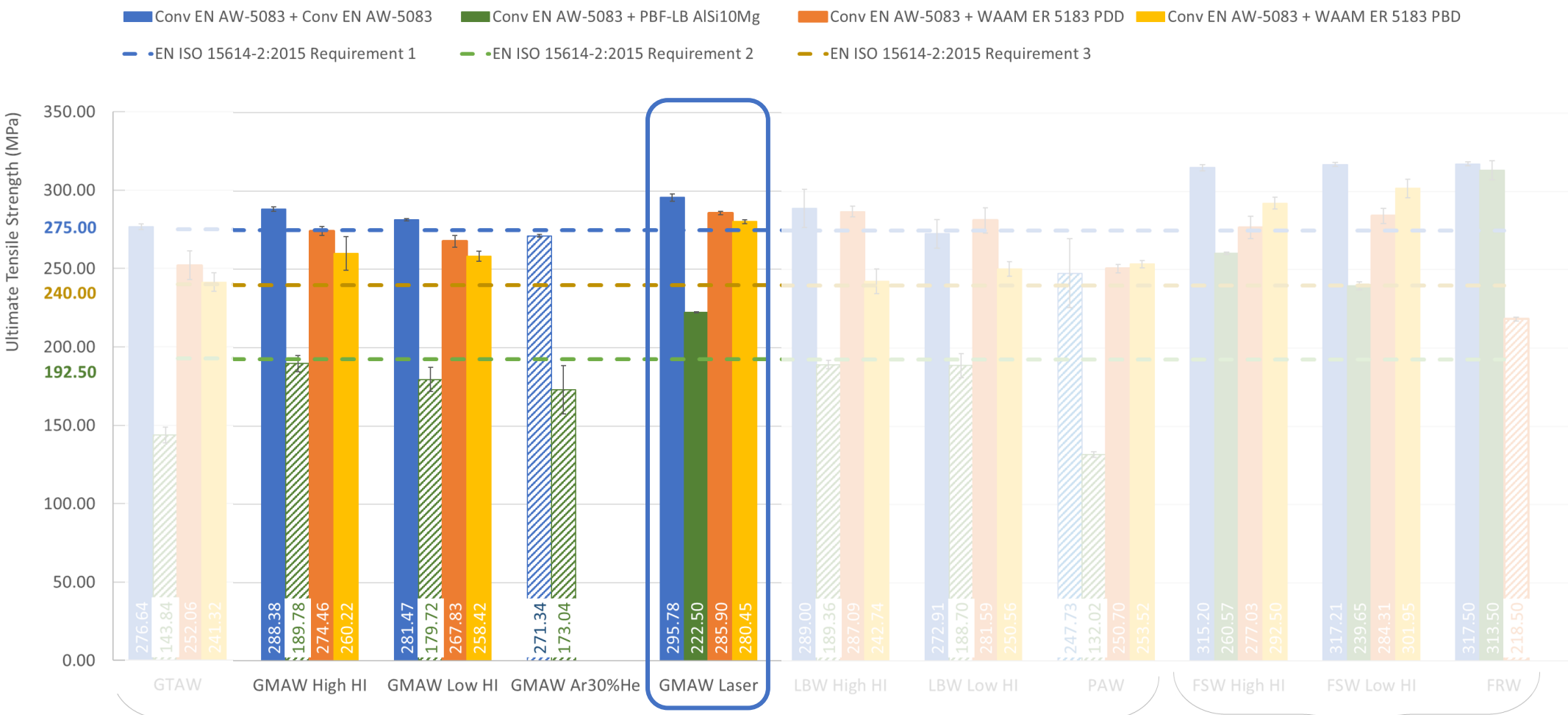
Evaluated Welding Processes and Conditions | Tensile Testing



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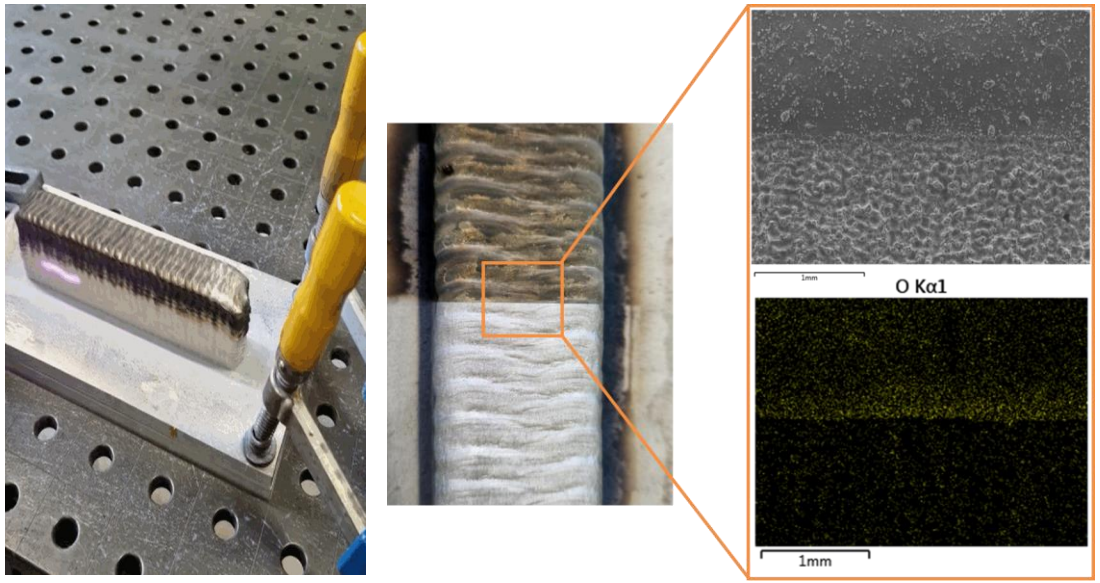
Fusion Welding Processes

Solid-State Welding Processes

Joining your future.

Promising Results & Final Remarks

WAAM Manufacturing of Al alloys

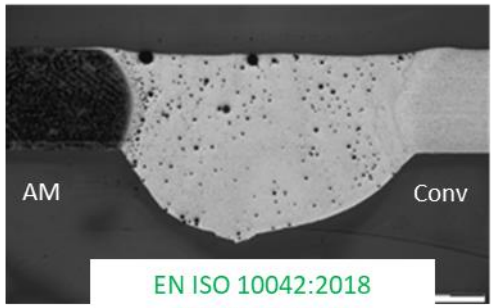


Welding of AM-ed (PBF-LB) Al alloys

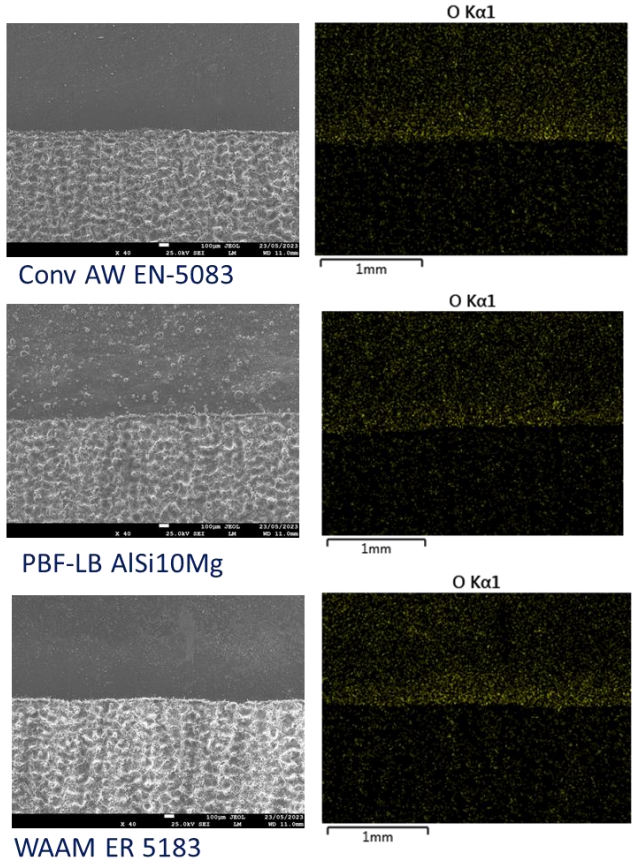
Without Laser Cleaning

EN ISO 10042:2018
Non-Approved

With Laser Cleaning



EN ISO 10042:2018
Quality Level C



Laser Cleaning is a very efficient and promising technique to improve the quality in very advanced and complex applications

Interested in these topics? Let’s talk more!

Engage in Deeper Discussions: If today's presentation sparked your interest, let's continue the conversation.

Join an Open Meeting: We're hosting a session to explore the topics further and share insights.

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!

SCAN ME

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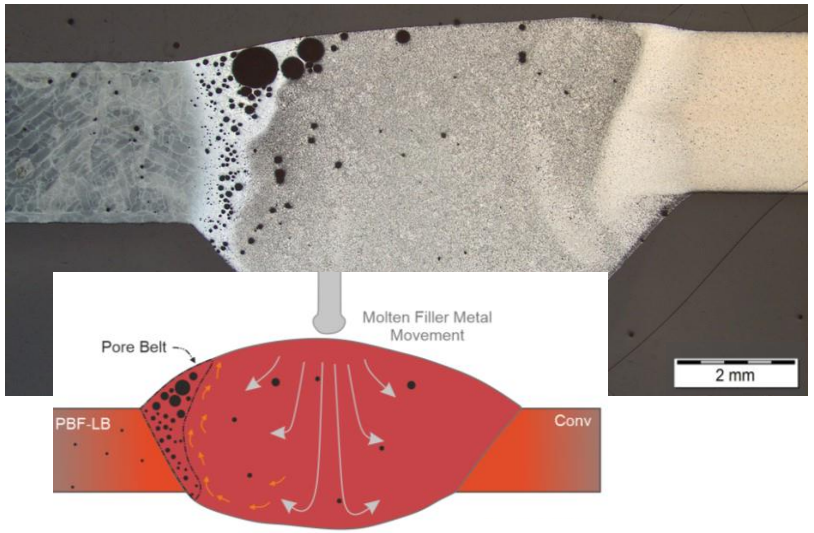
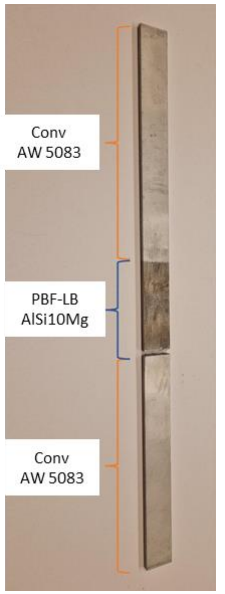
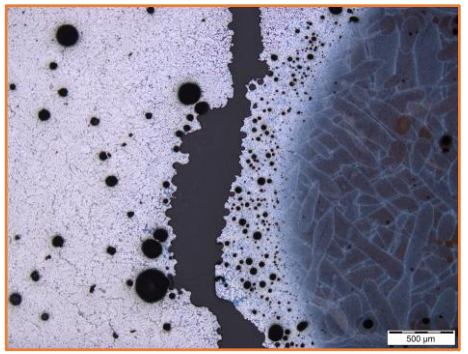
Evaluated Welding Processes and Conditions | Bend Testing

	Welding Process	Material A	Material B	Bend Testing Result*
Fusion Welding Processes	GMAW	Conv EN AW-5083	Conv EN AW-5083	Approved
		Conv EN AW-5083	PBF-LB ALSi10Mg	Not Approved
		Conv EN AW-5083	WAAM ER 5183	Approved
	GTAW	Conv EN AW-5083	Conv EN AW-5083	Approved
		Conv EN AW-5083	PBF-LB ALSi10Mg	Not Approved
		Conv EN AW-5083	WAAM ER 5183	Approved
	LBW	Conv EN AW-5083	Conv EN AW-5083	Approved
		Conv EN AW-5083	PBF-LB ALSi10Mg	Not Approved
		Conv EN AW-5083	WAAM ER 5183	Approved
	PAW	Conv EN AW-5083	Conv EN AW-5083	Approved
		Conv EN AW-5083	PBF-LB ALSi10Mg	Not Approved
		Conv EN AW-5083	WAAM ER 5183	Approved
Solid-State Welding Processes	FSW	Conv EN AW-5083	Conv EN AW-5083	Approved
		Conv EN AW-5083	PBF-LB ALSi10Mg	Approved
		Conv EN AW-5083	WAAM ER 5183	Approved
	RFW	Conv EN AW-5083	Conv EN AW-5083	Approved
		Conv EN AW-5083	PBF-LB ALSi10Mg	Approved
		Conv EN AW-5083	WAAM ER 5183	Not Approved

* EN ISO 15614-2:2005







Main factor for strength and ductility reduction:

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

Conclusion and Final Remarks

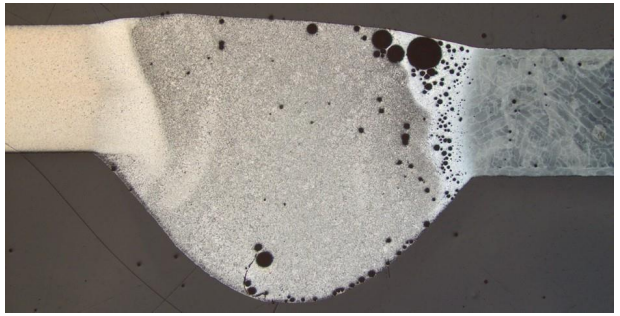
- Different thermal cycles → Different microstructure
- Different filler metal form (wire/powder) → Different mechanical (material) properties

Fusion Welding Processes

Solid-State Welding Processes

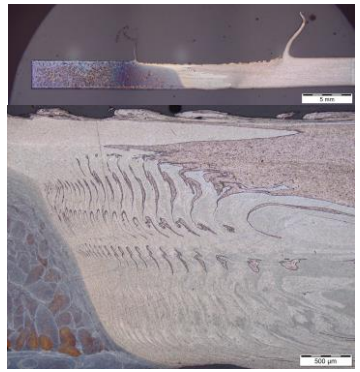
Weldability

Welding of PBF-LB Al Alloy Parts



Arc Welding / LBW

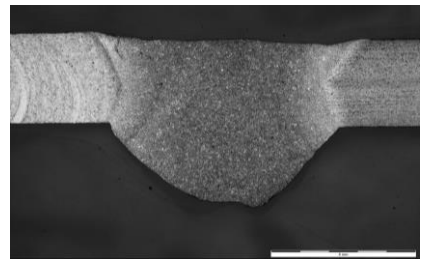
FRW



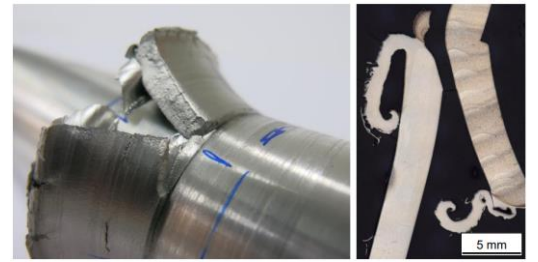
FSW

Welding of WAAM Al Alloy Parts

FSW



Arc Welding / LBW



FRW

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