77th IIW Annual Assembly and International Conference on Welding and Joining
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The COAMWELD project is founded by VLAIO, under Grant Number HBC.2020.2994

Understanding and Overcoming the Challenges in the Welding of Additively Manufactured Aluminium Alloys Components

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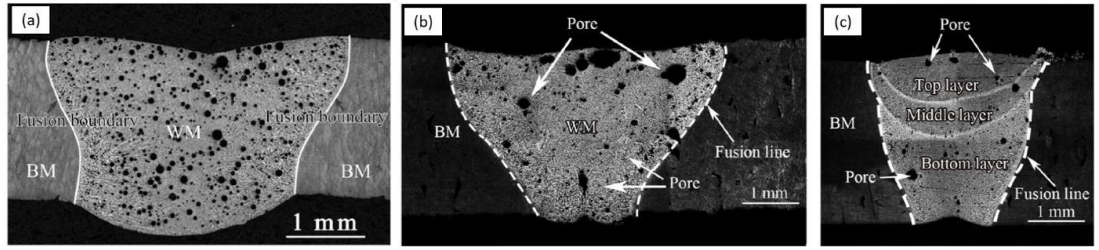
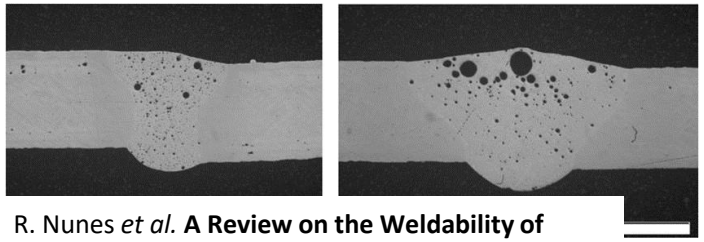
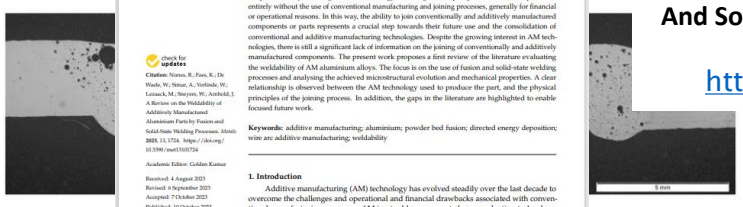
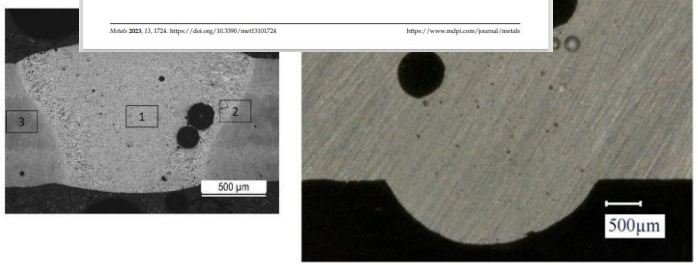
[3] Université Catholique de Louvain, Belgium

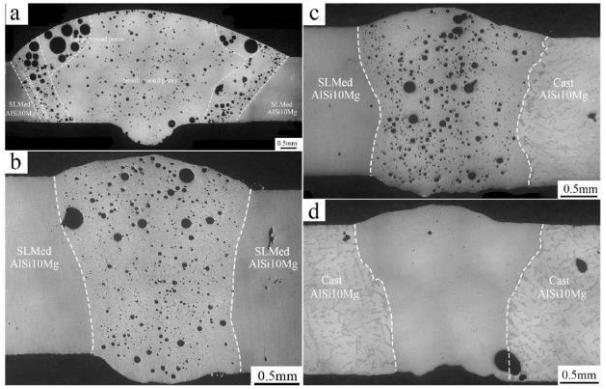
Current Status of the Art | Weldability of AM-ed Al Alloy Parts











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.

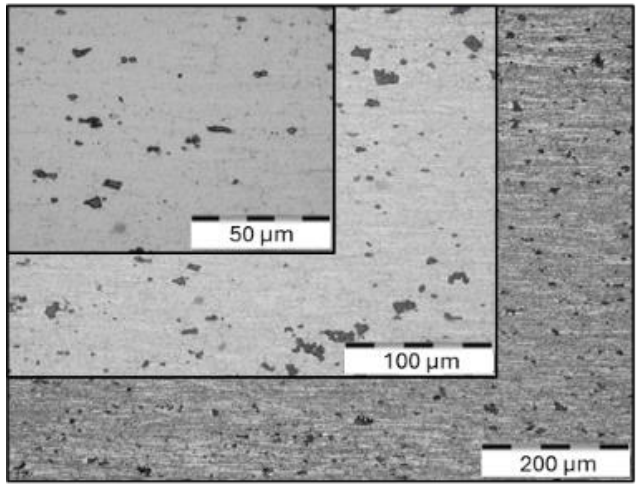
Main Theory:
High porosity levels in PBF-LB joints are formed due to the hydrogen porosity in the PBF-LB base material.

- 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.

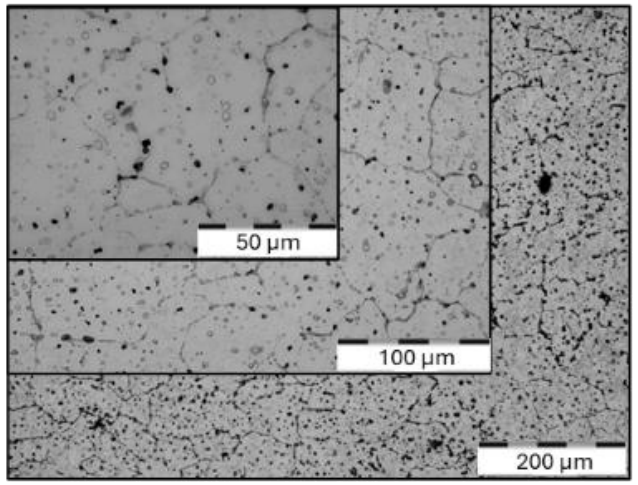
Base Materials

PBD: Parallel to Build Direction (vertical direction) / PDD: Parallel to Deposition Direction (horizontal direction)

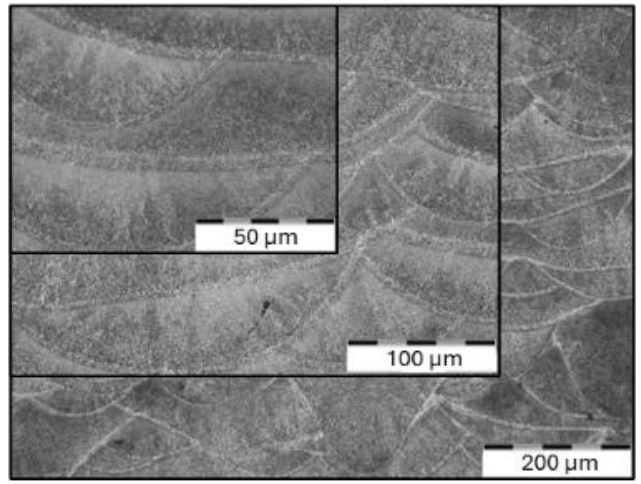
CONV EN AW-5083 Longitudinal



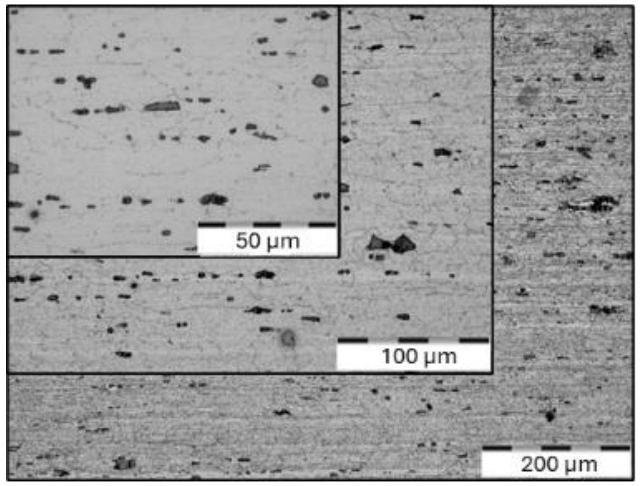
WAAM ER 5183 PBD



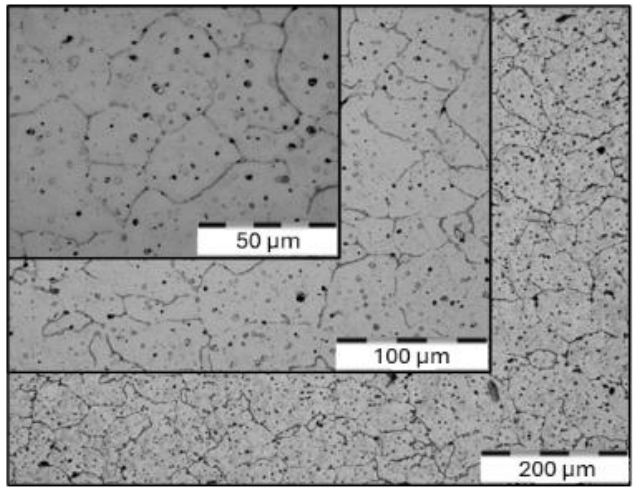
PBF-LB AlSi10Mg PBD



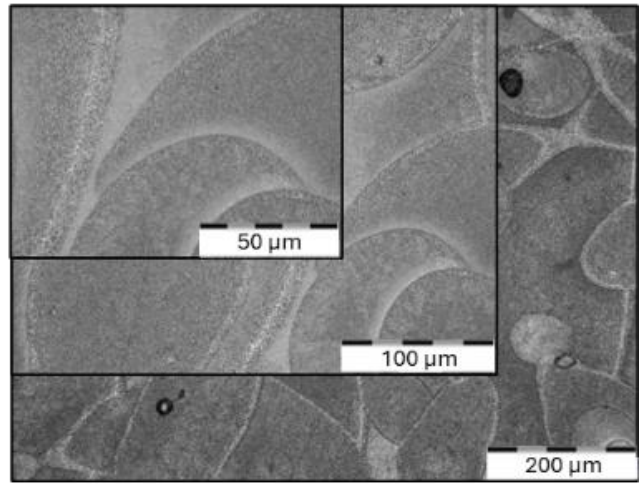
CONV EN AW-5083 Transversal



WAAM ER 5183 PDD



PBF-LB AlSi10Mg PDD



CONV UTS: 310.6 MPa

PBF-LB UTS: 435.6 MPa

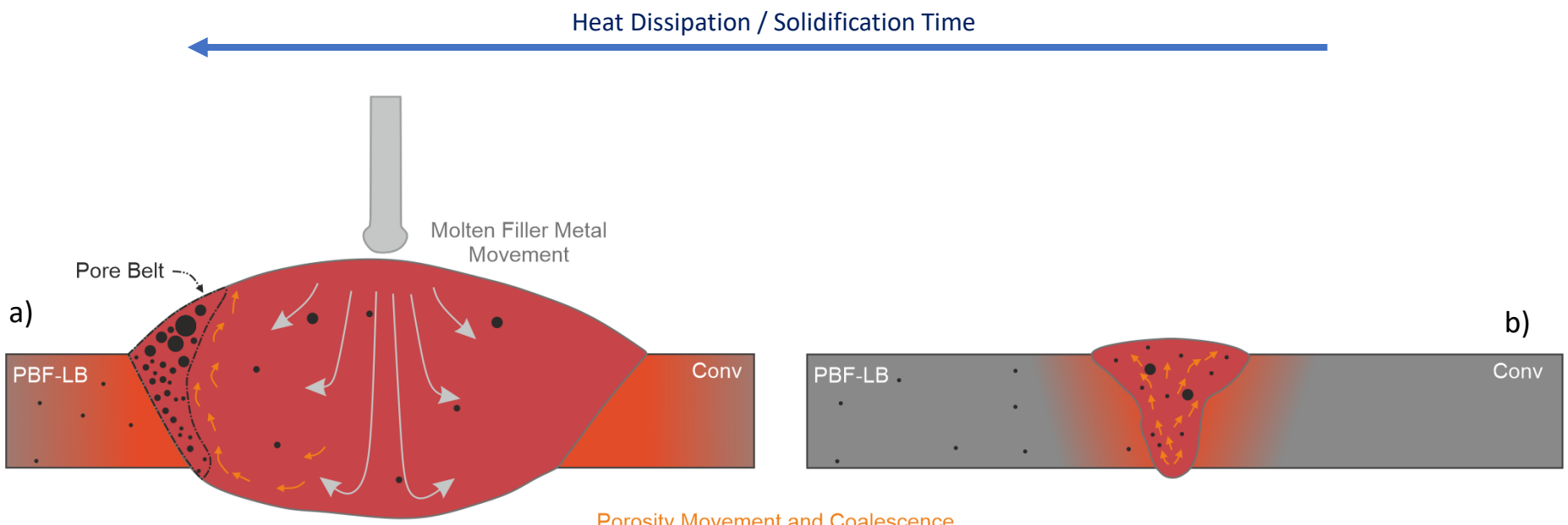
WAAM UTS: 288.4 MPa

Evaluated Welding Processes | Metallographic Examination

High Porosity Level

Evaluated Welding Processes | Pore Belt Region

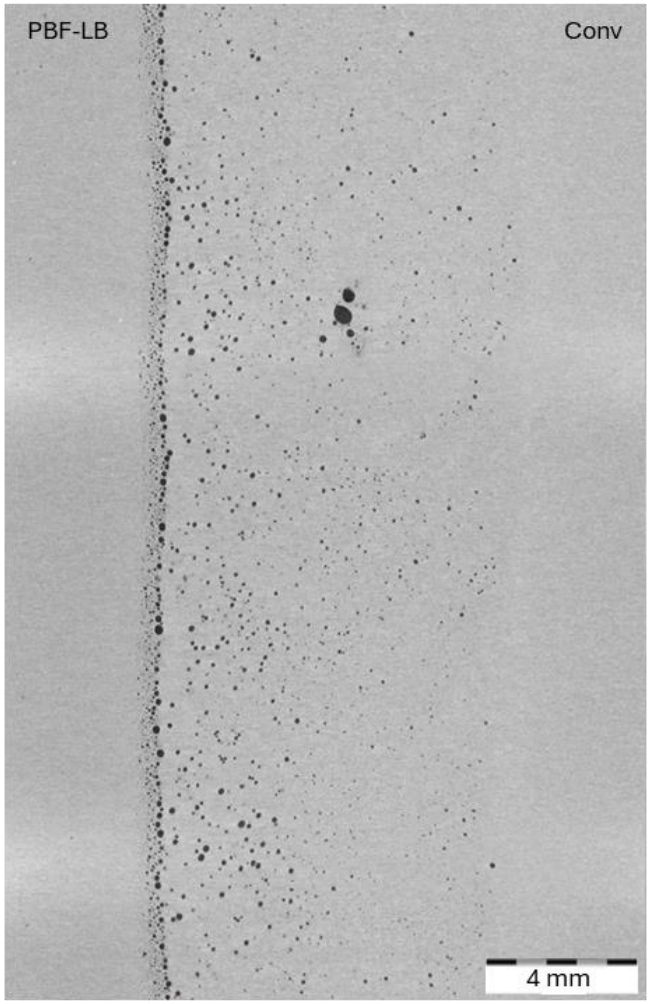
(a) Arc Welding Processes with Filler Metal Feeding



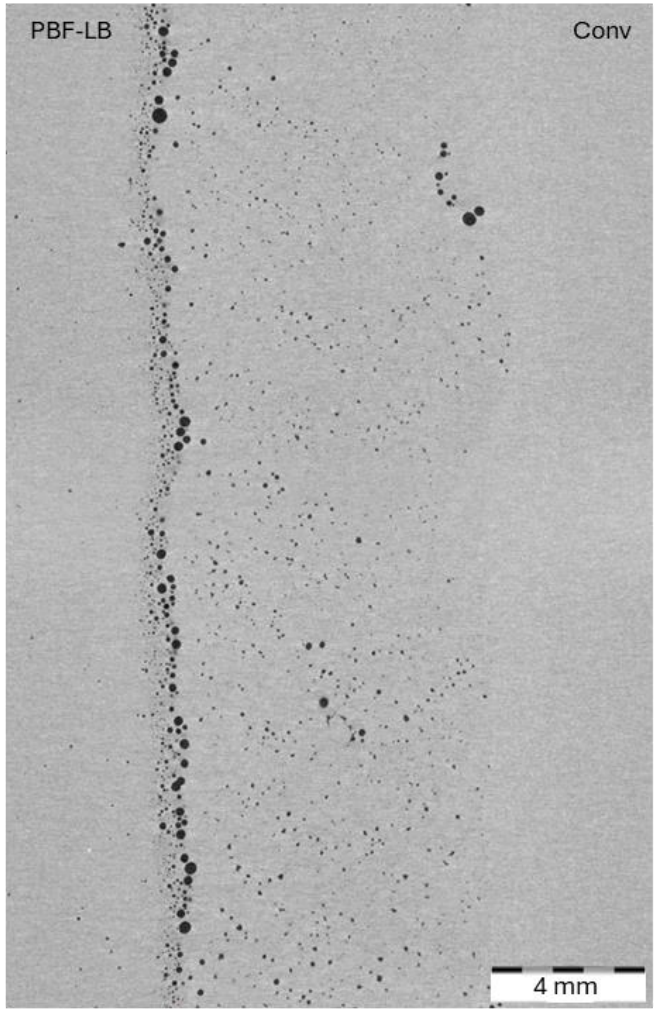
(b) Laser and Electron Beam Welding Processes without Filler Metal Feeding

Evaluated Welding Processes | CT of Pore Belt Region

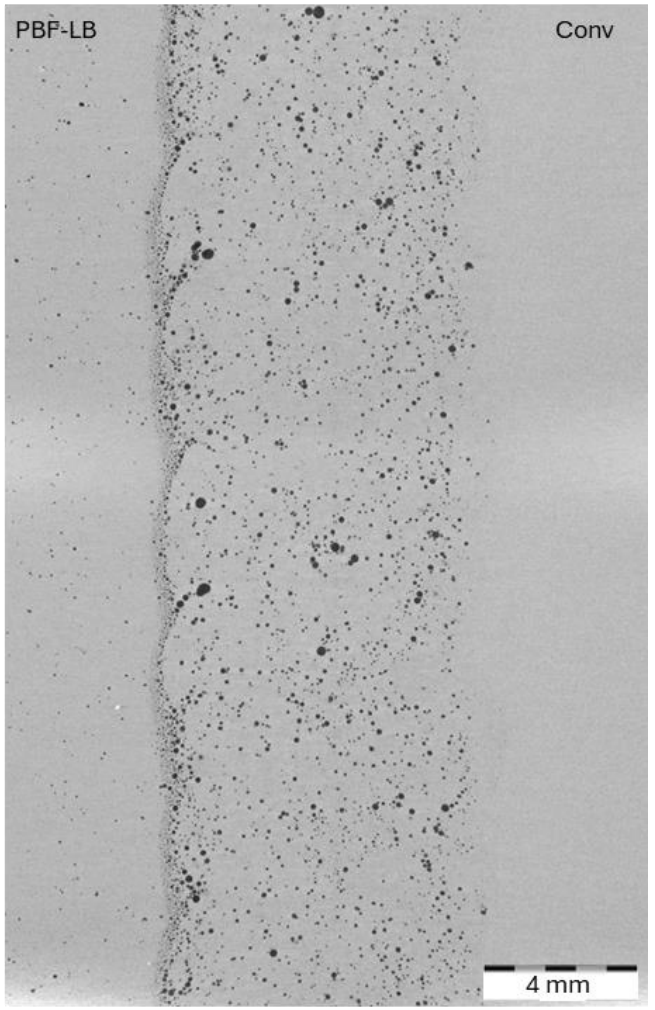
a) GMAW with Laser Cleaning



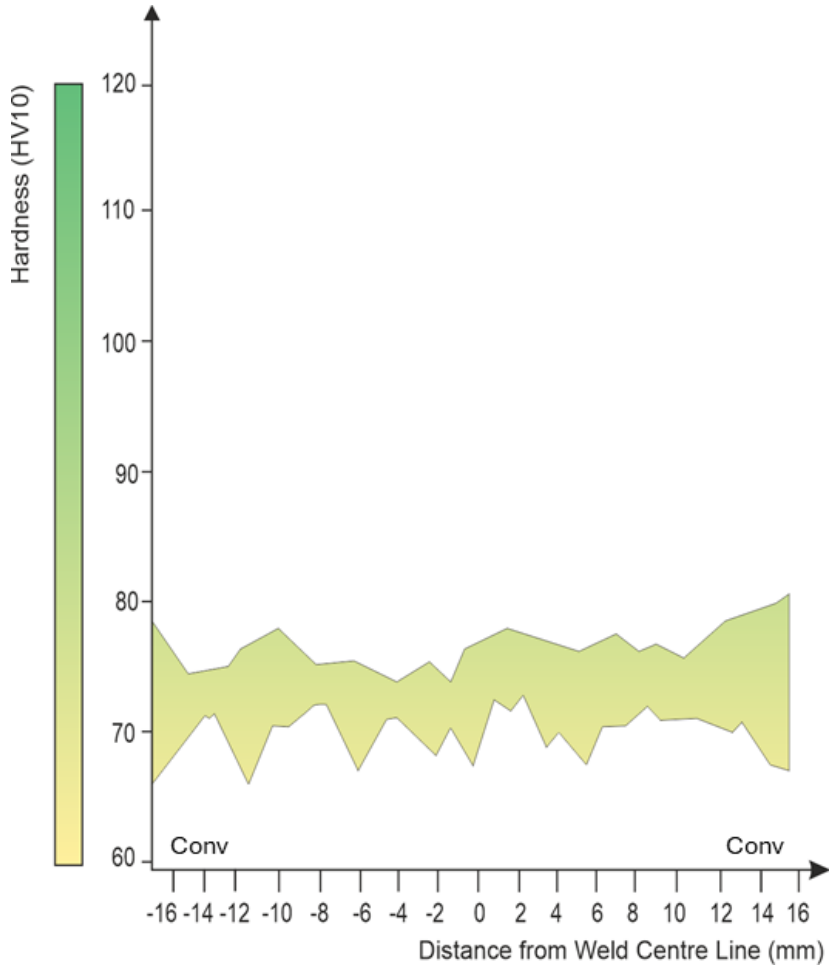
b) GTAW

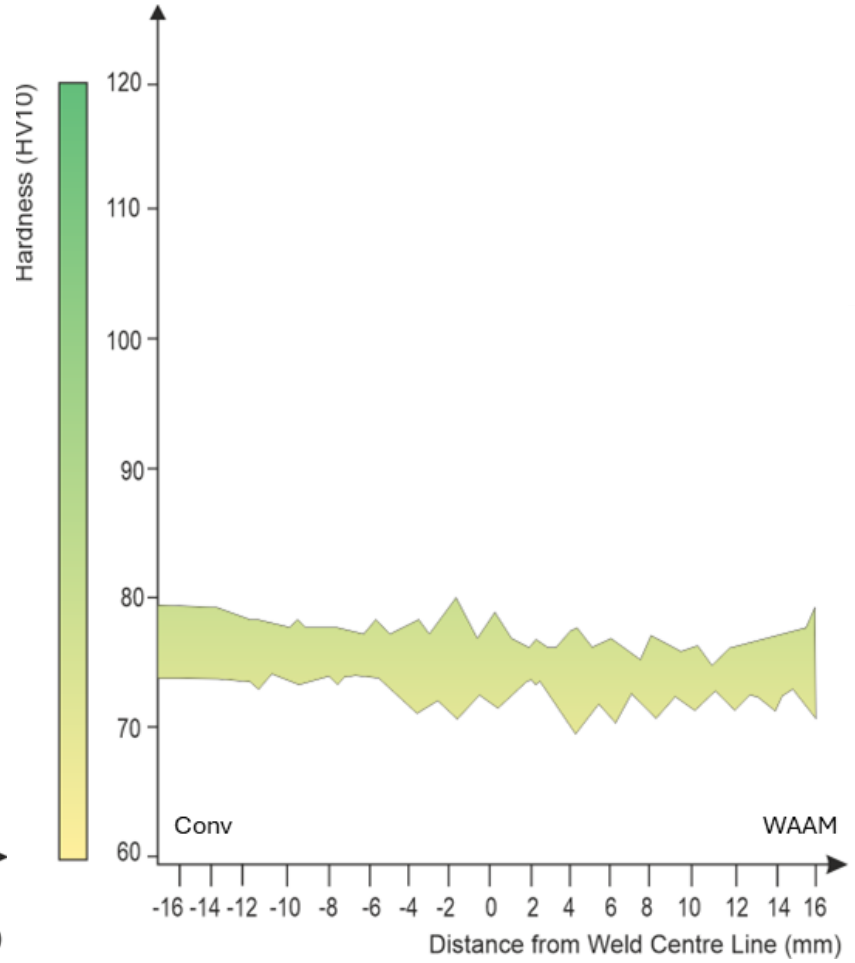


c) PAW



Evaluated Welding Processes | Hardness Evolution
Welds Between Conv - Conv and Conv - WAAM Materials





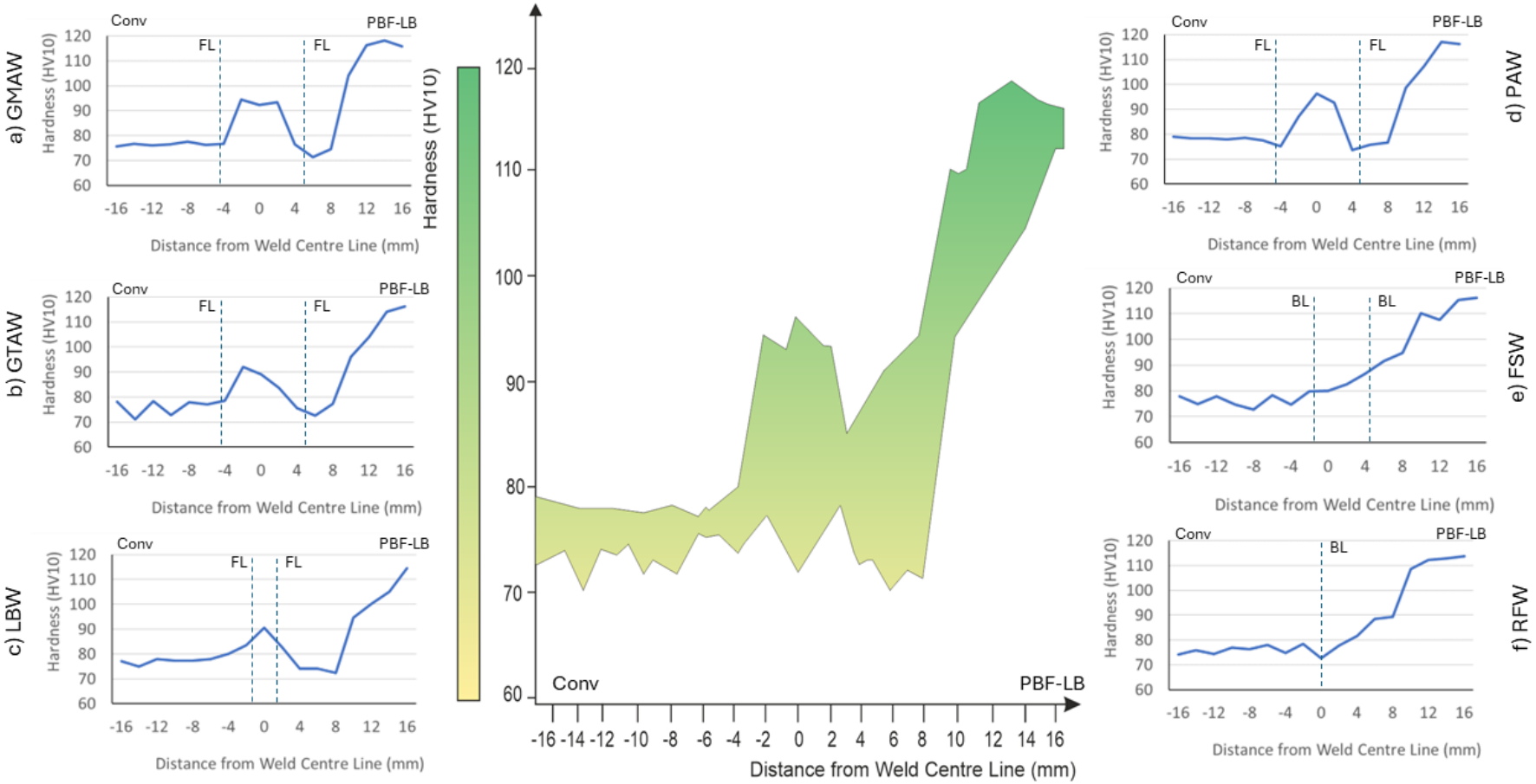
Hardness Profile of Welds Performed by GTAW, GMAW, PAW, LBW, FSW, and RFW

Hardness measurements (HV10) taken in the centre of the plate thickness. Distance between indentations = 2 mm

Welds between Conv – Conv and Conv-WAAM materials:

- No signifcant variations in the hardness profiles

Evaluated Welding Processes | Hardness Evolution
Welds Between Conv – PBF-LB Materials



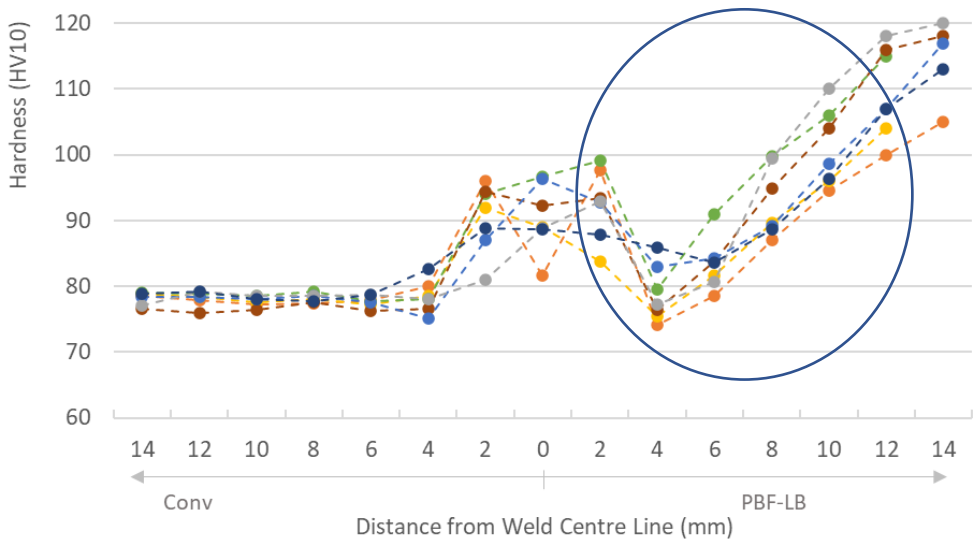
Hardness Profile of Welds Performed by GTAW, GMAW, PAW, LBW, FSW, and RFW

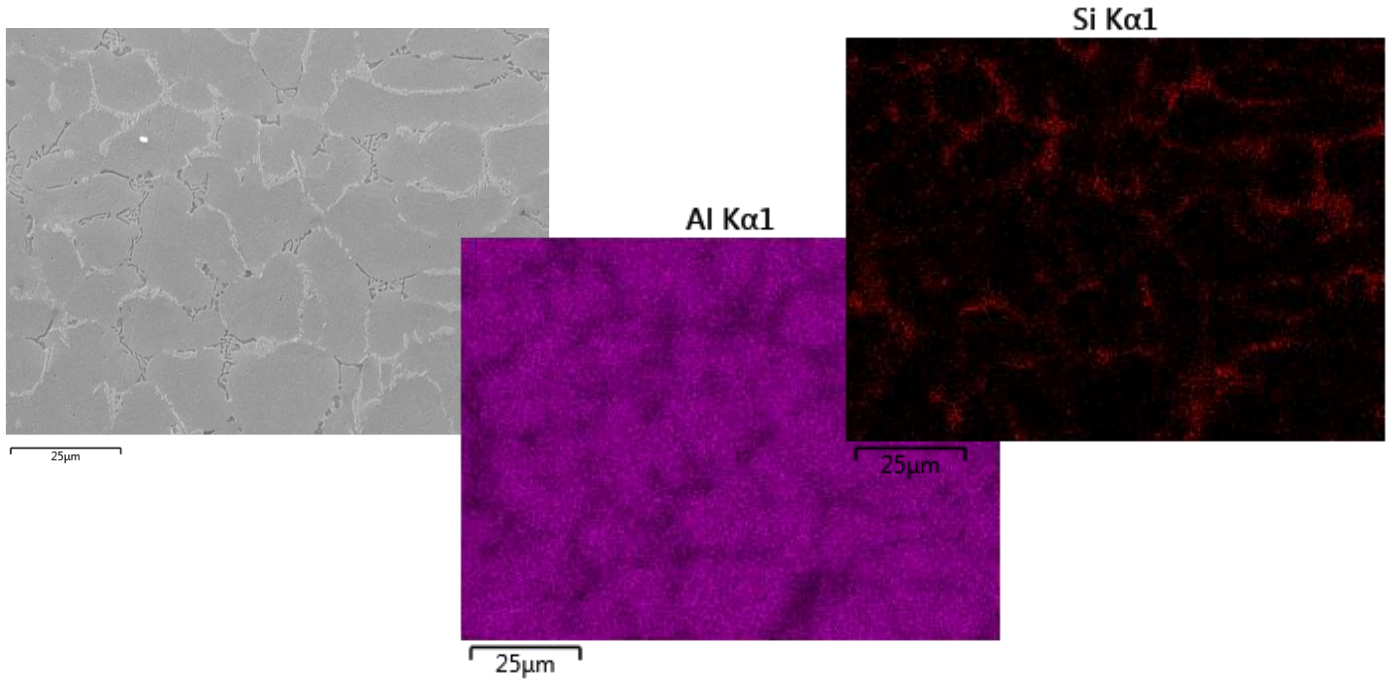
Hardness measurements (HV10) taken in the centre of the plate thickness. Distance between indentations = 2 mm

Welds between Conv – PBF-LB materials:

- Fusion Welding Processes:
  - Hardening in the WM zone
  - Softening in the HAZ of the PBF-LB material
- Solid-State Welding Processes:
  - Smooth increasing of the hardness from the Conv to the PBF-LB material

Evaluated Welding Processes | Metallographic Examination - Fusion



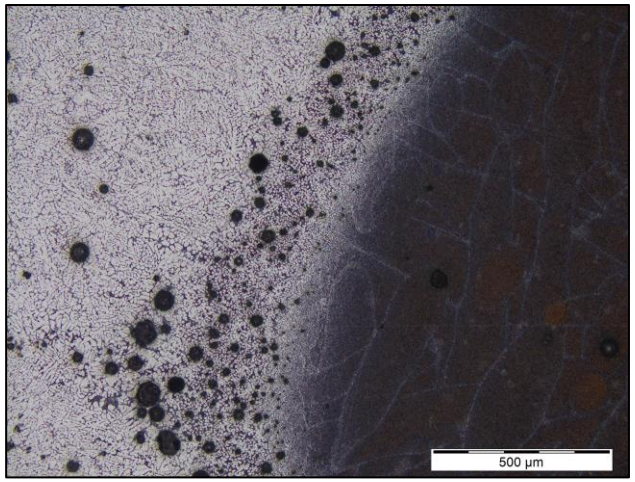


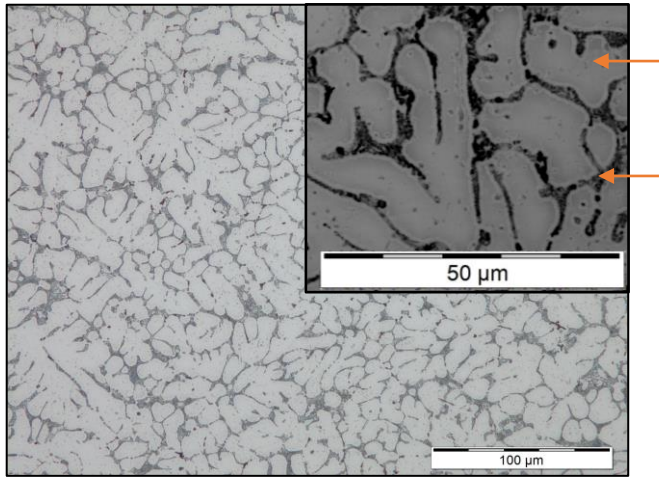
<u>Hardening</u> in WZ in the Conv - PBF-LB welds :

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

<u>Softening</u> in HAZ of Conv - PBF-LB welds :

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

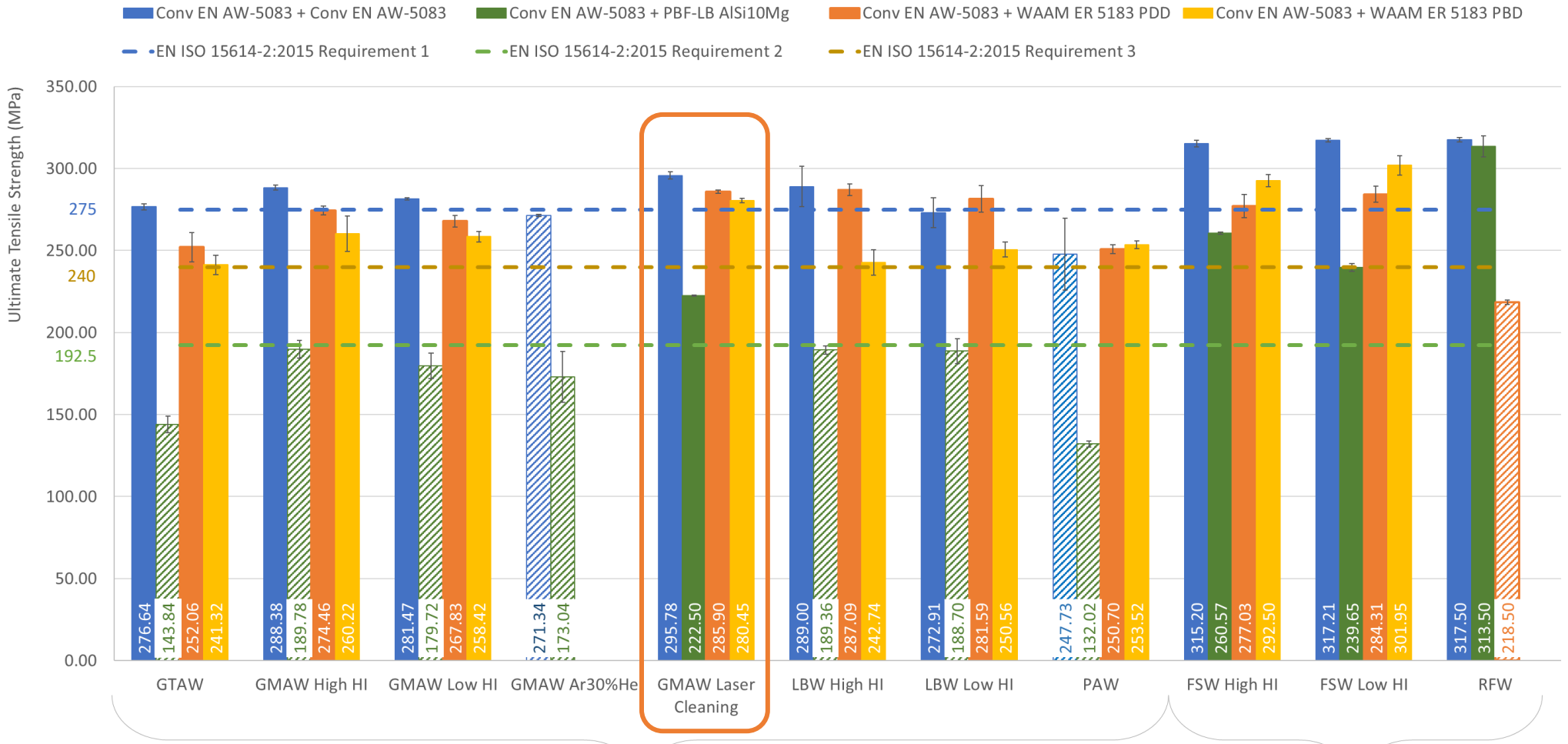




α-Al cells

Si-rich eutectic phases

Evaluated Welding Processes and Conditions | Tensile Testing

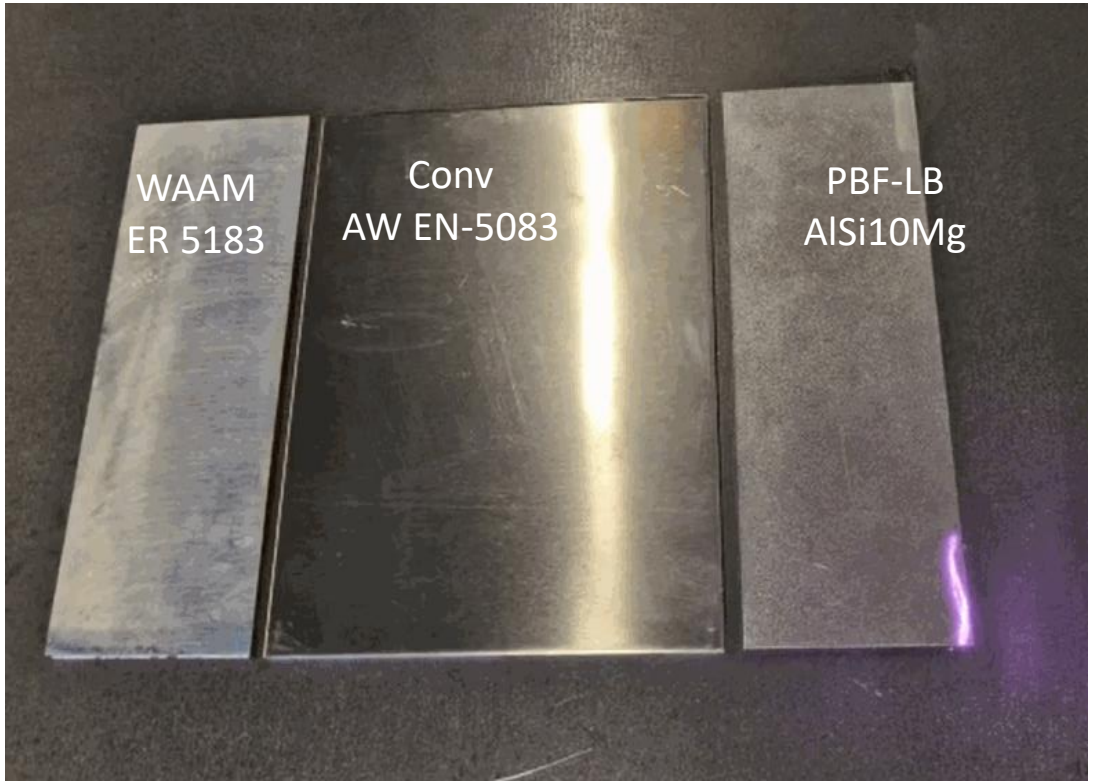


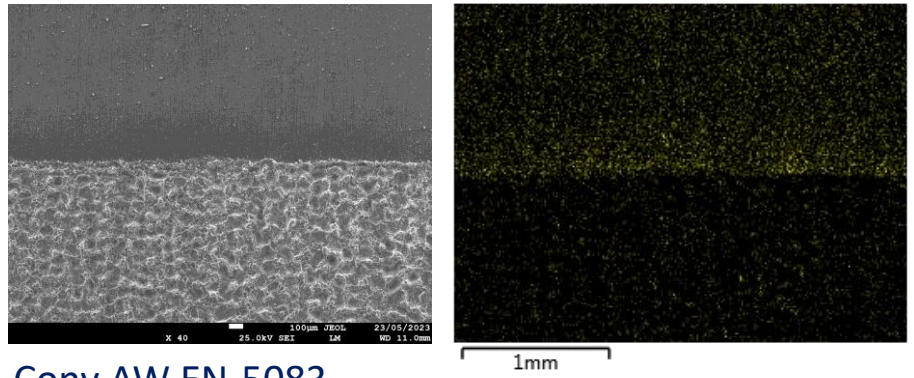
Solid Columns = Approved EN ISO 15614-2:2005
Non-solid Columns = Not Approved EN ISO 15614-2:2005

Conv EN AW-5083 + Conv EN AW-5083 = EN ISO 15614-2:2005 Requirement 1
Conv EN AW-5083 + PBF-LB AlSi10Mg = EN ISO 15614-2:2005 Requirement 2
Conv EN AW-5083 + WAAM ER 5183 = EN ISO 15614-2:2005 Requirement 3

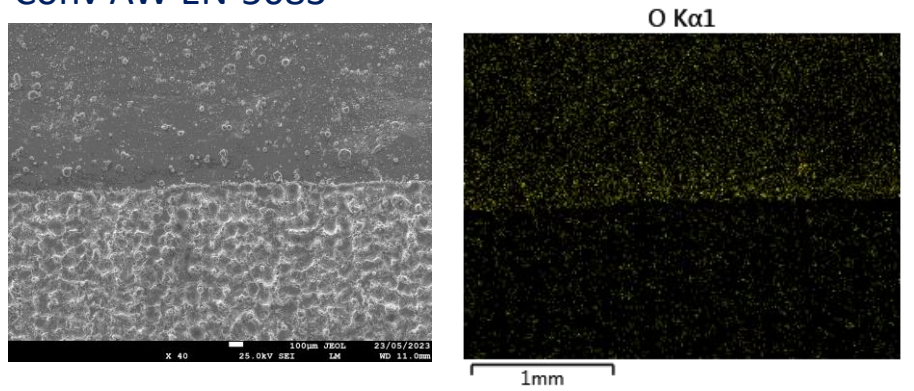
Weldability of AM Al Alloys | Laser Cleaning Prior to Welding

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

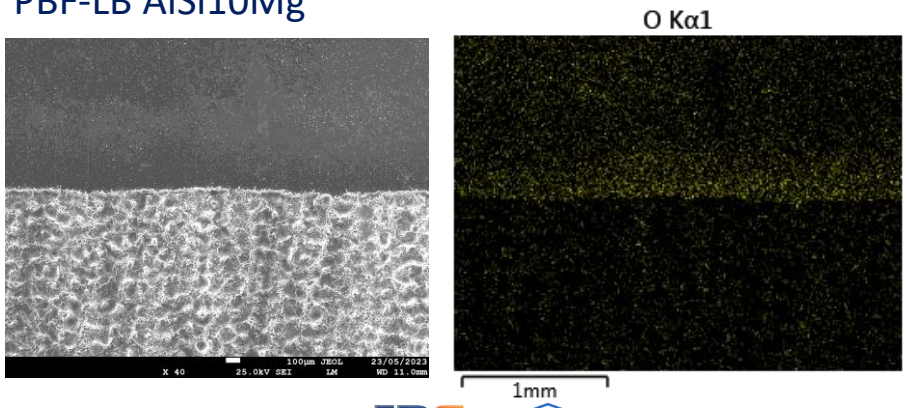




Conv AW EN-5083



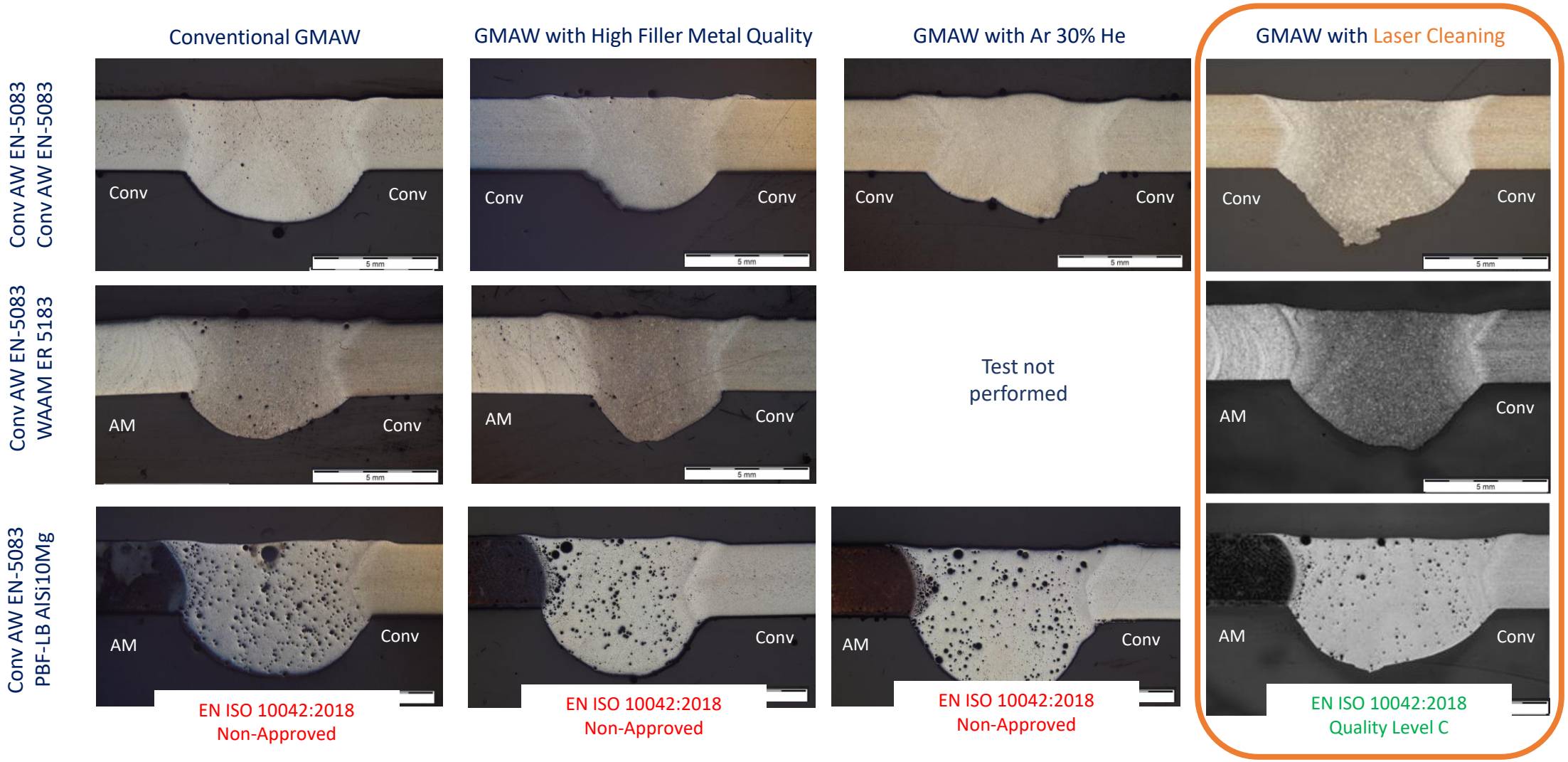
PBF-LB AlSi10Mg



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

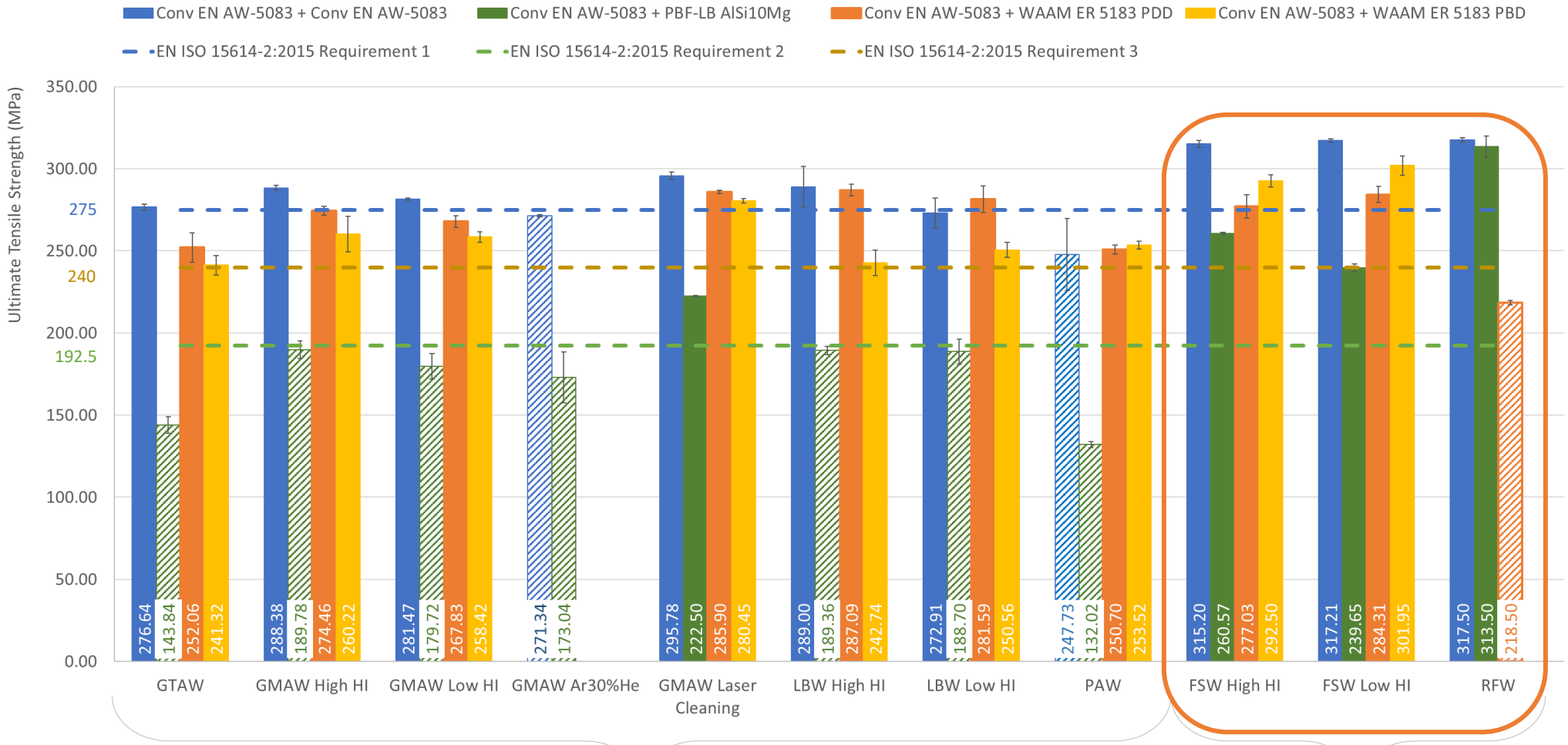
*SEM analysis performed 1 day after the Laser cleaning

Evaluated Welding Processes | Metallographic Examination



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



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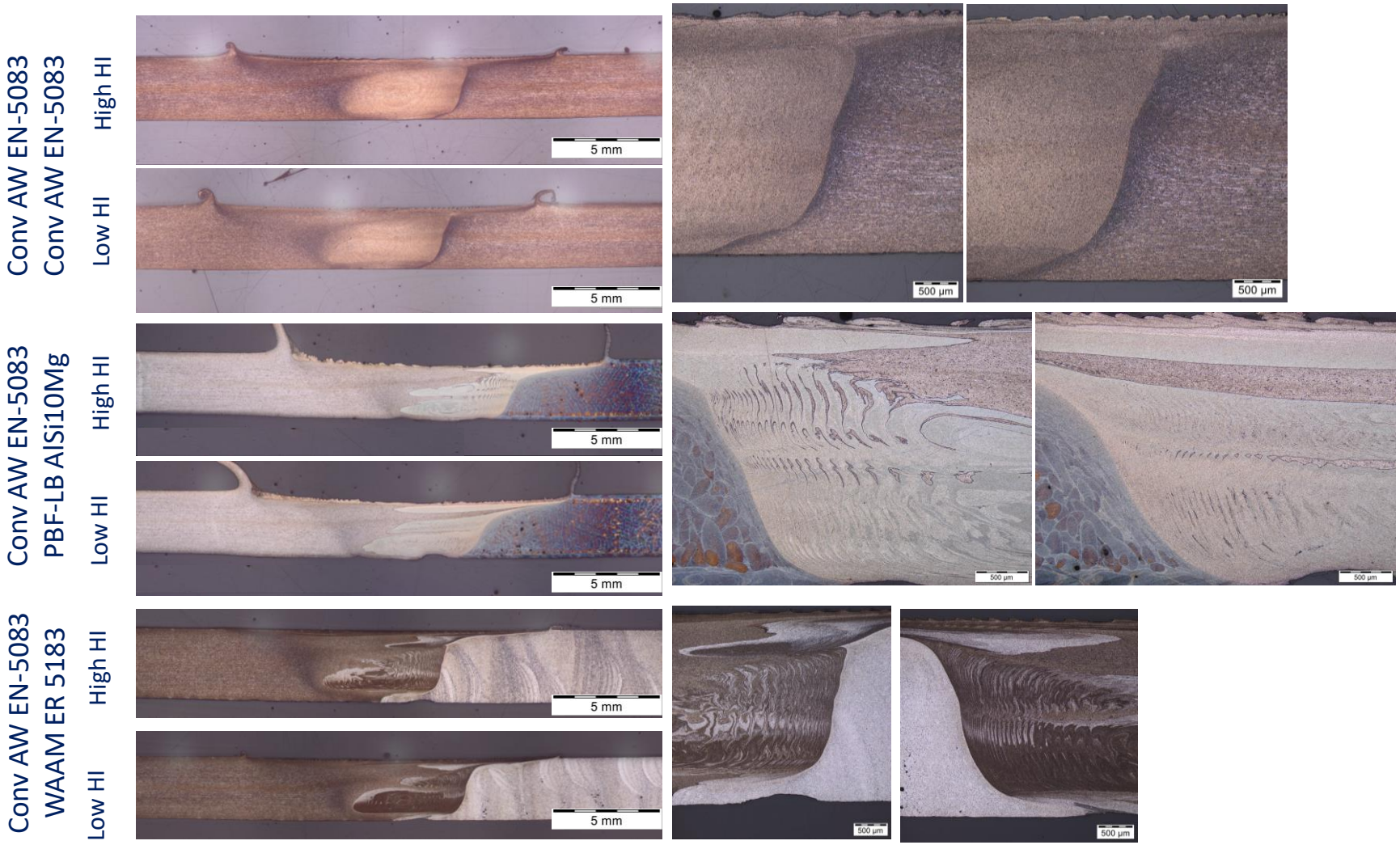
Conv EN AW-5083 + PBF-LB AlSi10Mg = EN ISO 15614-2:2005 Requirement 2
Conv EN AW-5083 + WAAM ER 5183 = EN ISO 15614-2:2005 Requirement 3

Fusion Welding Processes

Solid-State Welding Processes

Evaluated Welding Processes | 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

Significant difference of properties between the materials

Ductility WAAM >> Conv

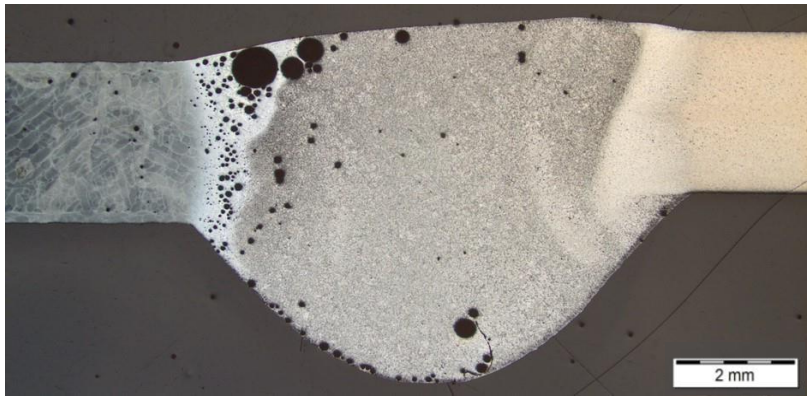
- Using a low friction pressure and/or a short friction time can minimise the deformation of the highly ductile WAAM part. However, this approach increases the risk of a poor bond formation in the weld zone, because there is not enough heat to create a strong connection

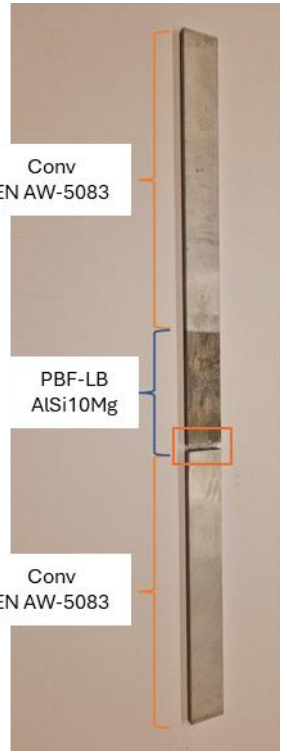
- The WAAM part tends to deform excessively under the frictional heat and pressure

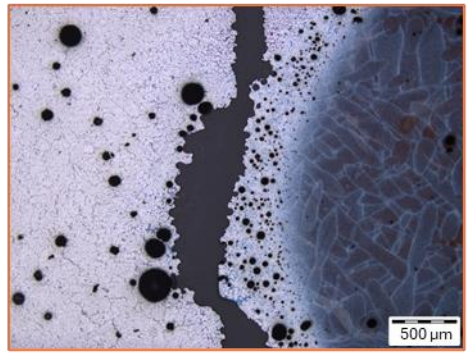
Evaluated Welding Processes and Conditions | Bend Testing

	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:

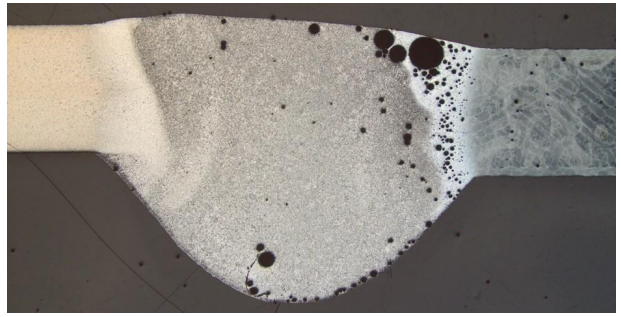
High porosity level in HAZ near the PBF-LB part (Pore Belt Region)

Conclusion and Final Remarks

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

Welding of PBF-LB Al Alloy Parts

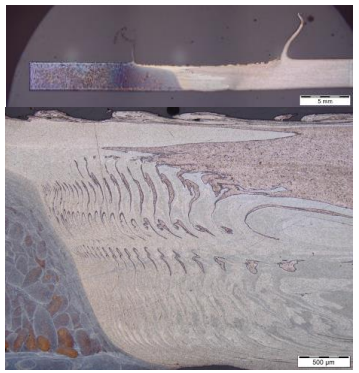
Fusion Welding Processes



Arc Welding / LBW

Solid-State Welding Processes

RFW

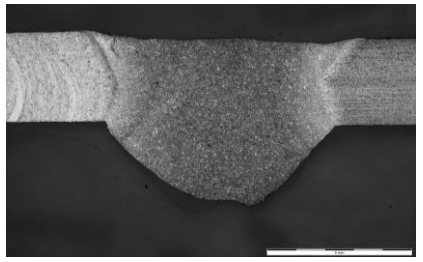


FSW

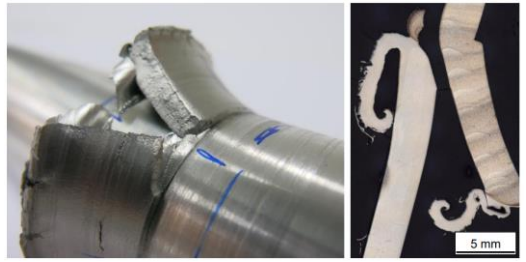
Weldability

Welding of WAAM Al Alloy Parts

FSW



Arc Welding / LBW



RFW

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

- Highest Weldability/Welding Quality for all Materials Combinations: FSW

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

Thank you for your attention!

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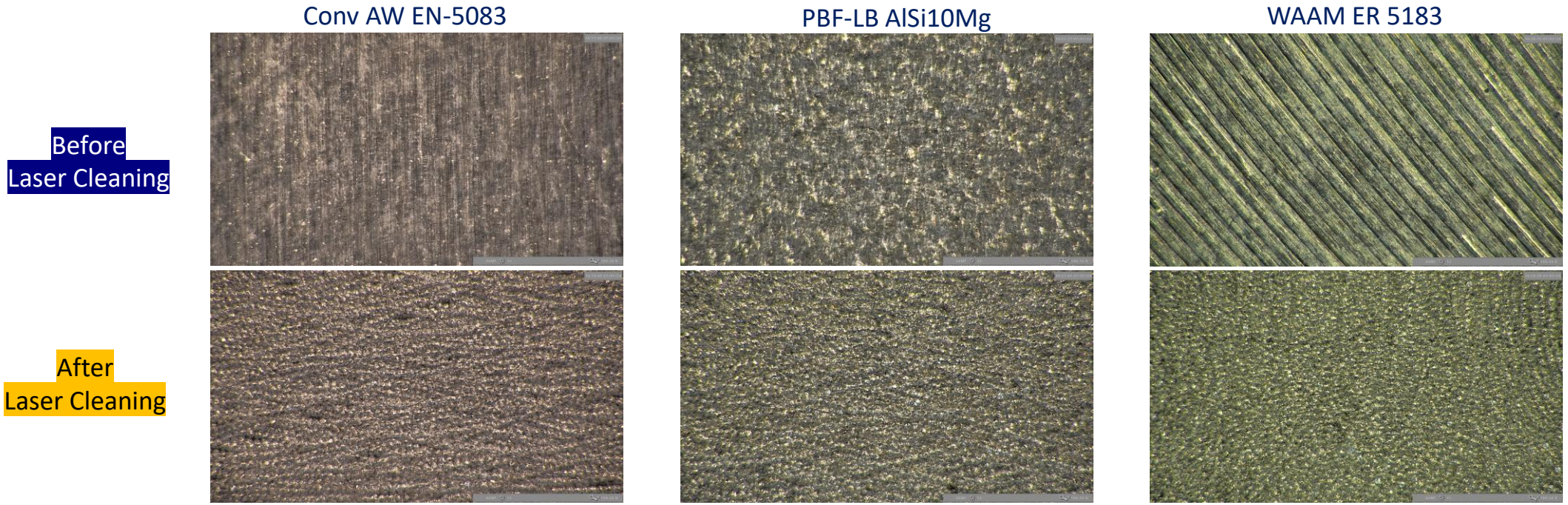
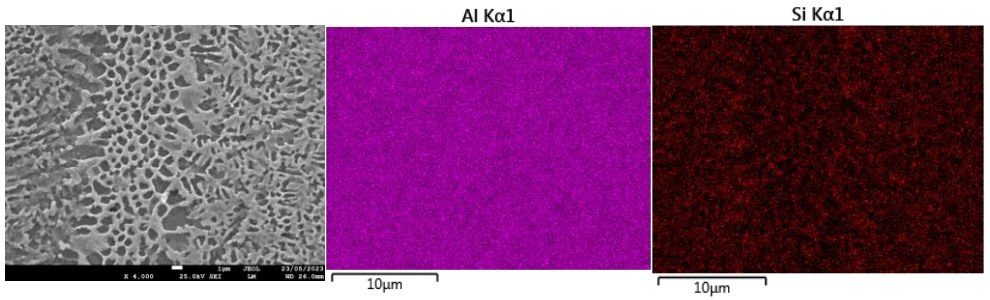
Weldability of AM Al Alloys | Laser Cleaning Prior to Welding

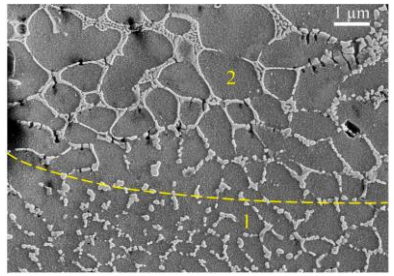


Material	Before Laser Cleaning				After Laser Cleaning			
	Ra (µm)		Rz (µm)		Ra (µm)		Rz (µm)	
Conventional AW EN-5083	0.269	**0.271**	1.980	**1.997**	3.902	**4.129**	29.300	**31.100**
	0.261		1.930		4.137		31.600	
	0.284		2.080		4.348		32.400	
PBF-LB AlSi10Mg	7.011	**6.576**	49.300	**46.167**	7.561	**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 | Metallographic Examination – Fusion Eutectic Si Particles



Zhao *et al.* (2019)



HAZ of Conv – PBF-LB weld (PBF-LB side)