böhler welding by voestalpine
3Dprint

Impact of WAAM Process on Material Characteristics

Dr. Martin Schmitz-Niederau

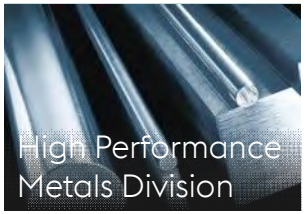
m2i – Dec 2020

Agenda

- Who´s voestalpine Böhler Welding?
- Intro - Vision
- WAAM and joint welding - What is different?
- Impact on low alloyed steels for construction
- Impact on duplex steels/ni-alloys

WE ARE PART OF VOESTALPINE AG

Tool steel & leading position for high-speed steel & special forged parts



Turnouts, rails, processed wire, seamless tubes & welding consumables

Welding:
608 Mio EUR |
2,300 Employees

Premium steel strip, electrical steel strip, heavy plate, cast products

High-quality metal processing solutions, precision steel strip & special components

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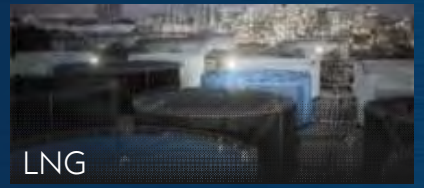
böhler welding by voestalpine

Best products for demanding industries



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böhler welding
by voestalpine
3Dprint

Our Vision:
The Future of Productivity
Wire Arc Additive Manufacturing

voestalpine Böhler Welding
www.voestalpine.com/welding

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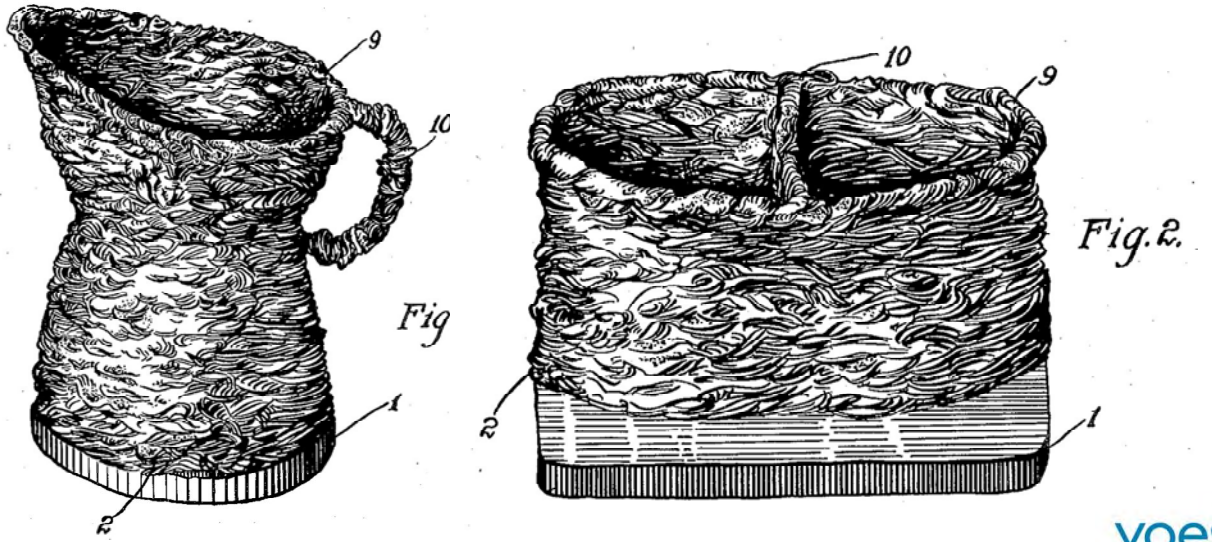
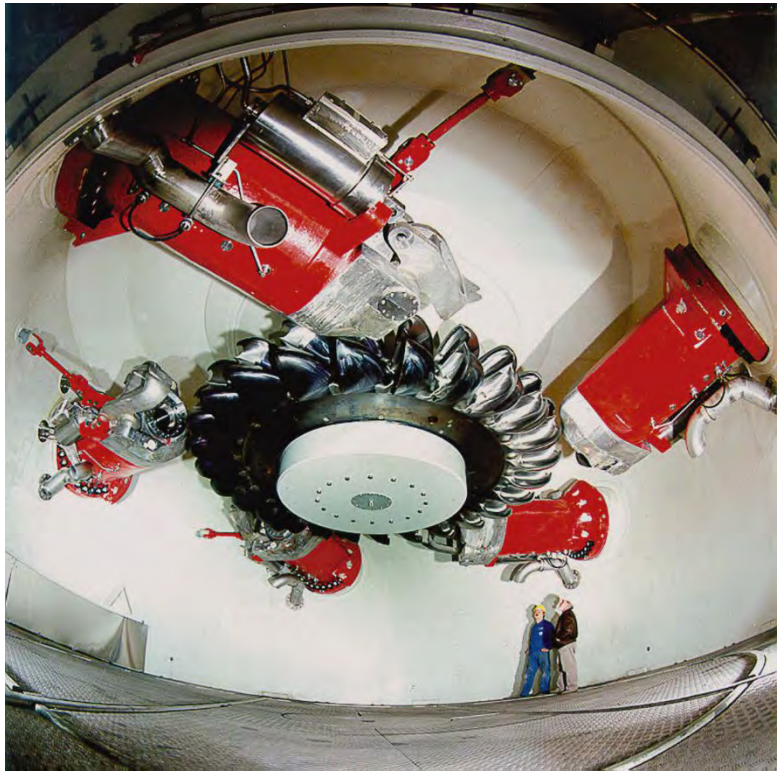
The **early** vision…

1926 Baker – patented "The use of an electric arc as a heat source to generate 3D objects depositing molten metal in superimposed layers"



Today to some extent real .....



Application of additive manufactured buckets of a martensitic chromium steel in a pelton water turbine.

www.andritz-hydro.com

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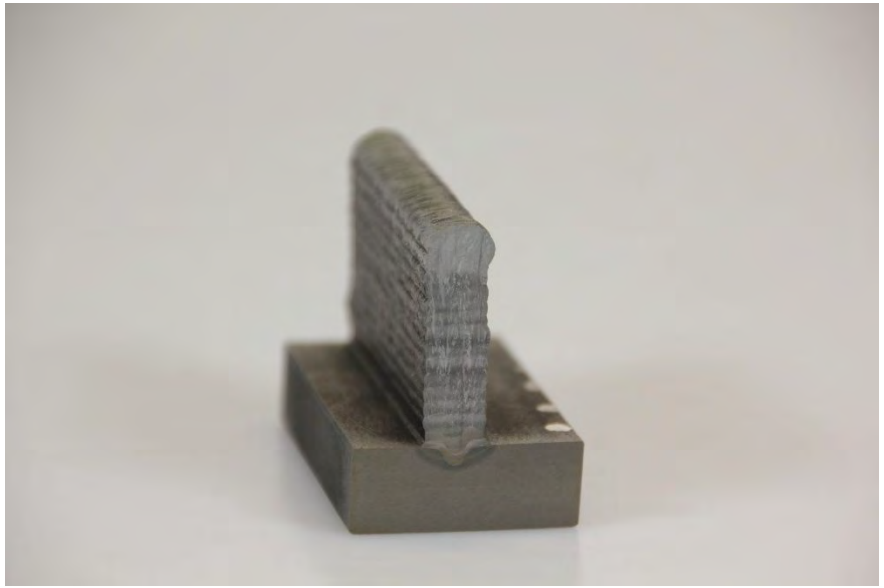
WAAM and the heat...

side view on a printed wall



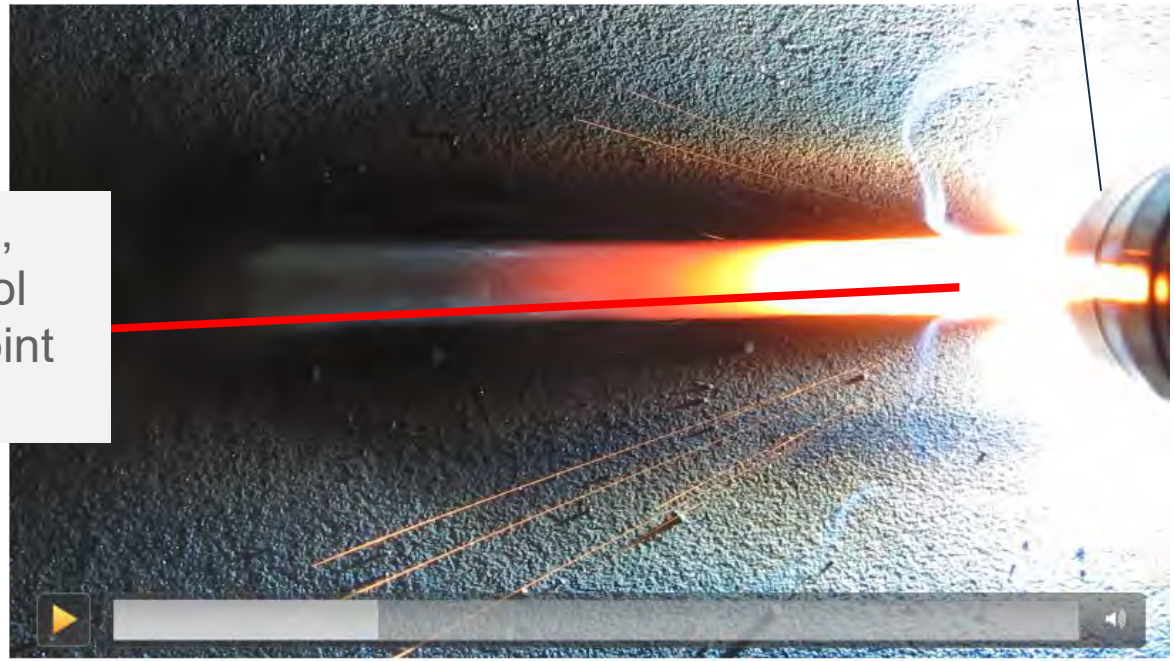
WAAM and the heat...

top view on a printed wall

WAAM and the heat...

top view during printing

edge of GMAW burner nozzle



printing direction

long heat track, longer melt pool compared to joint welding

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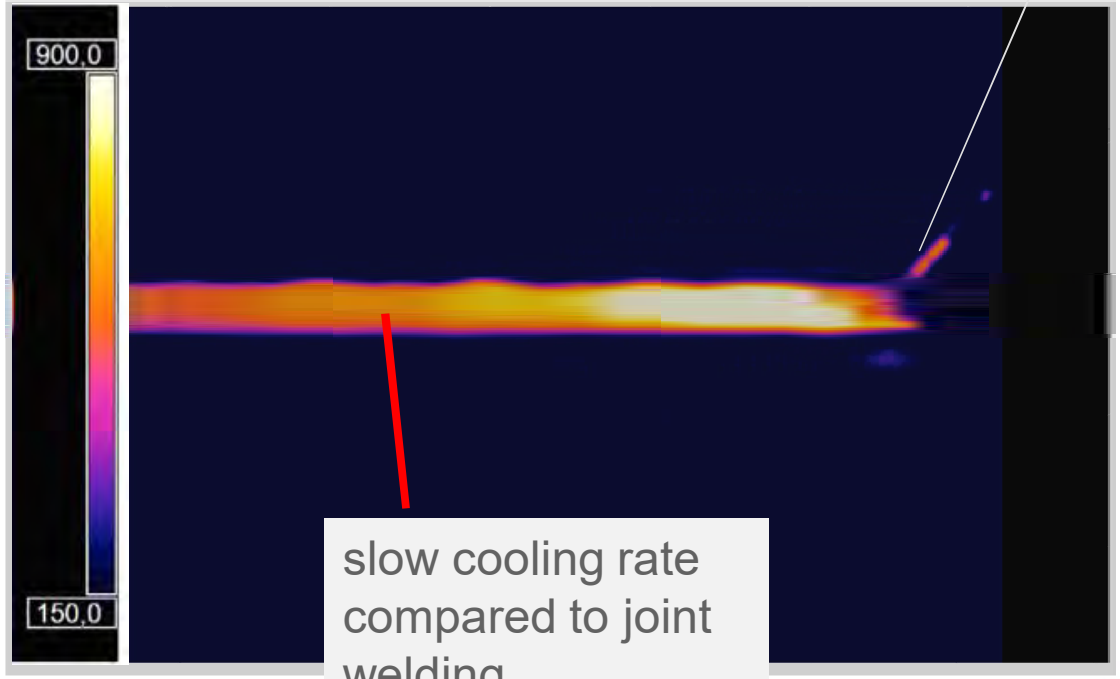
WAAM and the heat...

side view with thermocam (max. 900 °C) during printing

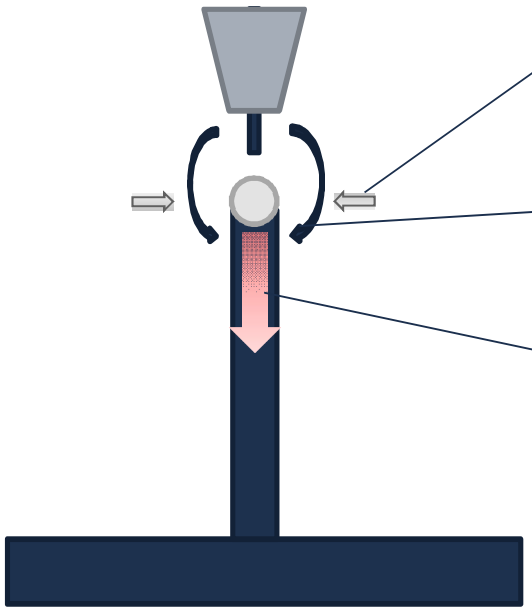
GMAW burner nozzle



slow cooling rate compared to joint welding

printing direction

3Dprint wires – Tasks



Adjust welding parameters and surface tension and viscosity to keep melt pool in position

Control gas flow and shielding conditions (different from joint welding)

(pores, more silicates)

One dimensional conductive heat flow

Agenda

böhler welding by voestalpine 3Dprint

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Print materials for construction

böhler welding by voestalpine 3Dprint

3Dprint AM 46

WAAM solid wire, unalloyed, structural steel

Material Type		
S460	8MnSi7	1.5115

Characteristics

WAAM solid wire designed for 3Dprinting of cryogenic fine grained steel structures.
The printed deposit is characterised by good low temperature properties.

Typical analysis of the solid wire (wt.-%)

	C	Si	Mn
wt.-%	0.1	1.00	1.7

Available products

Diameter: 1,0 mm – 1,2 mm
Package: BS300 15 kg – ECOdrum 100 – ECOdrum 250 – S760 300
Other diameters and packages on request.

Approvals

ABS (3YSA)

Typical mechanical properties acc. to EN ISO 15792-1

Heat treatment	Yield strength Rp0.2	Tensile strength Rm	Elongation (L0=5d0)	Impact energy ISO-V KV J	
	MPa	MPa	%	-20 °C	-40 °C
u	480	580	24	60	47

u untreated, shielding gas Ar + 18 % CO2, DC+

Classification as welding consumable:

EN ISO 14341-A	AWS A5.18
G 46 4 M21 4Si1 / G 46 2 C1 4Si1	ER70S-6

böhler welding by voestalpine 3Dprint

3Dprint AM 35

WAAM solid wire, unalloyed, structural steel

Material Type		
S355	10Mn4	1.1108

Characteristics

WAAM solid wire designed for 3Dprinting of unalloyed steel structures.
The printed deposit is characterised by a low Mn and Si content.

Typical analysis of the solid wire (wt.-%)

	C	Si	Mn
wt.-%	0.10	0.3	1.05

Available products

Diameter: 1,0 mm – 1,2 mm
Package: BS300 15 kg – ECOdrum 100 – ECOdrum 250 – S760 300
Other diameters and packages on request.

Typical mechanical properties acc. to EN ISO 15792-1

Heat treatment	Yield strength $R_{p0.2}$	Tensile strength R_m	Elongation ($L_0=5d_0$)	Impact energy ISO-V KV J
	MPa	MPa	%	-20 °C
u	420	500	25	75

u untreated, as welded – shielding gas Ar + 18 % CO_2, DC+

Classification as welding consumable:

EN ISO 14341-A	AWS A5.18
G 35 2 M21 Z2Si	ER70S-G

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3D print AM 46 vs. EN 10025-2 S355J2

böhler welding by voestalpine 3Dprint

Test aim: to reach the mech.-techn. data of S355J2 with a high effiencency process

3D print AM 46 (class. EN ISO 14341-A G 46 4 M21 4Si1 / G 46 2 C1 4Si1 as welding consumable)

- » Rp0,2 typical: 480 MPa
- » Rm typical: 580 MPa
- » El% typical: 24
- » Impact Energy KV_2 typical : 47J @ -40°C
- » tested as welding consumable with shielding gas M21 (Ar – CO_2 82-18) according to the classification standard

S355J2

» Rp0,2 min:	355 MPa	(W.T. ≤ 16mm)
	345 MPa	(16 < W.T. ≤ 40 mm)
	335 MPa	(40 < W.T. ≤ 63 mm)
» Rm:	470-630 MPa	(3 < W.T. ≤ 100 mm)
» Min El%:	20	(3 < W.T. ≤ 40 mm)
	19	(40 < W.T. ≤ 63 mm)
» Min. Impact Energy KV_2	27J @ -20°C	

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High Productivity WAAM procedure with 3Dprint AM 46

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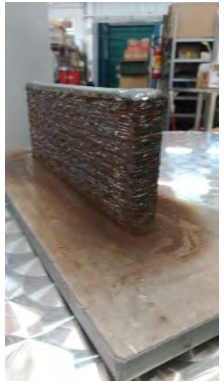
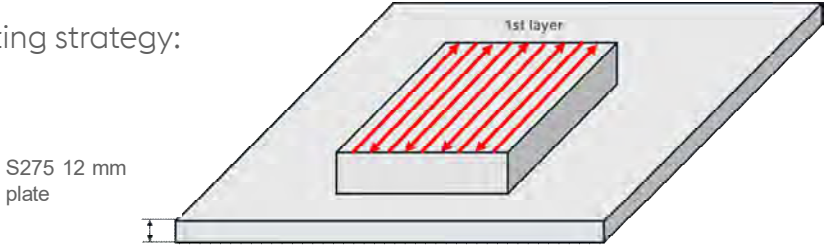
Wire Arc Additive Manufacturing of various thickness walls

Purpose: testing of a procedure matching with S355J2 structural plates with evaluation of the wall thickness effect on mechanical properties along the printing direction and layers build-up direction



- Wall1 – 3 beads 13mm
- Wall2 – 6 beads 24mm
- Wall3 – 12 beads 46mm
- 4 layers continuous printing
- Same printing conditions
- Printing strategy:



Printed by: ARC ADDITIVE

GTech 3D Additive Manufacturing

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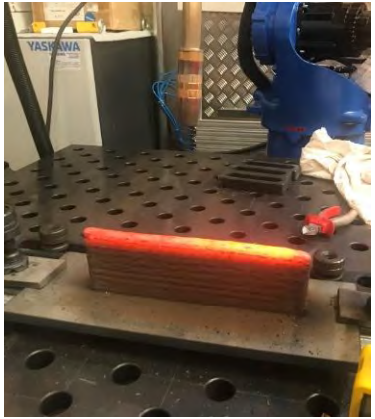
High Productivity WAAM Procedure with 3Dprint AM 46
Printing parameters and Deposition Rate

böhler welding by voestalpine 3Dprint

- Wire d.: Ø1,2 mm
- Welding Process: GMAW Cold Metal Transfer
- Shielding Gas: M21, 16 l/min (18 % CO_2, Rest Ar)
- Travel Speed: 90 cm/min
- Wire Speed: 6,5 m/min -> **3.5 kg/h**
- Current: 215-225 A
- Voltage: 17 – 18 V
- Heat Input: 2,57 kJ/cm
- Weaving/Stringer: Stringer Beads
- Cleaning: Hand brushing every for 4 layers
- Interlayer T Max 250°C **every 4 layers**
- Bead dimension (hxw) 2,3-2,5x4,5-5 mm



Wall 24mm

Wall 46 mm

	Thickness [mm]	Length [mm]	Height [mm]	Weight [kg]	Printing time [min.]	Real depos. [kg/h]
Wall1 -13 mm	13	263	101	2,71	72	2,26
Wall2 - 24mm	23,5	263	100	4,85	129	2,26
Wall3 - 46mm	46,1	263	101	9,61	235	2,45

Printed by: ARC ADDITIVE GTech 3D Additive Manufacturing

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High Productivity WAAM Procedure with 3Dprint AM 46
Specimen Positioning

Testing Lab: TEC-Eurolab we make you feel sure

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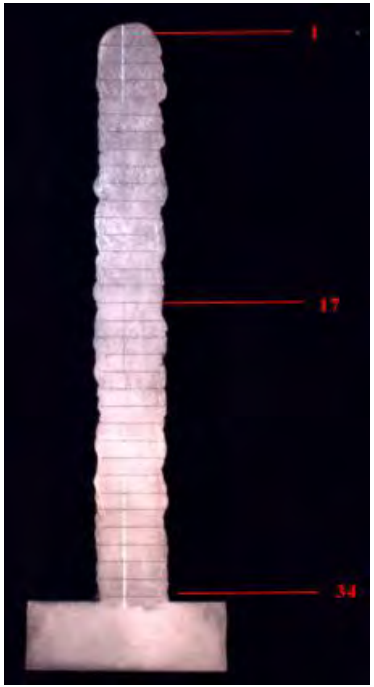
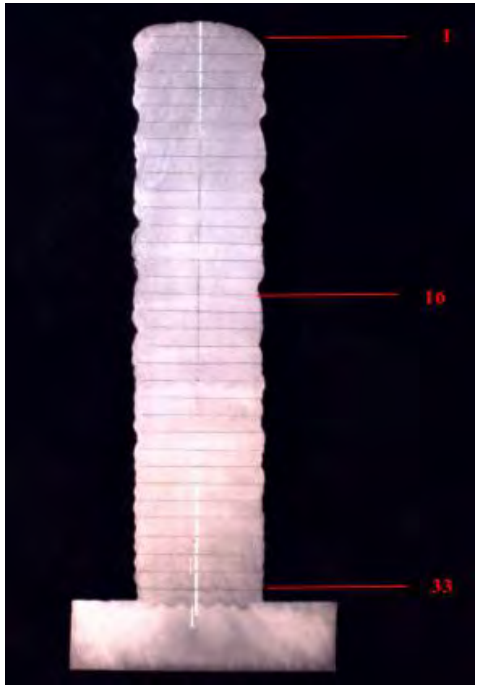
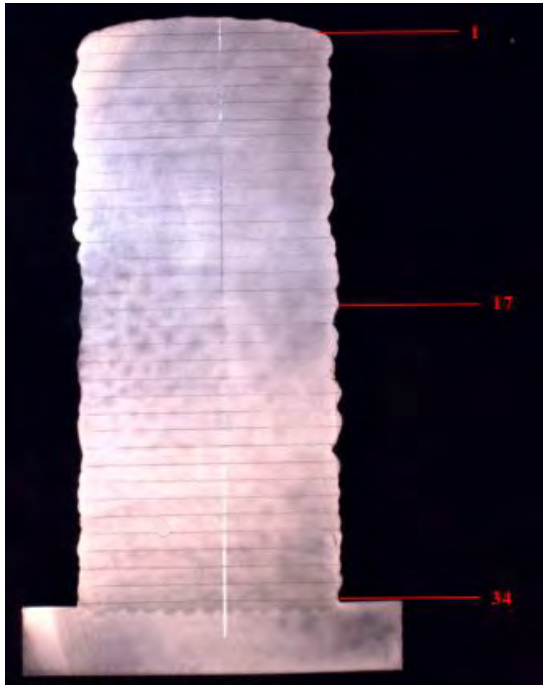
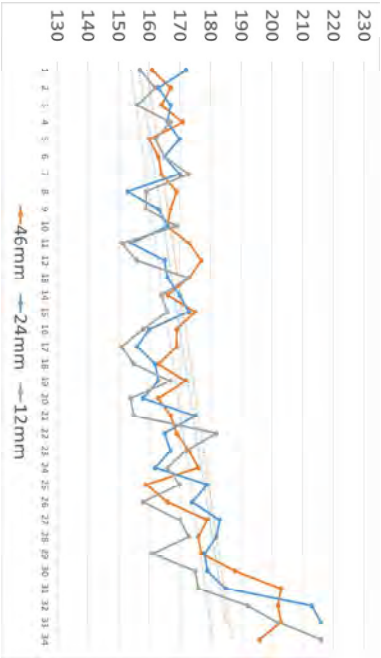
High Productivity WAAM procedure with 3Dprint AM 46
Hardness Survey (HV10)

böhler welding by voestalpine 3Dprint









Testing Lab: TEC·Eurolab we make you feel sure

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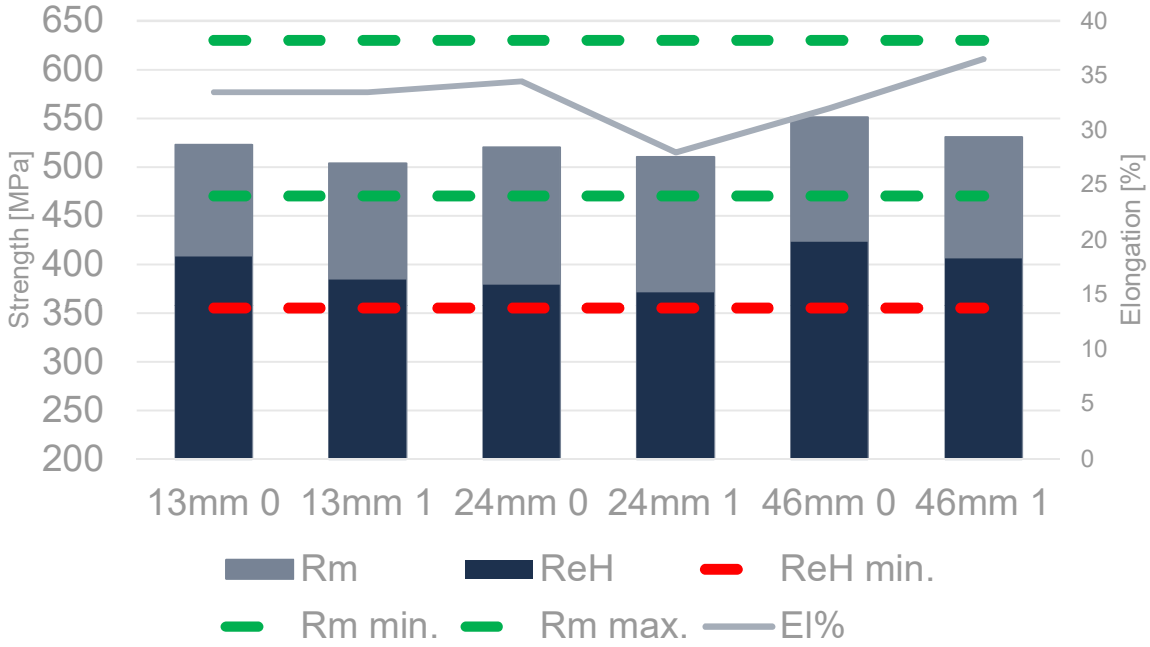
High Productivity WAAM procedure with 3Dprint AM 46 Longitudinal Tensile



- Strength meeting the requirement
- High Elongation %
- "Top" values lower than "Bottom" values
- Strength increase for the 46mm Wall

Testing Lab: TEC-Eurolab we make you feel sure

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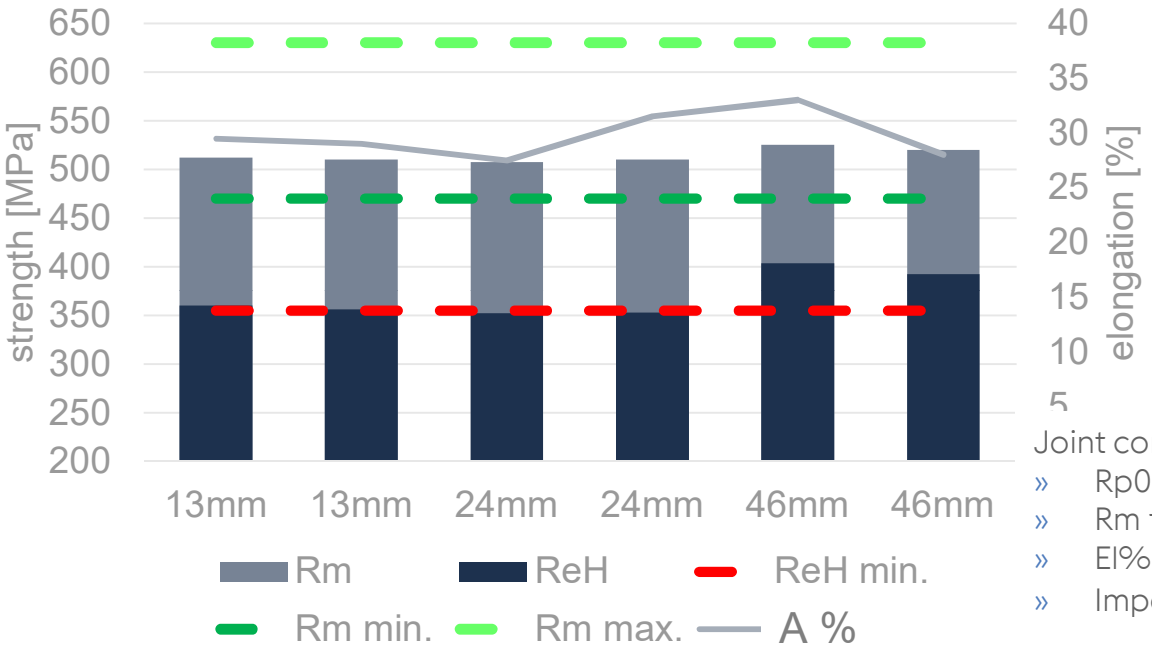
High Productivity WAAM procedure with 3Dprint AM 46
Transversal Tensile



- Strength meeting the requirement but generally slightly lower than the longitudinal tensile
- High Elongation %
- No significant difference between “near the border” and “at mid-length” specimen
- Strength increase for the 46mm Wall

Joint configuration:

- Rp0,2 typical: 480 MPa
- Rm typical: 580 MPa
- El% typical: 24
- Impact Energy KV_2 typical : 47J @ -40°C

Testing Lab: TEC-Eurolab we make you feel sure

See next sheet

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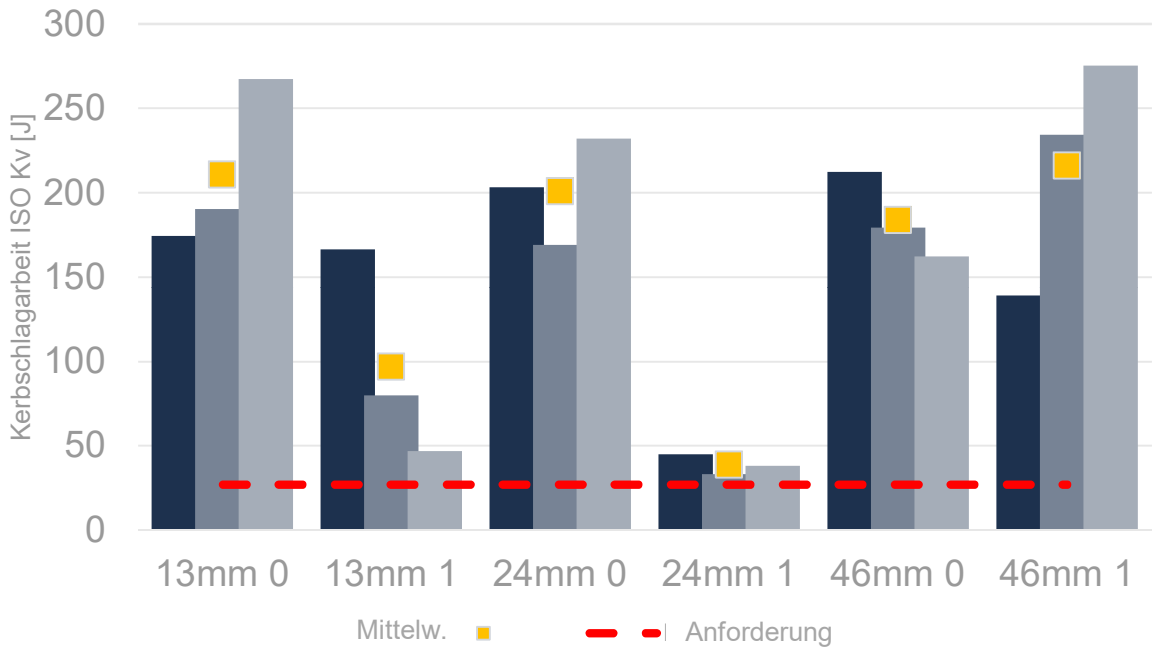
High Productivity WAAM procedure with 3Dprint AM 46 charpy impact values



- Toughness meeting the requirement
- "Top" values lower than "Bottom" values except for the 46 mm wall
- Strength increase for the 46mm Wall

Testing Lab: TEC-Eurolab we make you feel sure

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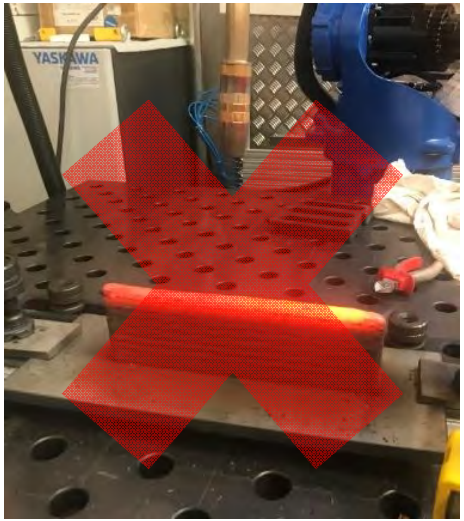
High Productivity WAAM procedure with 3Dprint AM 46 Learning



Don´t print on a red bead!

Agenda

böhler welding by voestalpine 3Dprint

Who´s voestalpine Böhler Welding?

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Product portfolio – WAAM
Duplex steels (with and without PWHT)

böhler welding by voestalpine 3Dprint

Product Name	C	Si	Mn	Cr	Mo	Ni	N	
3Dprint AM 2209	0.025	0.5	1.6	23	3	9	0.14	Duplex steel (no heat treatment)
3Dprint AM 2205	0.025	0.5	1.5	22	3	5	0.15	Duplex steel (with solution annealing heat treatment)

Chemical composition in wt.-%

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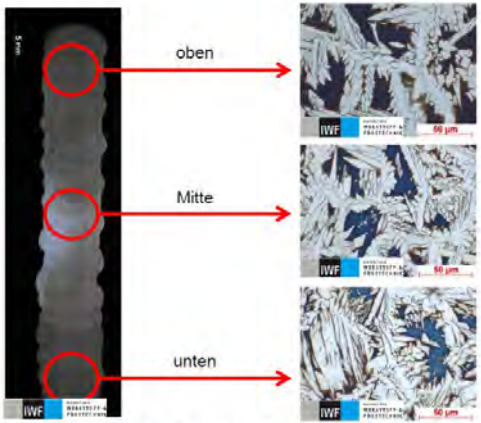
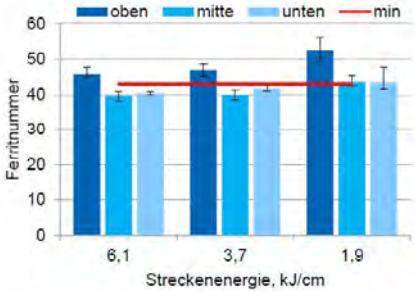
WAAM
Duplex steels (with and without PWHT)

böhler welding by voestalpine 3Dprint

Ferrit-Austenit-Verhältnis der Stegschweißungen



70Ar30He / v_{Dr} = 5,5 $\frac{m}{min}$ / v_S = 30 $\frac{cm}{min}$ / E = 5,9 $\frac{kJ}{cm}$ / T_{ZWL} = 150 °C



Ferritanteil in Abhängigkeit von Streckenenergie und Lagenhöhe
(Ermittlung der Ferritnummern erfolgte mittels Feritscope)

- Ferritanteil gemäß DIN EN ISO 17781 (30-70 % Ferrit ≈ 43-100 FN) wird trotz Minimierung der Streckenenergie nicht durchgängig erreicht

20 layers high, 10 cm long

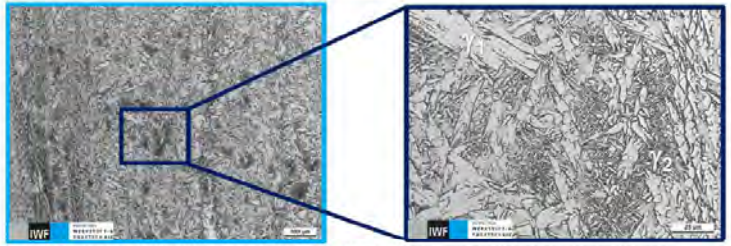
Ferrite to austenite ratio: borderline to critical!

WAAM
Duplex steels (with and without PWHT)

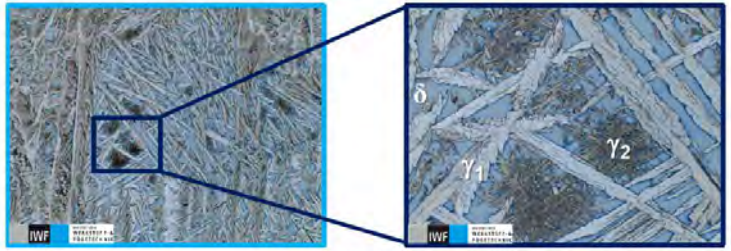
böhler welding by voestalpine 3Dprint

Ausscheidung von Sekundäraustenit

Probengeometrie



Mikroschliffaufnahmen des Schweißgutes bei 100- und 500-facher Vergrößerung, Ätzung nach Murakami



Mikroschliffaufnahmen des Schweißgutes bei 100- und 500-facher Vergrößerung, Ätzung nach Beraha II

- Übermäßige Ausscheidung von Sekundäraustenit in überschweißten Lagen

Secondary austenite leads to good impact properties but decrease in yield and total strength!

3Dprint AM 718

böhler welding by voestalpine 3Dprint

3Dprint AM 718

WAAM solid wire, high-alloyed, nickel-base

Material Type		
Alloy 718	S Ni 7718	2.4668

Characteristics

Solid wire designed for 3D-printing of alloy 718 structures. The structure can be heat treated (hardened) to increase the strength of the structure.

Typical analysis of the solid wire (wt.-%)

	C	Si	Mn	Cr	Mo	Ni	Nb	Al	Ti	Fe
wt.-%	0.05	< 0.1	<0.1	17.6	3.0	Bal.	5.2	0.45	0.95	19.5

Heat input: 1.5 kJ/mm.

Available products

Diameter: 1,0 mm – 1,2 mm
Package: BS300 15 kg – ECOdrum 100 – ECOdrum 250 – S760 300
Other diameters and packages on request.

Typical mechanical properties acc.to EN ISO 15792-1

Heat treatment	Test temperature	Yield strength $R_{p0.2}$	Tensile strength R_m	Elongation (L_0=5d_0)	Impact energy ISO-V KV J	
	°C	MPa	MPa	%	+20 °C	-196 °C
u	20	530	800	32	60	45
u	600	420	670	33		
h	20	930	1110	4		
h	600	785	890	4		

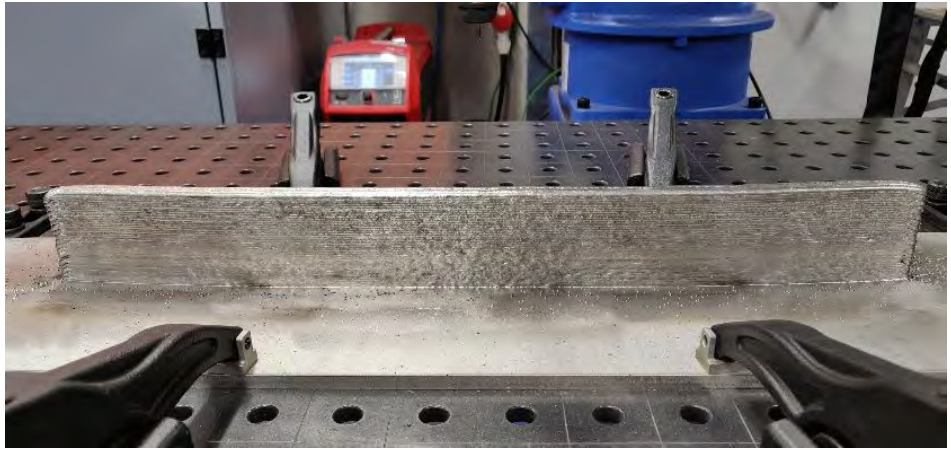
u untreated, shielding gas Ar + 30 % He + 2 H_2 + 0.005 % CO_2
h hardened, 960 °C – 0,5 h, air cooled to 20 °C, 720 °C – 8 h, 2 h furnace cooling, 620 °C – 8h, air

Classification as welding consumable:

EN ISO 18274	AWS A5.14
G NiCr19Fe19Nb5Mo3	ERNiFeCr-2

Typical analysis of the solid wire (wt.-%)

	C	Si	Mn	Cr	Mo	Ni	Nb	Al	Ti	Fe
wt.-%	0.05	< 0.1	<0.1	17.6	3.0	Bal.	5.2	0.45	0.95	19.5



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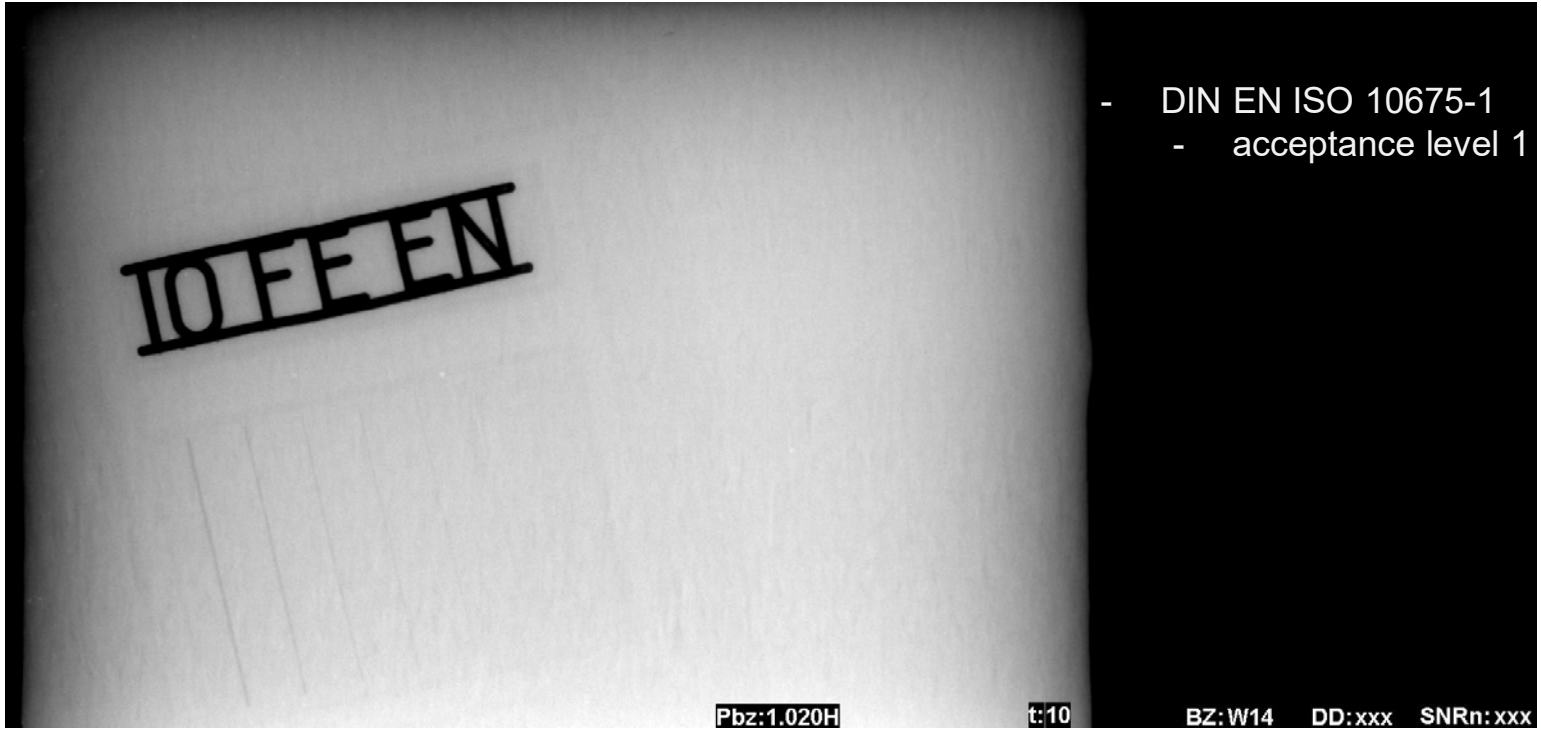
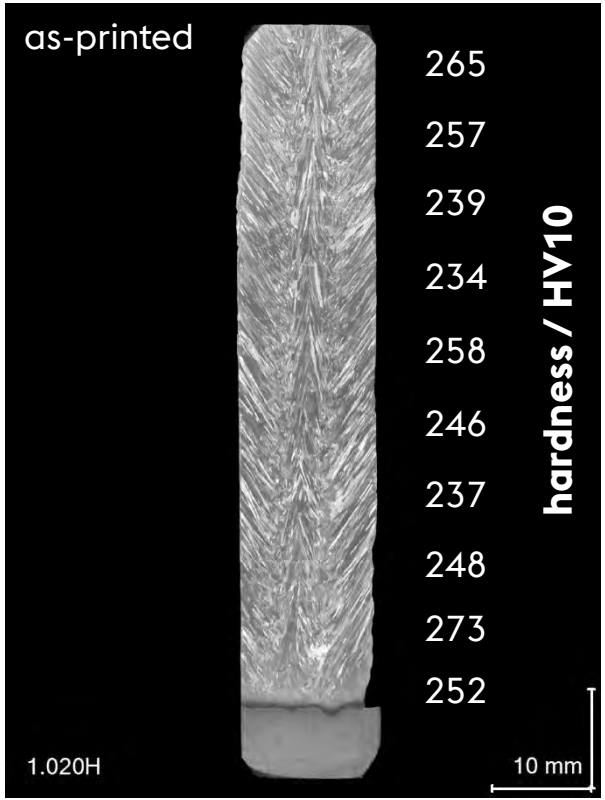
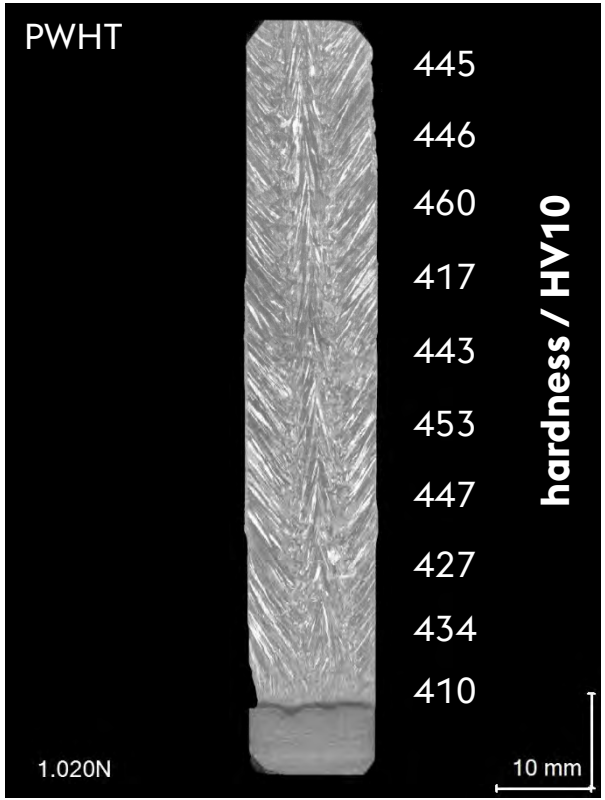
X-ray – IPT < 100 °C



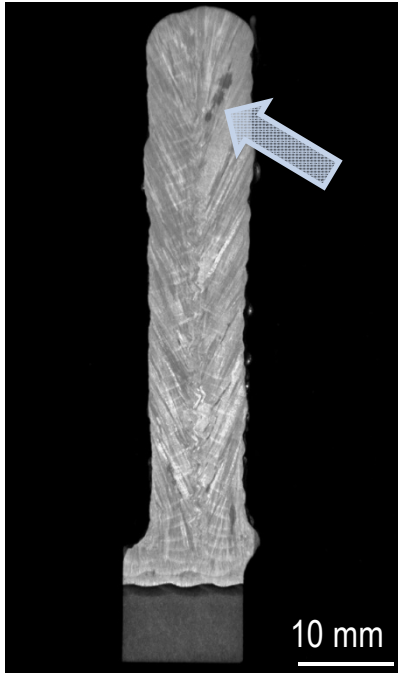
- DIN EN ISO 10675-1
  - acceptance level 1

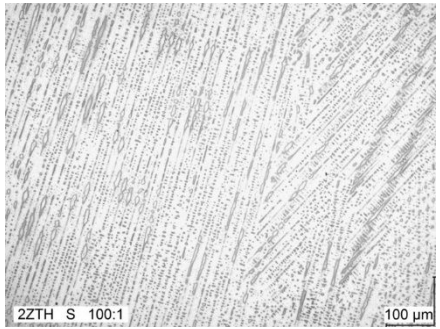
Makro structure – IPT < 100 °C

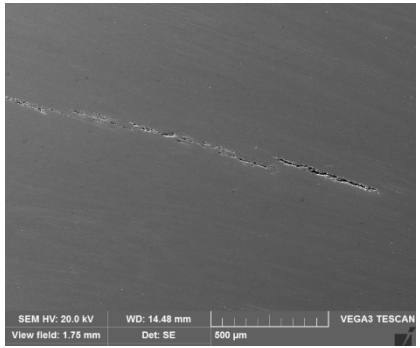


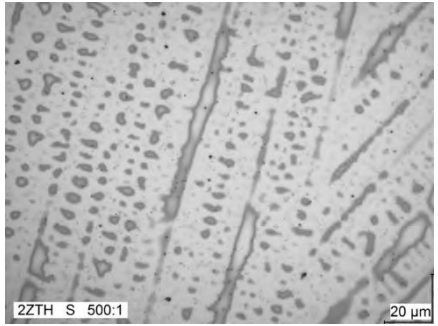


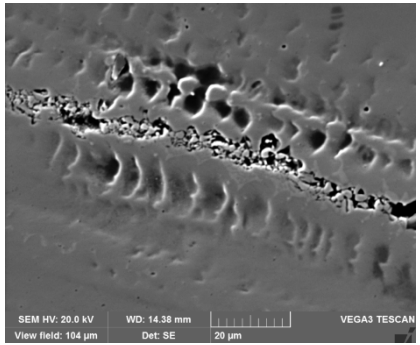
Macro structure – IPT **150 – 200 °C**





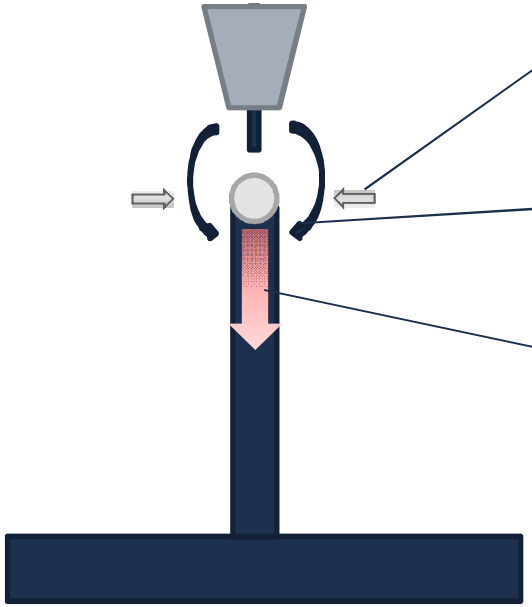






How to keep the impact under control

böhler welding by voestalpine 3Dprint



Adjust welding parameters and surface tension and viscosity to keep melt pool in position

Control gas flow and shielding conditions (different from joint welding)

(pores, more silicates)

One dimensional conductive heat flow

Control the interpass temperatures!

Low interpass temperatures are mandatory for most alloys!

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ONE STEP AHEAD.

Thank You!

Dr. Martin Schmitz-Niederau
martin.schmitz-niederau@voestalpine.com