An overview of research in welding and additive manufacturing at University West

Ebrahim Harati

UNIVERSITY WEST

Creating change together.

History
University West and research in Production Technology

2023 Complete Academic Environment

2012 Research education rights

2008 Production Technology Center

1999 Master of Science

1994 Research together with Volvo Aero

1993 Bachelor of Science

1990 Founded

Production Technology Center

Complete Academic Environment Production Technology, organization

- **Director, Joel Andersson**
- **Deputy directors, Lennart Malmsköld & Shrikant Joshi**

  - **Mechanical Engineering (ME)**
    - Thermal spray **(Shrikant Joshi)**
    - AM powder bed fusion **(Thomas Hansson)**
    - **Welding and welding-based AM (Jörg Volpp)**
    - Advanced non-destructive testing &evaluation **(Håkan Wirdelius)**

  - **Industrial Automation (IA)**
    - Flexible Automation **(Fredrik Danielsson)**

  - **Industrial Engineering (IE)**
    - Operations & supply chain management **(Henrik Eriksson)**

Part of Engineering Science but outside Production Technology:

- *Computer Engineering (Thomas Pederson)*
- *Electrical Engineering (Boel Ekergård)*

UNIVERSITY WEST

COMPLETE ACADEMIC ENVIRONMENT PRODUCTION TECHNOLOGY

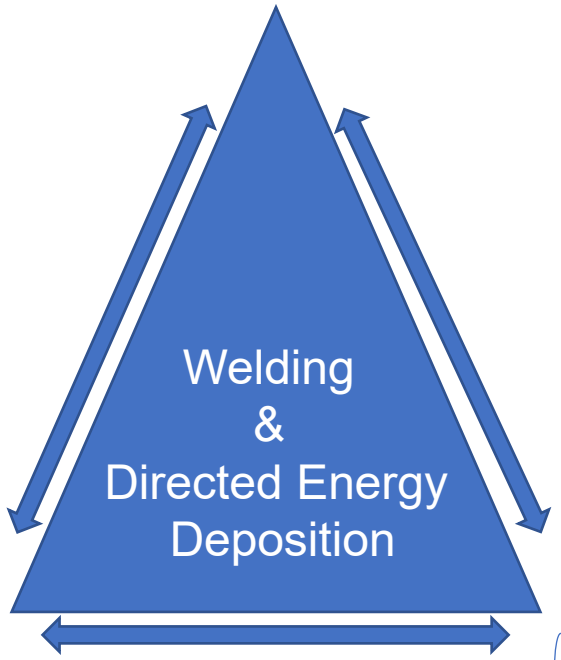
Welding and welding-based AM

UNIVERSITY WEST

Research Areas Welding

Metallurgy

Fundamental research of welding and deposition technologies - understanding of microstructure and defects and their influence on mechanical performance



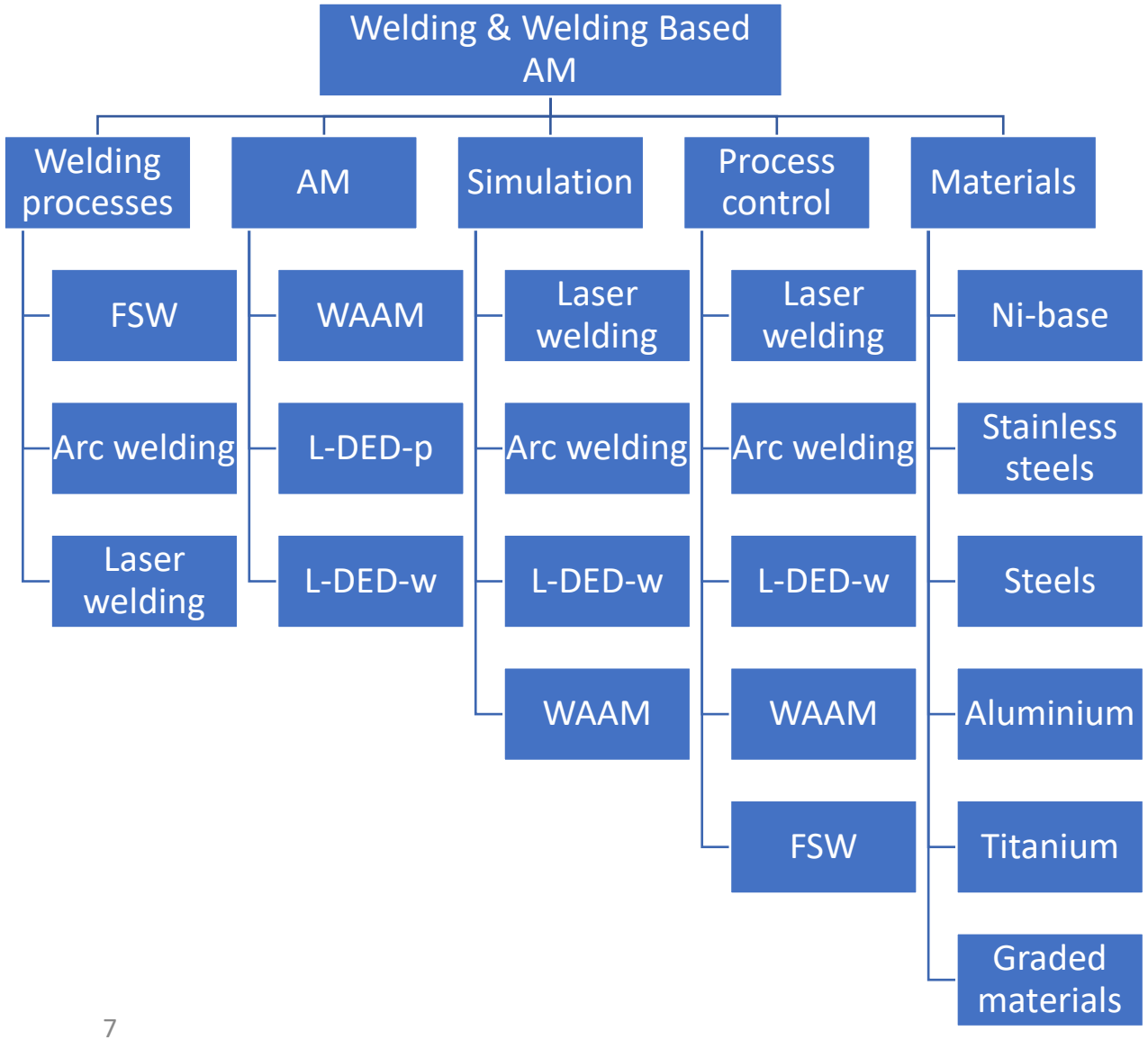
Process development

Laser, TIG,
CMT, MIG/MAG,
FSW and Plasma

Process physics

Laser, arc and melt pool physics

Research focus – ’Welding group’



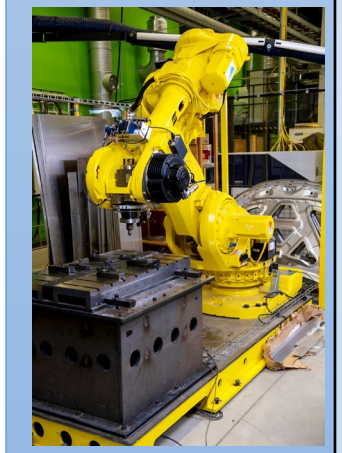
	2024	2025
Professor	2	2
Docent	4	4
Lektor	5	5
Postdoc	1	1
PhD student	12	12
Engineer	4	4
Adjunct/Guest	X	X
TOTAL	**29+**	**30+**

Welding and Welding-Based Additive Manufacturing

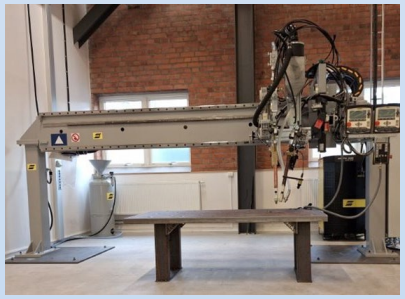
Research and development from process fundamentals, fluid-dynamic simulation, process development, monitoring to material analysis and testing

Welding

Solid-state
FSW
UW



Laser, Plasma/arc
(TIG, SAW, MIG/MAG)

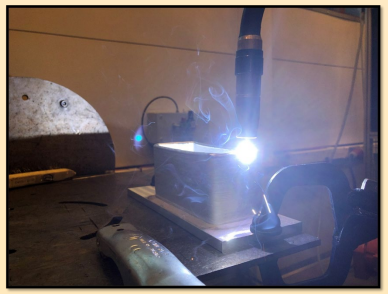


Directed Energy Deposition

Thermal

Wire

Arc



Laser beam

Powder

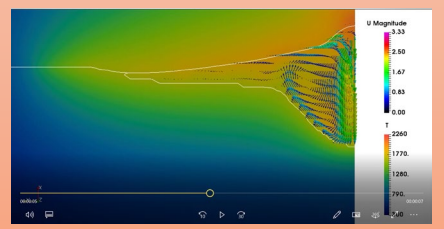
Material analysis

Metallurgy, properties

Gleeble

SEM

Process simulation

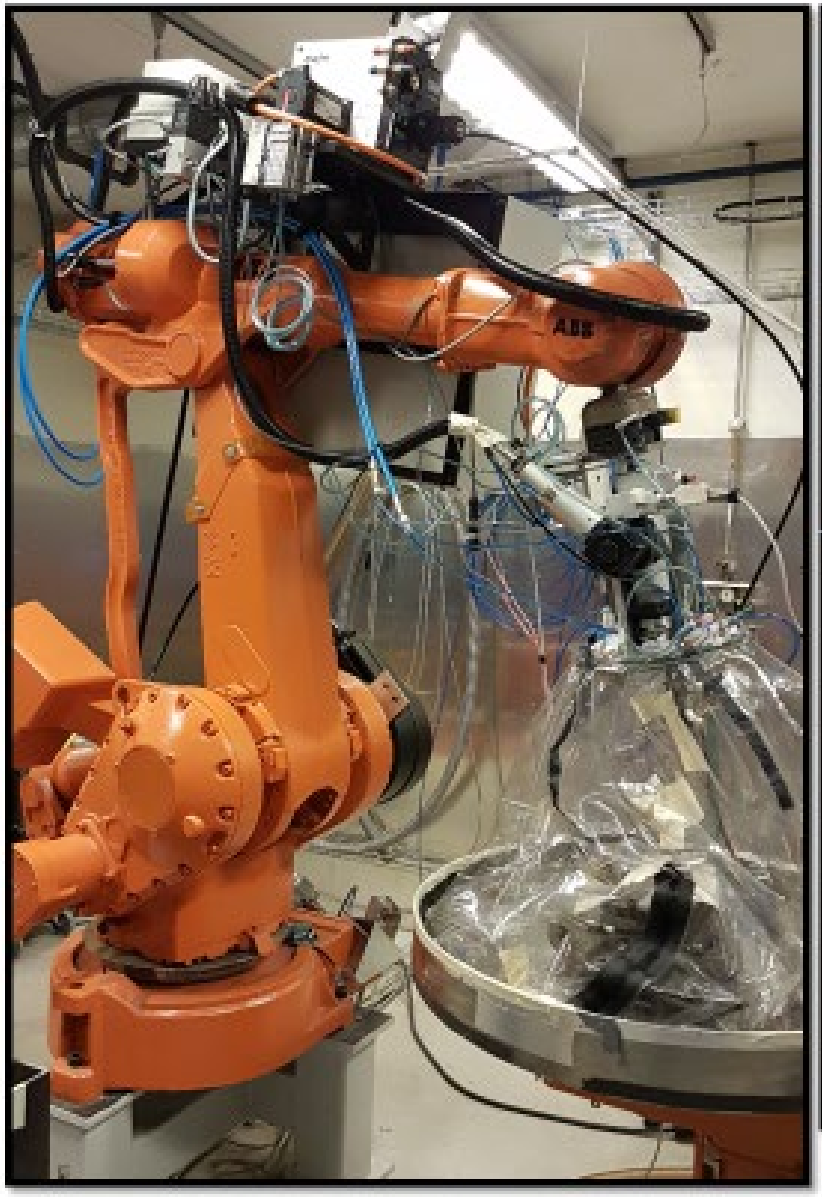


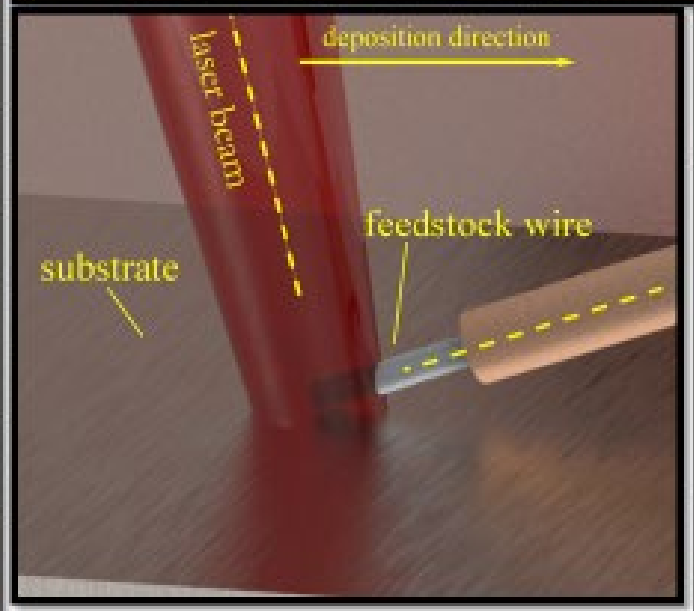
Monitoring and control (selection): Thermal imaging, Optical imaging, Spectroscopy

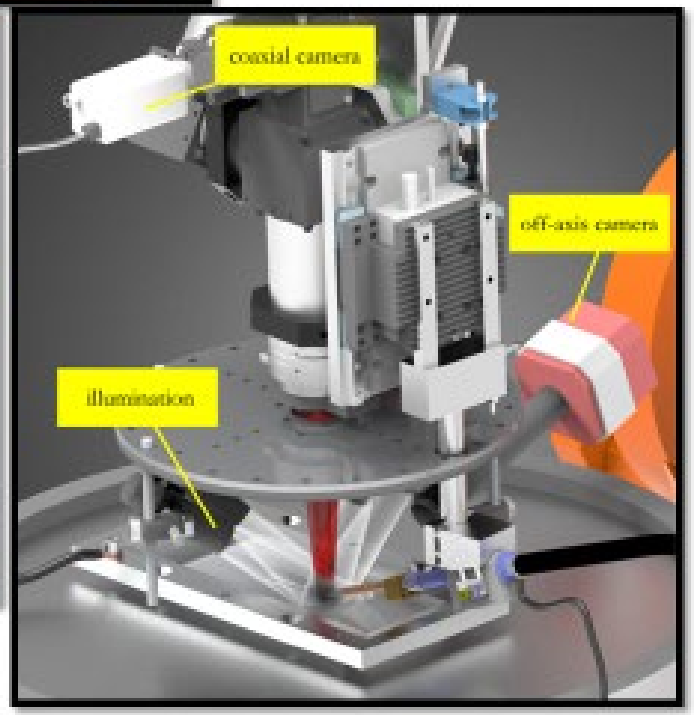
Materials (selection): Ni-based alloys, Stainless steels, Tool steels, Ti based alloys, Steel alloys

Contact: Jörg Volpp (jorg.volpp@hv.se)

Directed Energy Deposition of metal with laser beam (DED-LB/M) - Wire



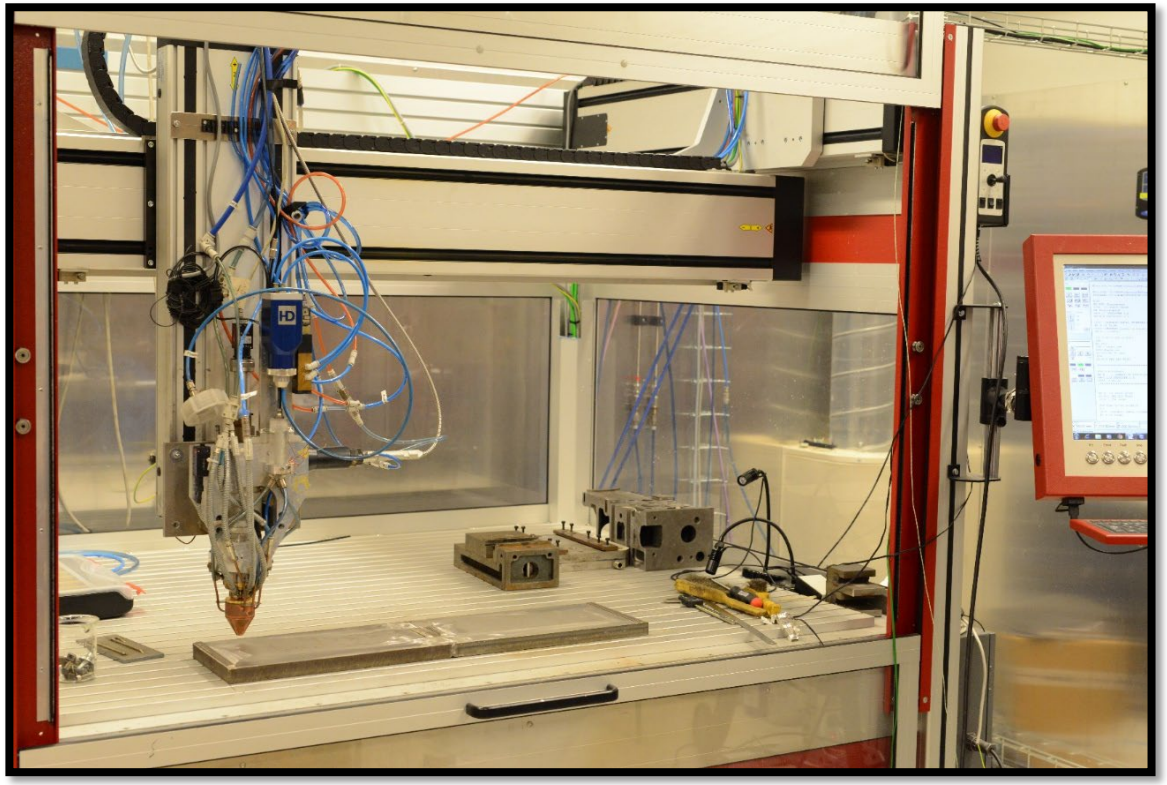


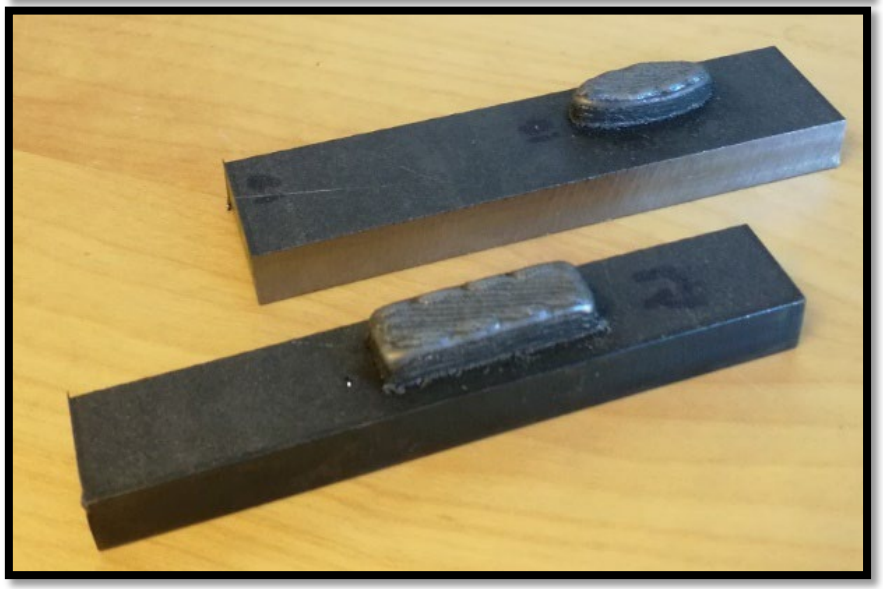


Materials:
- Titanium
- Duplex stainless steel
- …

Research focus:
- Process development
- Material properties
- Automation and process control

Directed Energy Deposition of metal with laser beam (DED-LB/M) - Powder





Materials:
- Ni based alloys, ex. Alloy 718, Alloy 625
- Stainless steels
- Tool steels
- …

Research focus:
- Process development
- Measuring and regulation
- Material properties

Arc welding / WAAM

WE HAVE:
Fully robotized welding processes
Advanced welding machines:
- Fronius TPS 500i, PMC,
- CMT, LSC
- EWM Tetrix 551 AC/DC,
- Hot wire, Force TIG
State-of-the-art in-situ techniques to record temperature and electrical parameters

WE OFFER:
Cutting edge research on additive manufacturing, welding, welding metallurgy, arc physic, simulation and modelling, physical simulation of material processing.

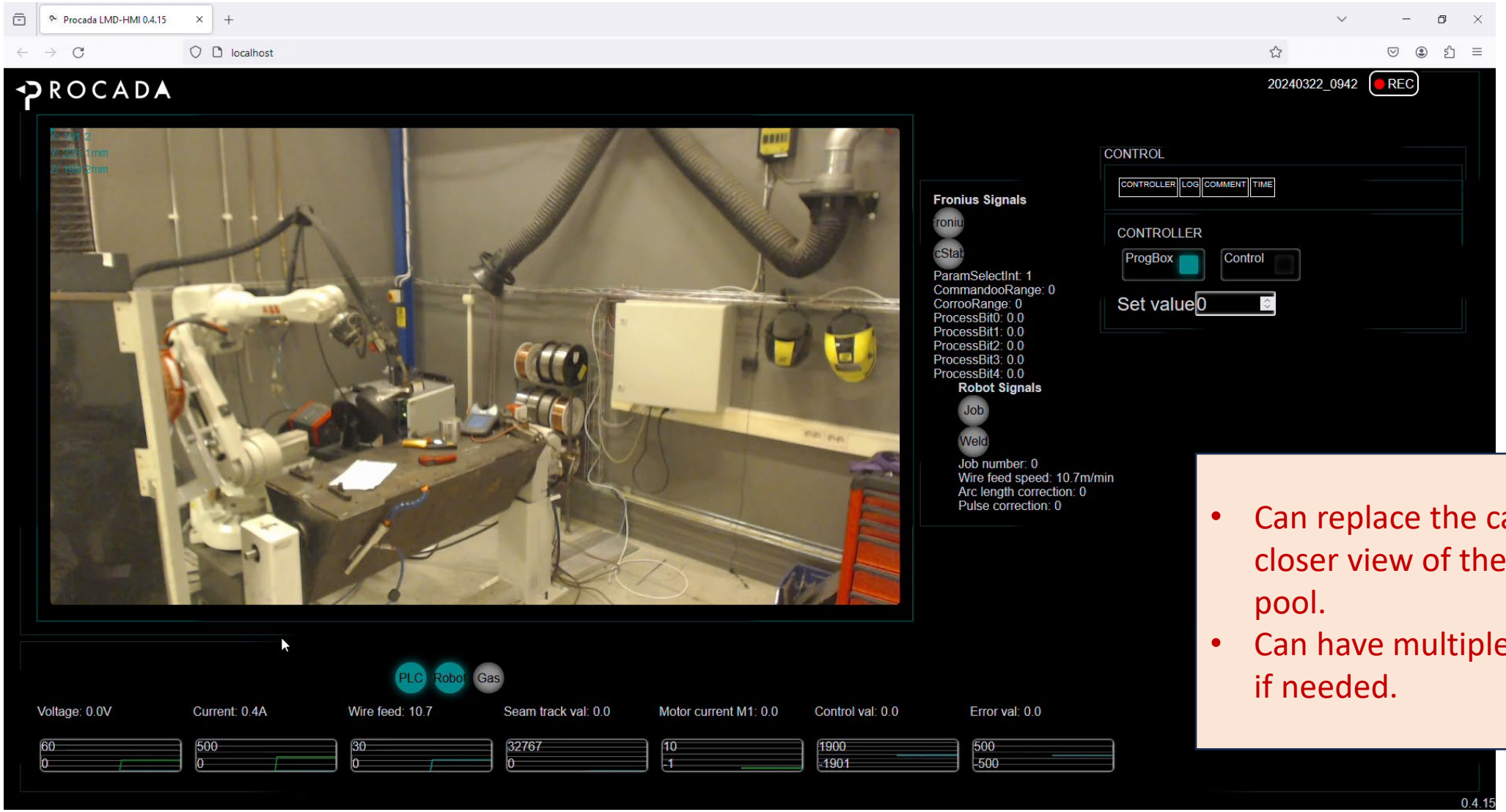
High speed imaging

Detailed process knowledge to:

- understand process dynamics

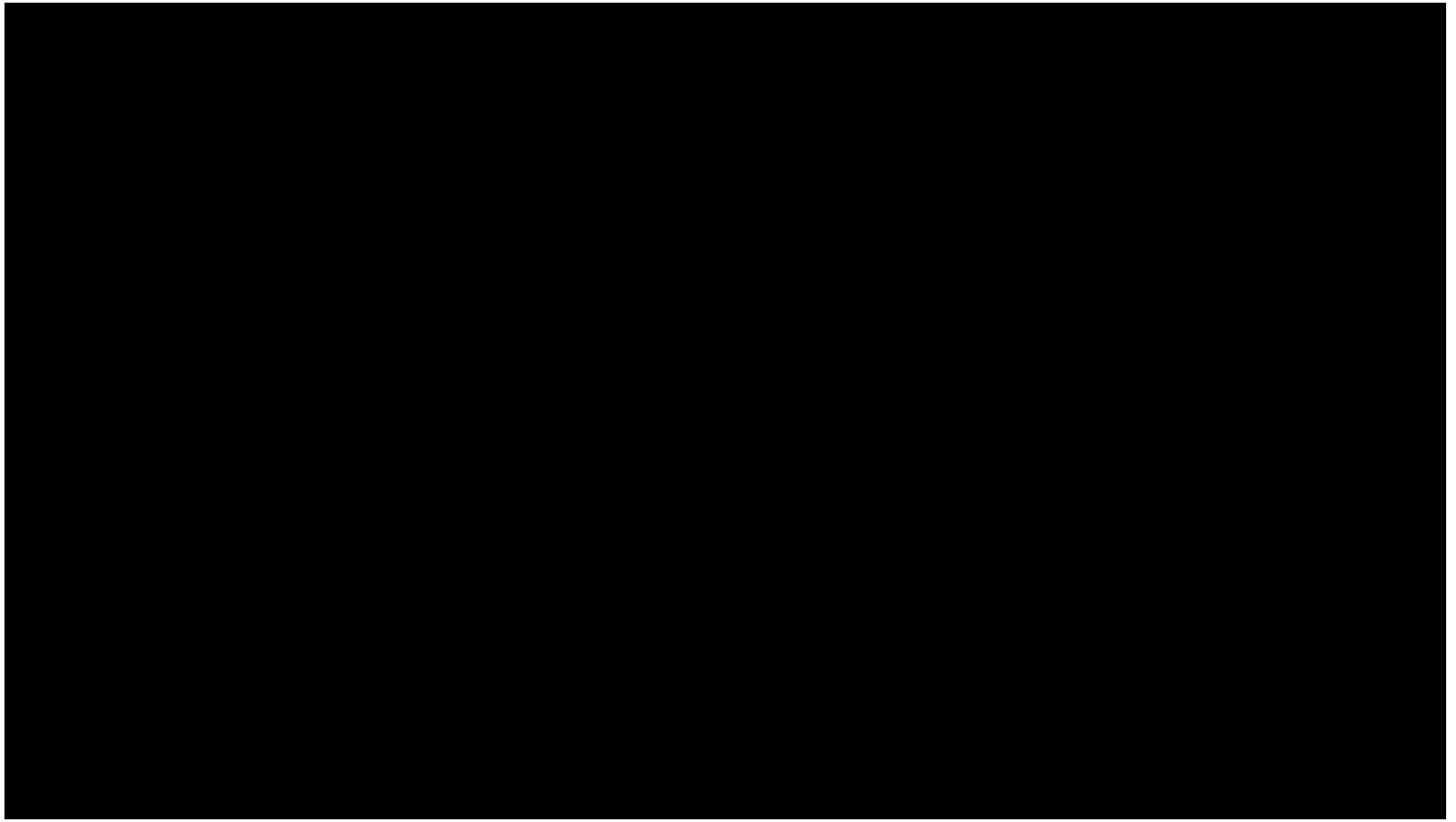
to correlate control inputs to controlled outputs

In-situ Process Monitoring during WAAM



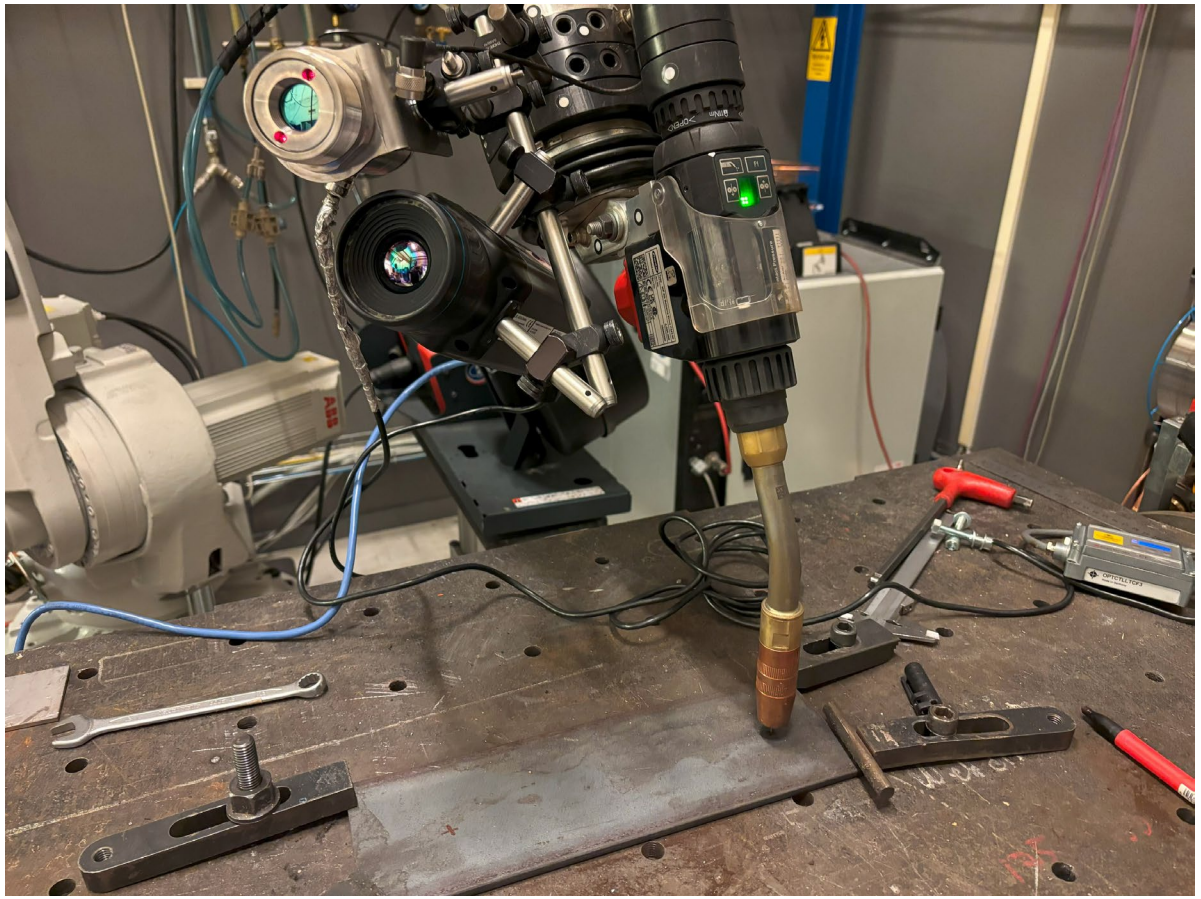
- Can replace the camera to get closer view of the arc, or melt pool.
- Can have multiple cameras placed if needed.

WAAM – temperature measurements

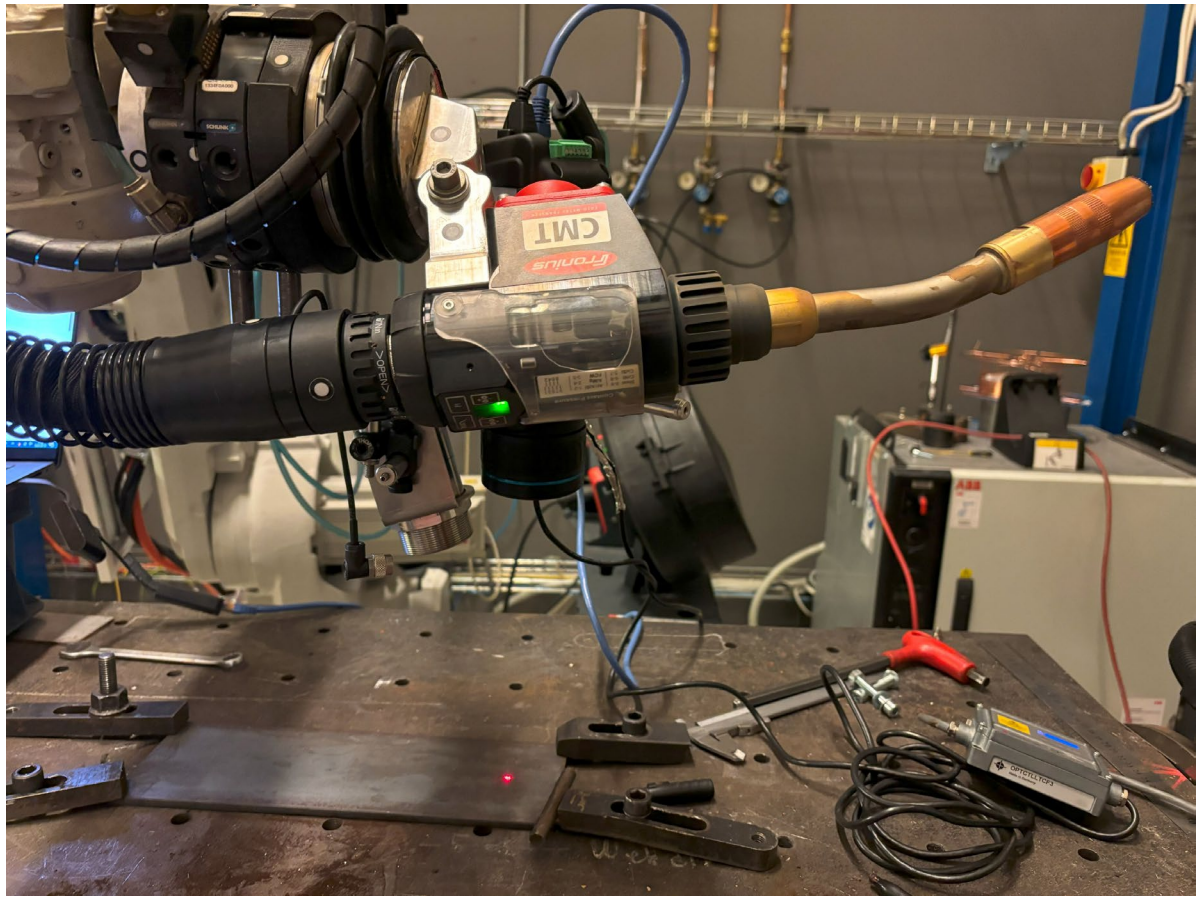


WAAM – temperature measurements

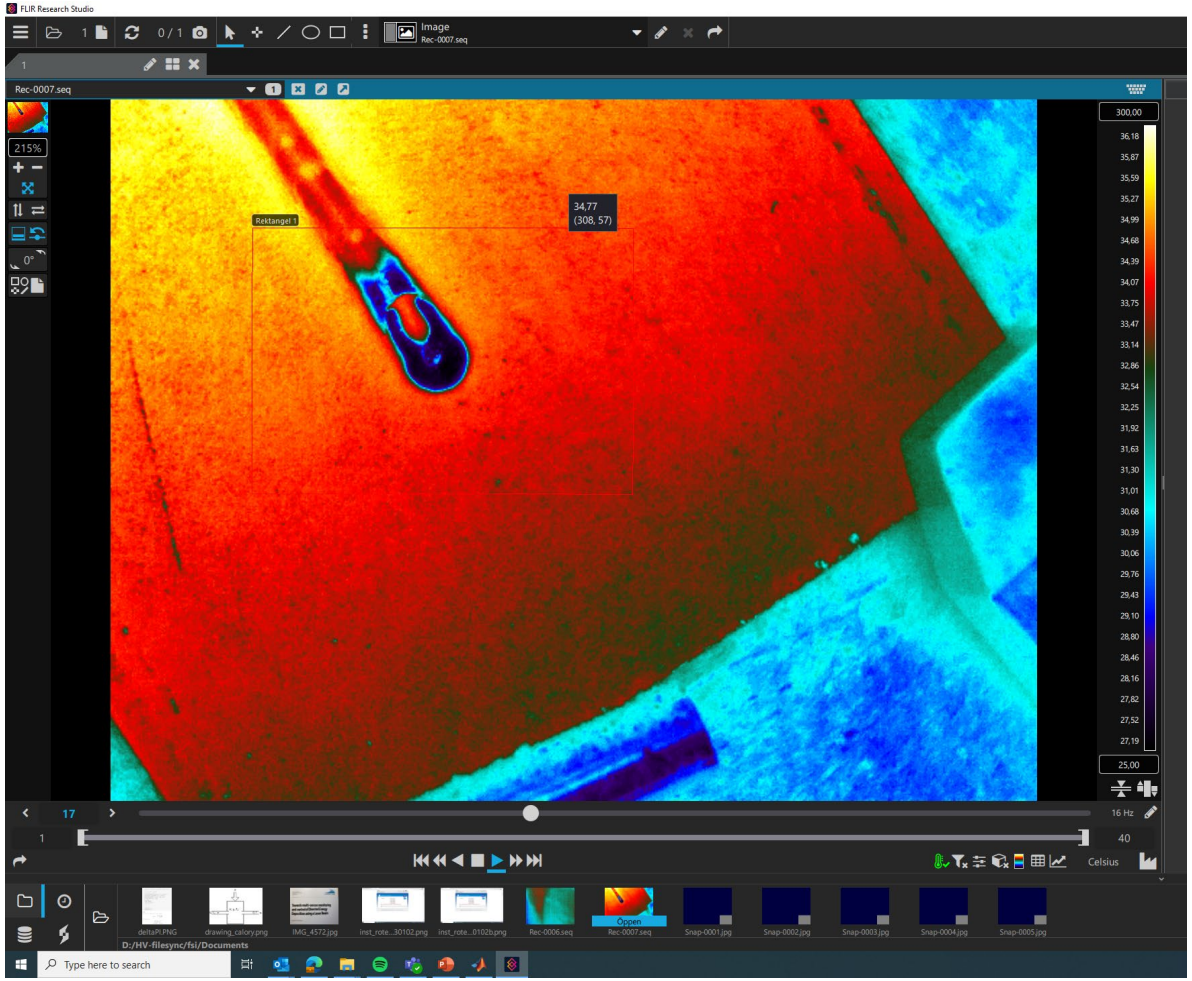
1) Processing



2) Measure temperature



WAAM – temperature measurements

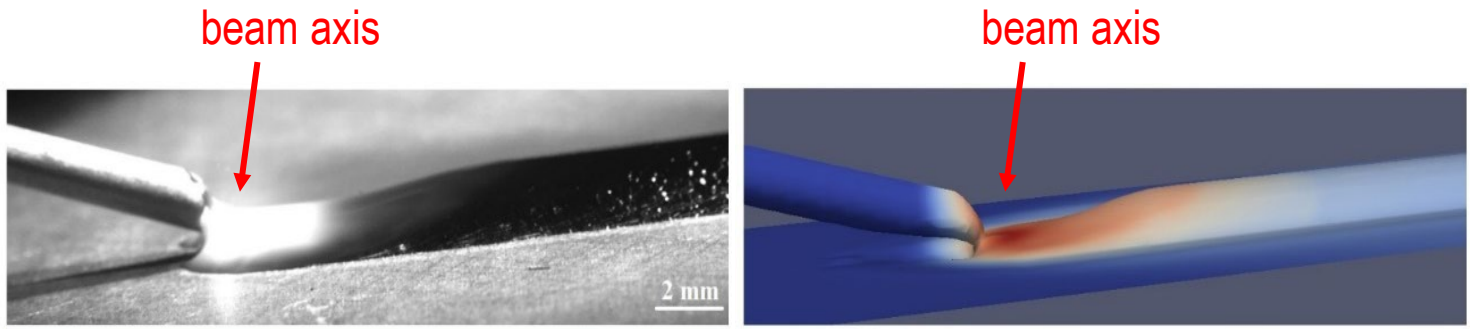


Process simulation – thermo-fluid approach

Laser beam and Melt pool

KK-SAMw - Additive Manufacturing

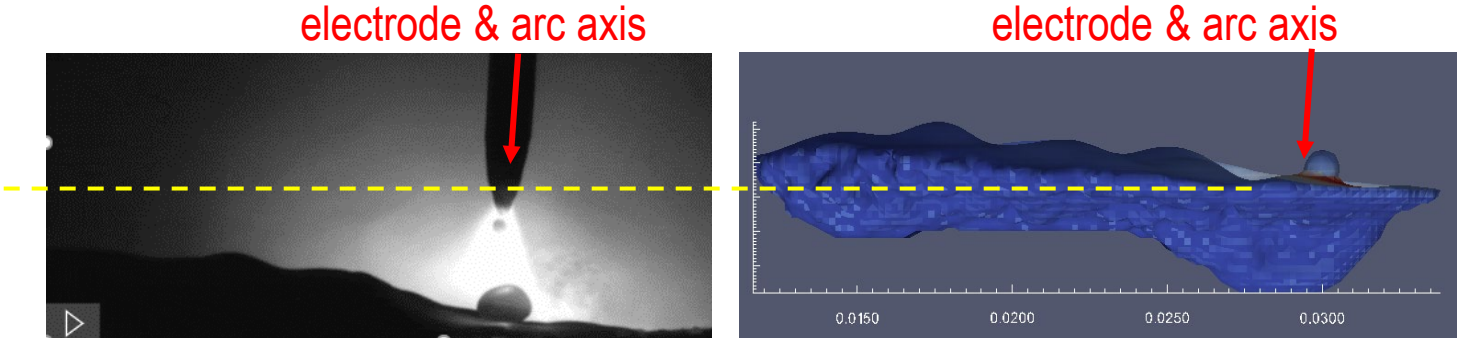
KK-AdOpt - Beam shaping, Welding



Electric arc (GMA) and Melt pool

EU-Integradde - Welding and AM

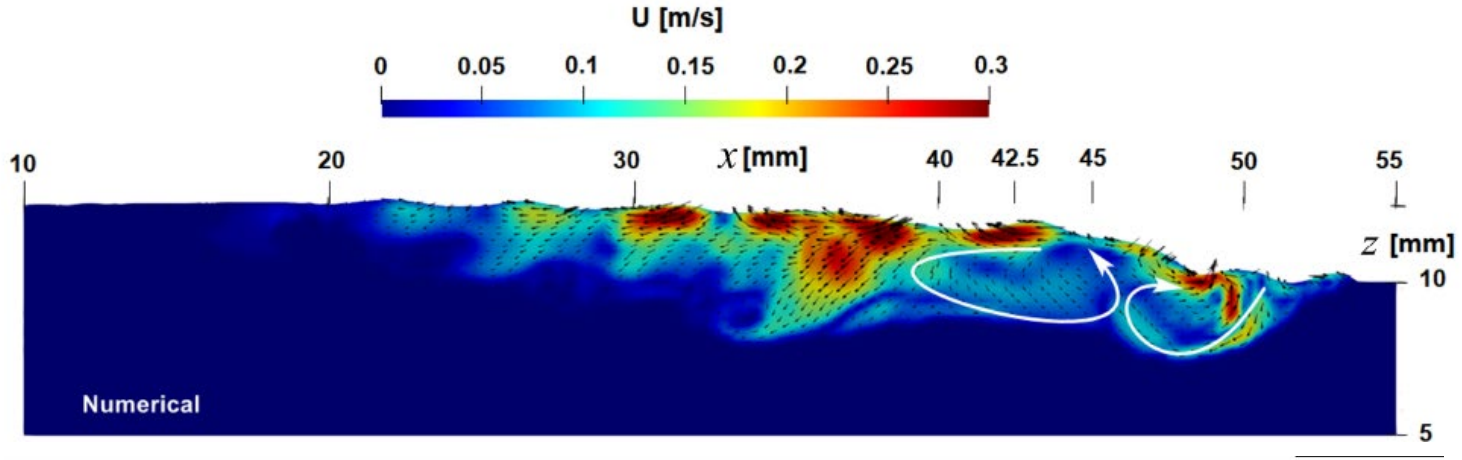
KK-Tappertech - AM

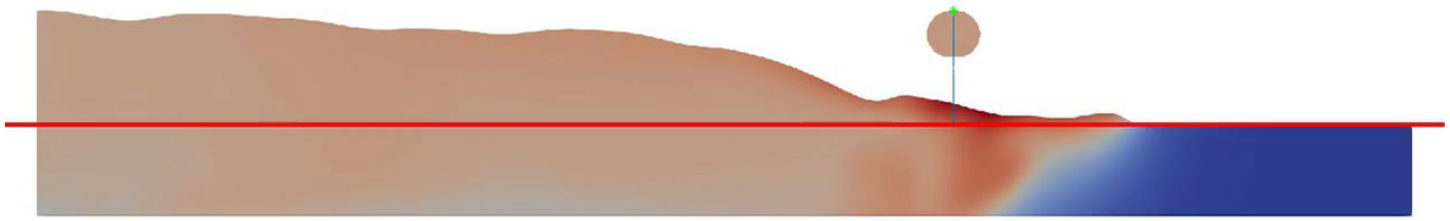


Process Modelling – CFD & multi-physics / WAAM

Melt pool

International Journal of Heat and Mass Transfer 194 (2022) 123068
https://www.sciencedirect.com/science/article/pii/S0017931022005415?via%3Dihub

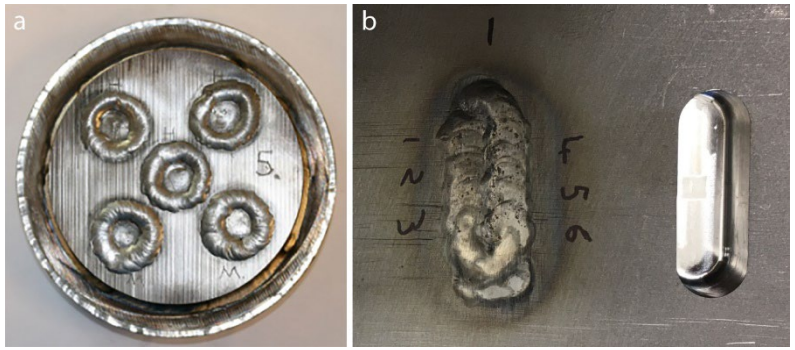




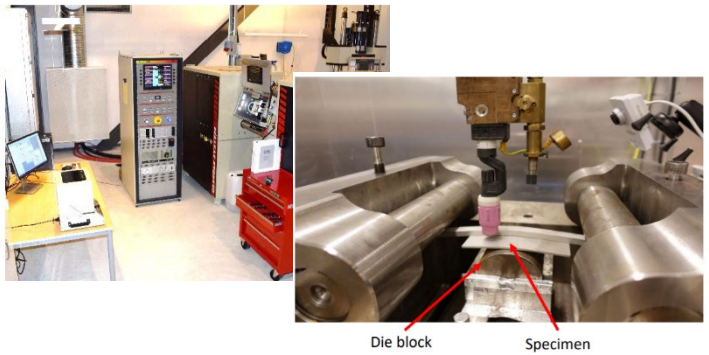
New ARC welding equipment from Esab!

Welding research

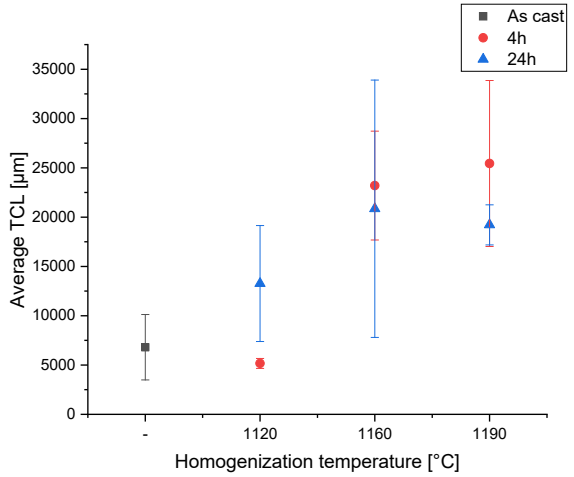
Representative testing

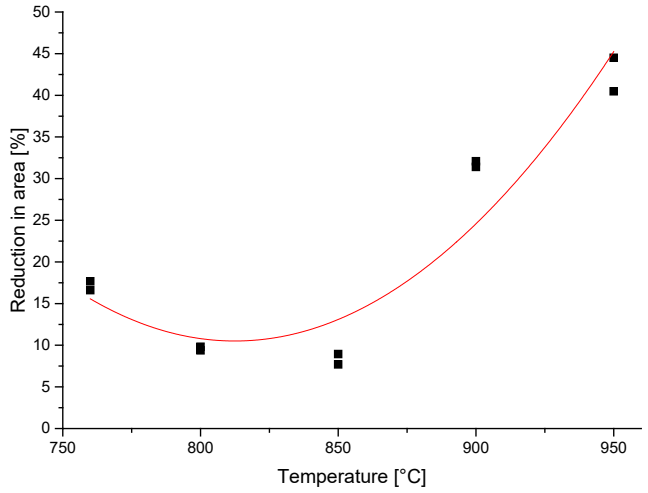


Simulative testing

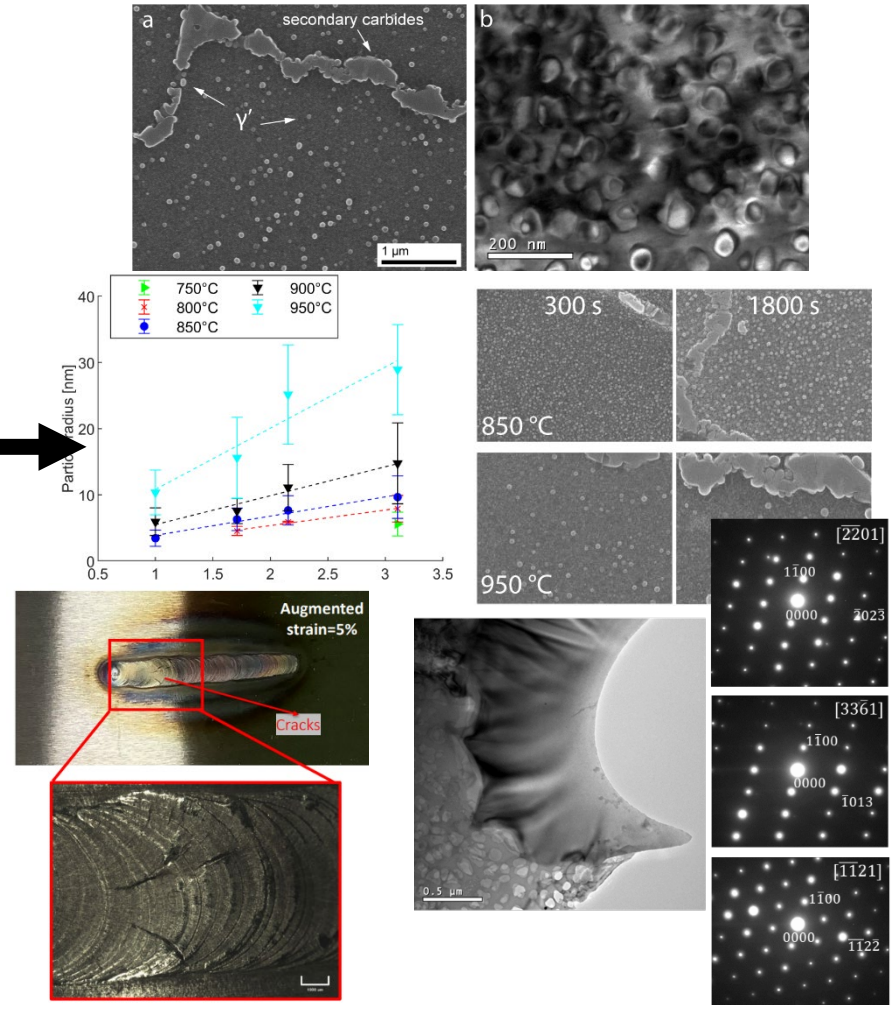


Analysis



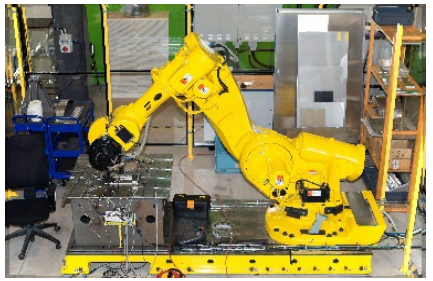
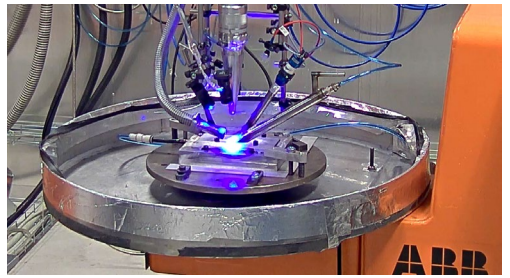


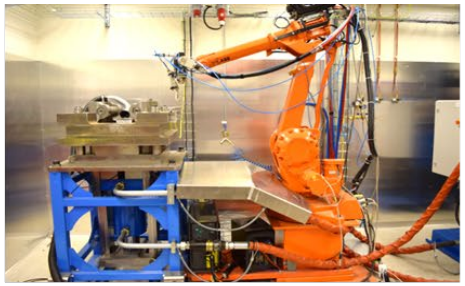
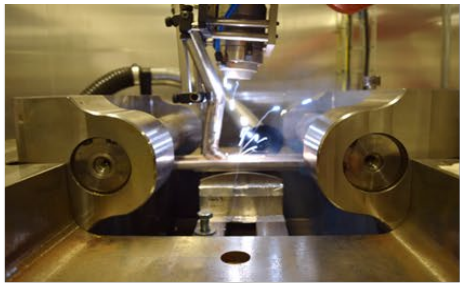
Microstructural characterization

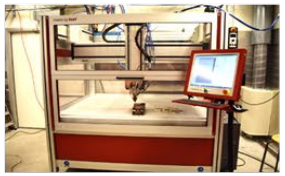


Research equipment

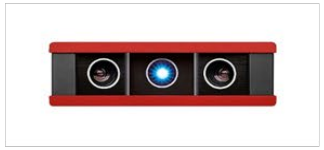
- Welding processes
  - Trumpf 12 kW disc laser
    - Wire and powder
  - TIG, HF-TIG, MIG, MAG, Plasma, CMT, SAW, and FSW
  - PBF (L-PBF and EB-PBF)
  - Thermal Spray Center
- Material testing
  - Tensile
  - Fatigue
  - Hardness
  - Varestraint (LBW, TIG…)
  - NDT
  - Lab furnaces (≤1200 °C)
  - Vacuum furnace
  - Local heat treatment capabilities
  - Material preparation
  - Gleeble 3800D
- Characterization
  - Optical microscopy
  - SEM-EDX/EBSD (3 SEMs)
  - GOM – measurment
  - CT scan
- Simulation
  - OpenFoam
  - JMatPro
  - Thermocalc
  - Simufact Welding
  - COMSOL
  - MSC Marc, Simufact additive, MSC fluid etc
  - LS-Dyna






Examples ongoing/recent work

Directed Energy Deposition of metal with laser beam (DED-arc/M)
Wire Arc Additive Manufacturing (WAAM)

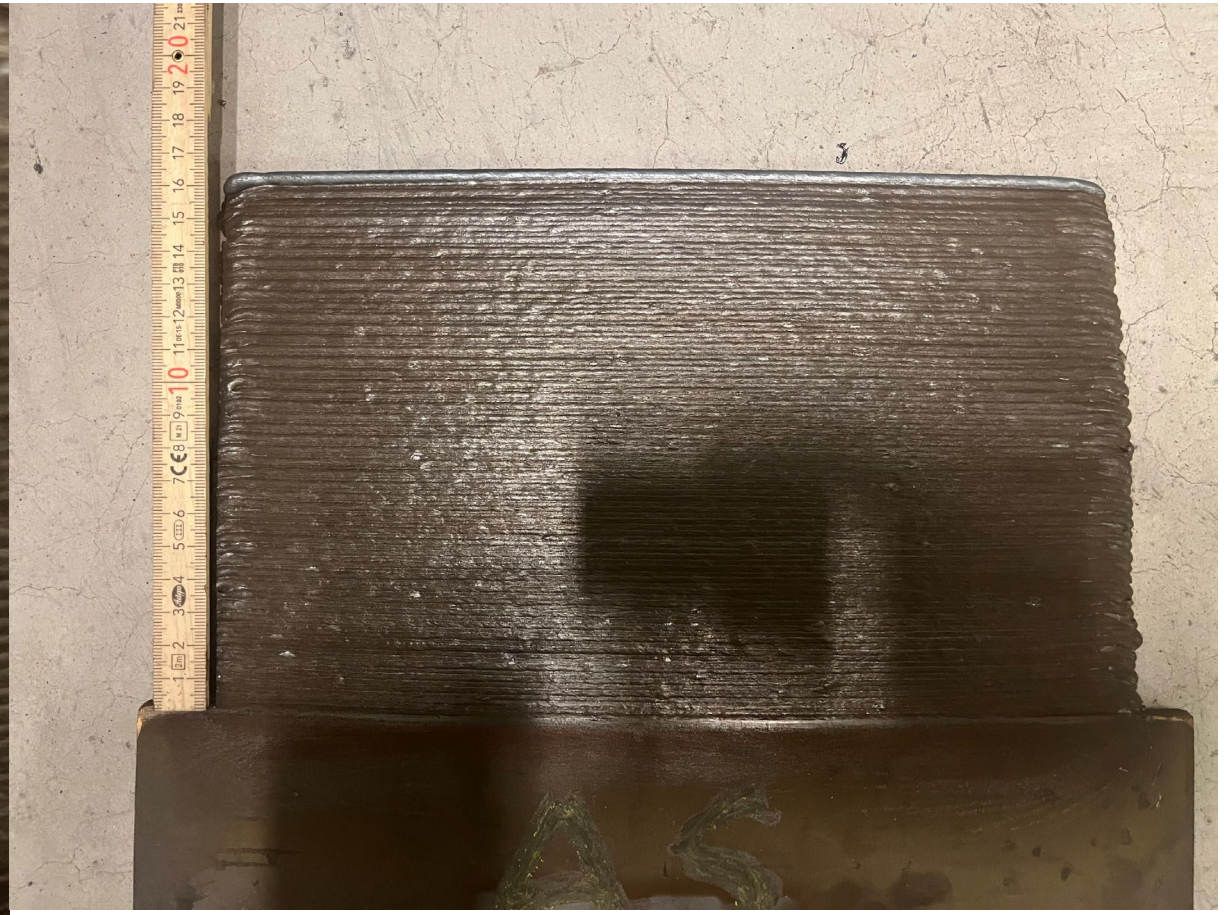
Materials:
- Steel
- Stainless steel
- Aluminium
- Ni-based alloys

Research focus:
- Process development
- Measuring and regulation
- Material properties

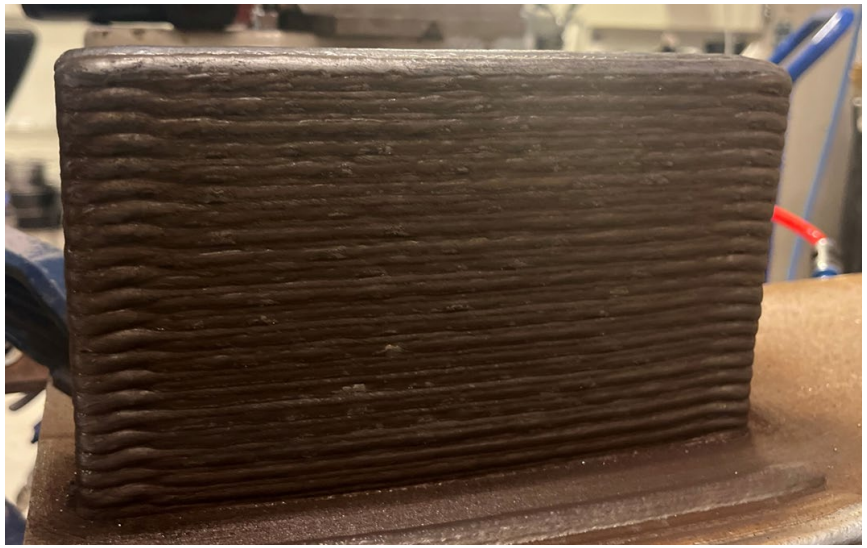
Welding-based AM as an enabler for high deposition rate produced light weight components

HYDRO SWERIM BAE SYSTEMS

Steel



HIGHLIGHT project



pre-heat/interpass temperature of 100°C

	Wire	Gas
Build 1	MF742-M1	8%CO2
Build 2	MF742-M1	18%CO2
Build 3	MF742	8%CO2
Build 4	MF742	18%CO2
Build 5	EM135	8%CO2
Build 6	EM135	18%CO2

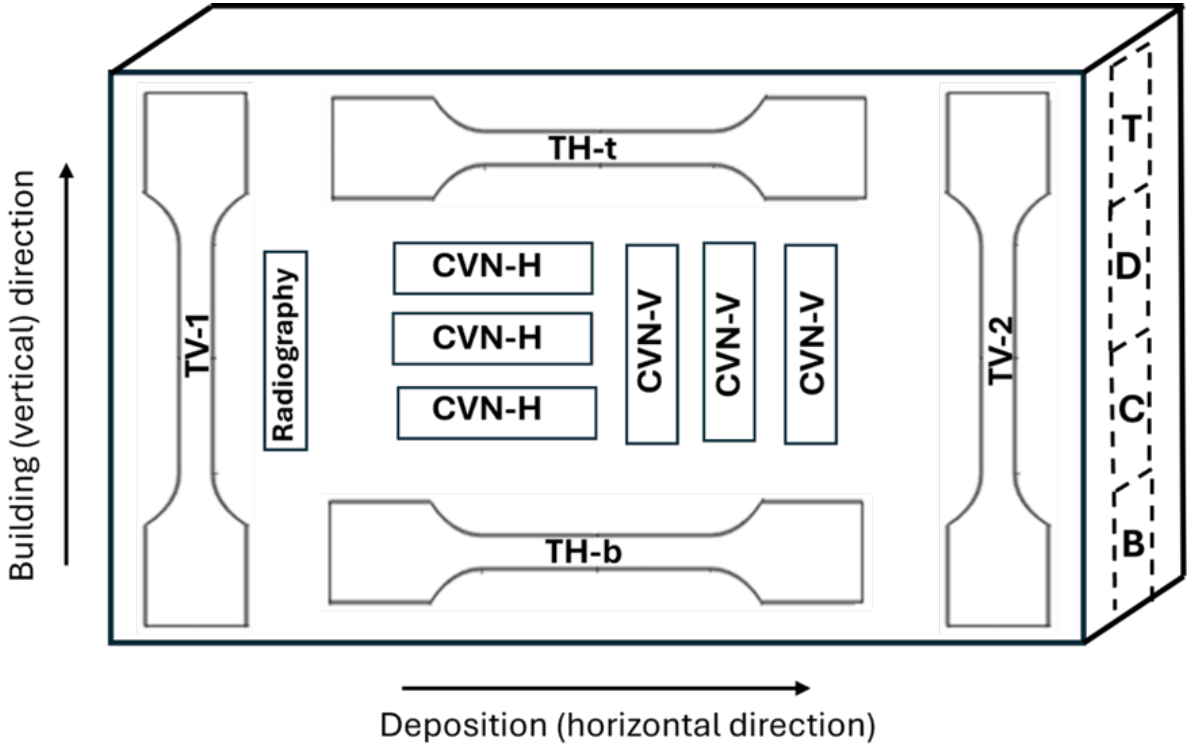
Metal cored wire

Solid wire

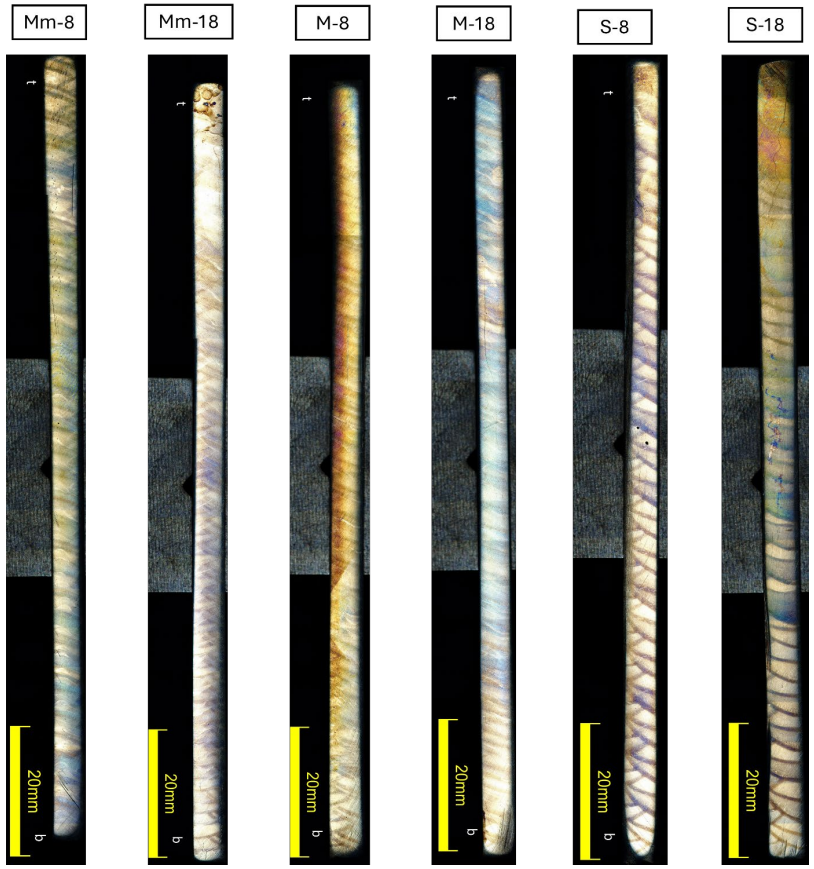
Chemical composition (in wt.%) of the wires and base plate

Material	C	Mn	Si	Ni	Cr	Mo	Ti	Fe
SW	0.08	1.57	0.49	1.41	0.32	0.21	-	**Balance**
MCW	0.04	1.47	0.45	2.33	0.31	0.31	0,039	**Balance**
MCW-m	0.06	1.64	0.47	2.55	0.34	0.27	0,037	**Balance**
S355	**0.24**	**1.6**	**0.55**	**-**	**-**	**-**	**-**	**Balance**

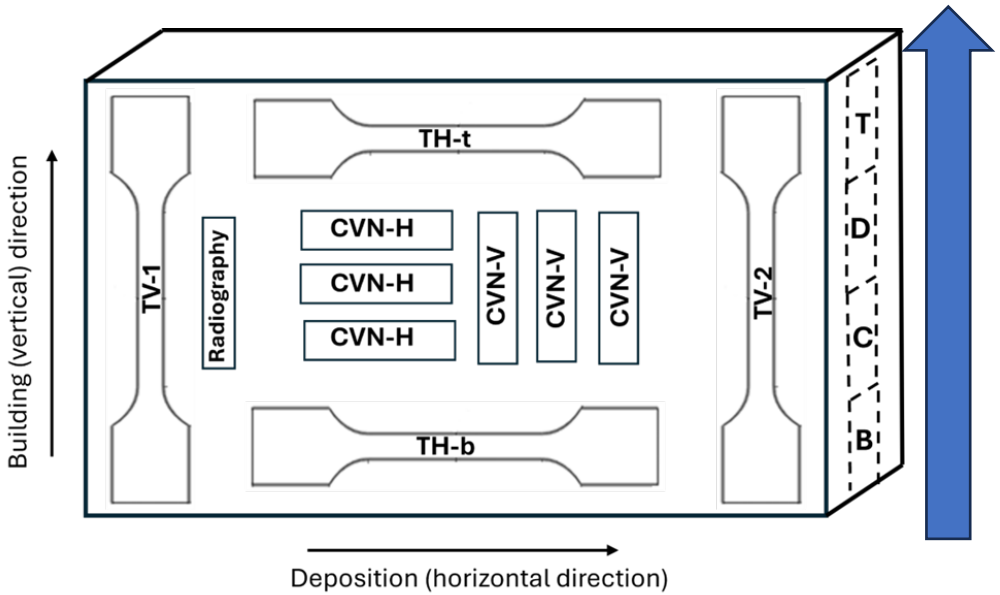
Location of specimens used for analysis and tests

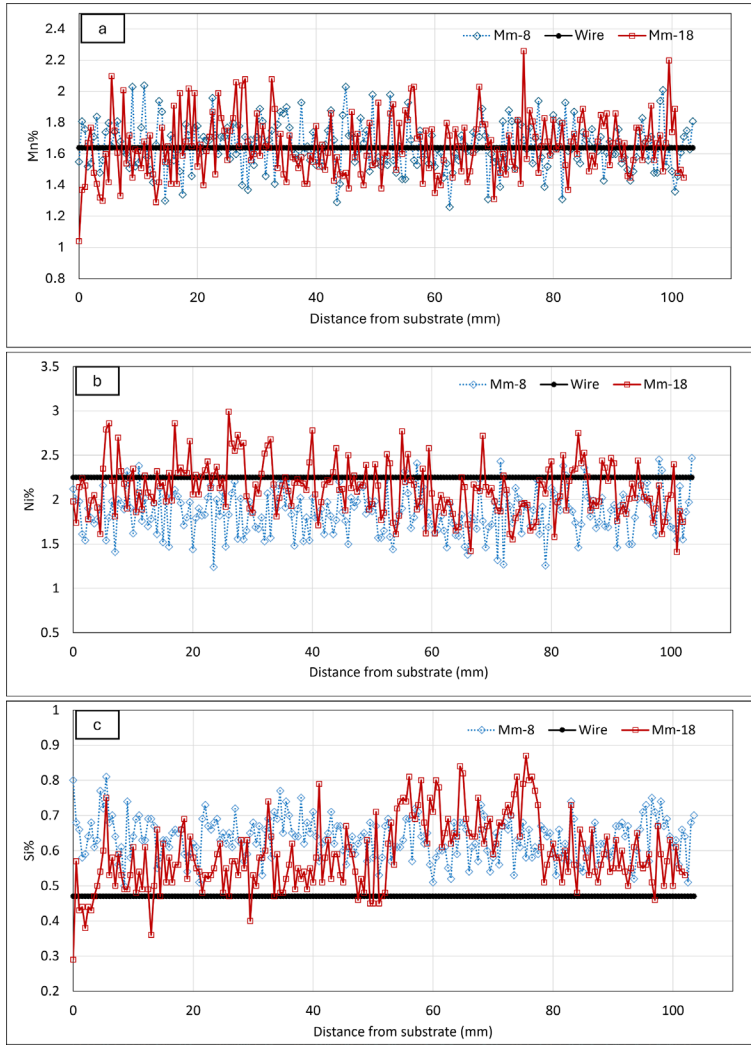


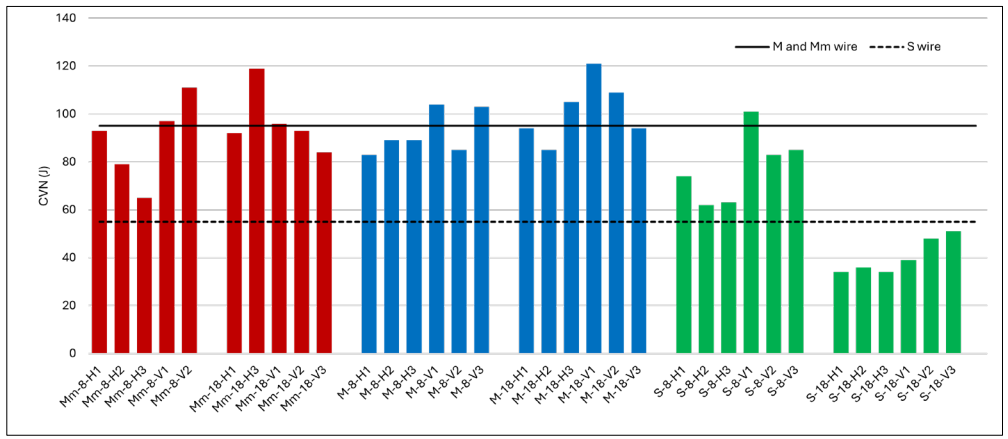
Macrographs of WAAM walls built using different wire types



Chemistry

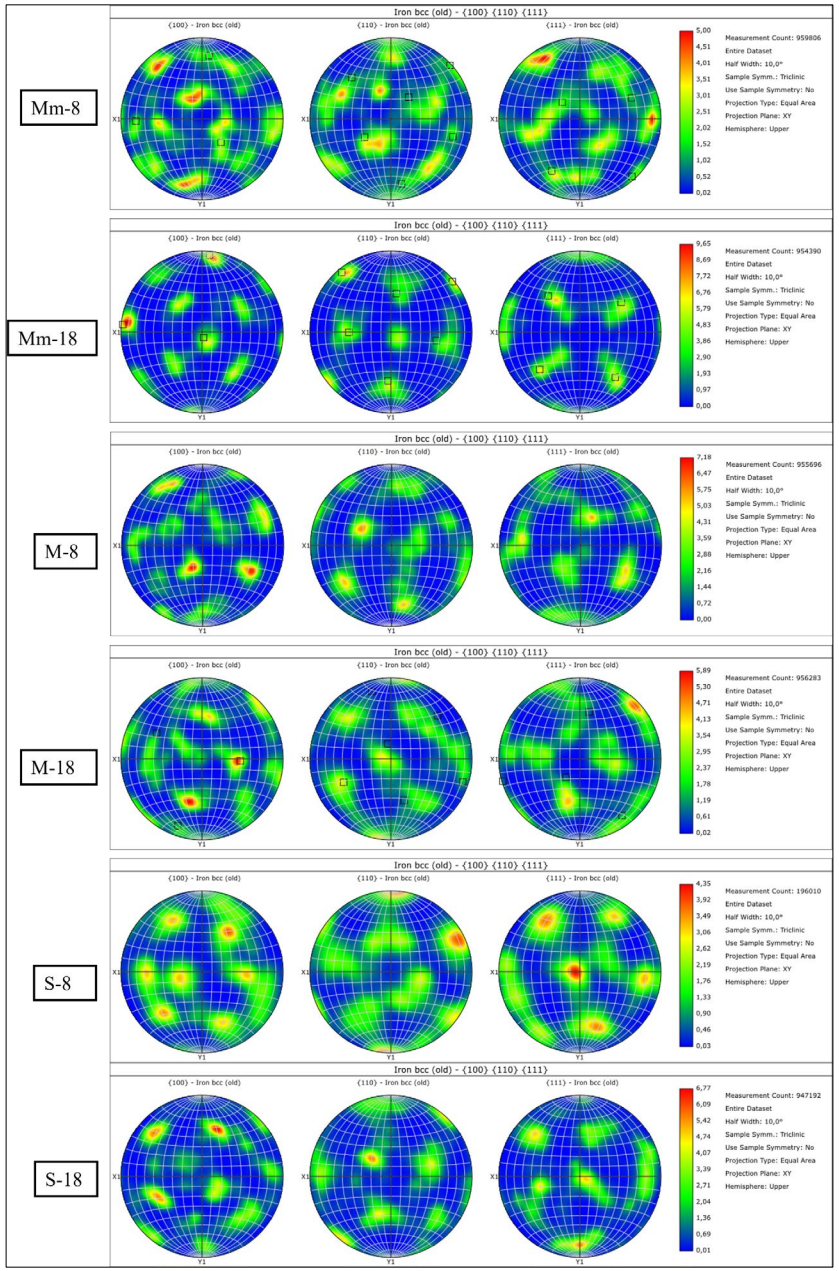

Building (vertical) direction
TV-1
Radiography
TH-t
CVN-H
CVN-H
CVN-H
CVN-V
CVN-V
CVN-V
TH-b
TV-2
T
D
C
B
Deposition (horizontal direction)


a
Mm-8
Wire
Mm-18
Mn%
Distance from substrate (mm)
b
Ni%
c
Si%


M and Mm wire
S wire
CVN (J)
0
20
40
60
80
100
120
140
Mm-8-H1
Mm-8-H2
Mm-8-H3
Mm-8-V1
Mm-8-V2
Mm-18-H1
Mm-18-H3
Mm-18-V1
Mm-18-V2
Mm-18-V3
M-8-H1
M-8-H2
M-8-H3
M-8-V1
M-8-V2
M-8-V3
M-18-H1
M-18-H2
M-18-H3
M-18-V1
M-18-V2
M-18-V3
S-8-H1
S-8-H2
S-8-H3
S-8-V1
S-8-V2
S-8-V3
S-18-H1
S-18-H2
S-18-H3
S-18-V1
S-18-V2
S-18-V3


Mm wire
S and M wires
El%
0
5
10
15
20
25
Mm wire
M wire
S wire
YS (MPa)
0
100
200
300
400
500
600
700
800
900
1000
Mm wire
M wire
S wire
TS (MPa)
650
700
750
800
850
900
950
Mm-8-TV1
Mm-8-TV2
Mm-18-TV1
Mm-18-TV2
Mm-18-TH-t
Mm-18-TH-b
M-8-TV1
M-8-TV2
M-8-TH-t
M-8-TH-b
M-18-TV1
M-18-TV2
M-18-TH-t
M-18-TH-b
S-8-TV1
S-8-TV2
S-8-TH-t
S-8-TH-b
S-18-TV1
S-18-TV2
S-18-TH-t
S-18-TH-b

Pole figures of {100}, {110}, and {111} planes showing crystallographic texture variations across all six WAAM walls.



SURG-WAM project
Högskolan Väst- GasiQ AB

Normal Gas regulator

Flow rate (L/min)

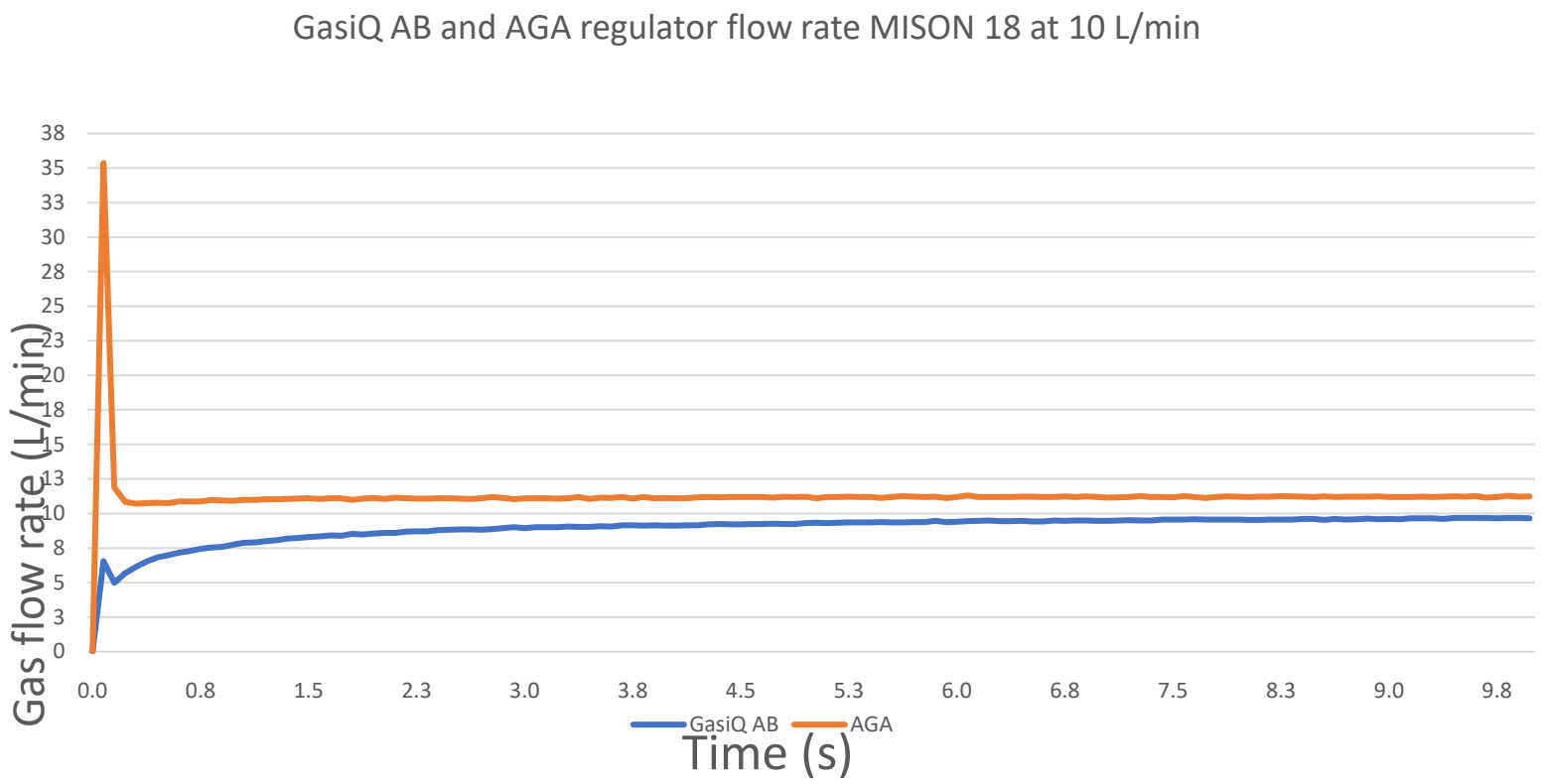
Time (sec)

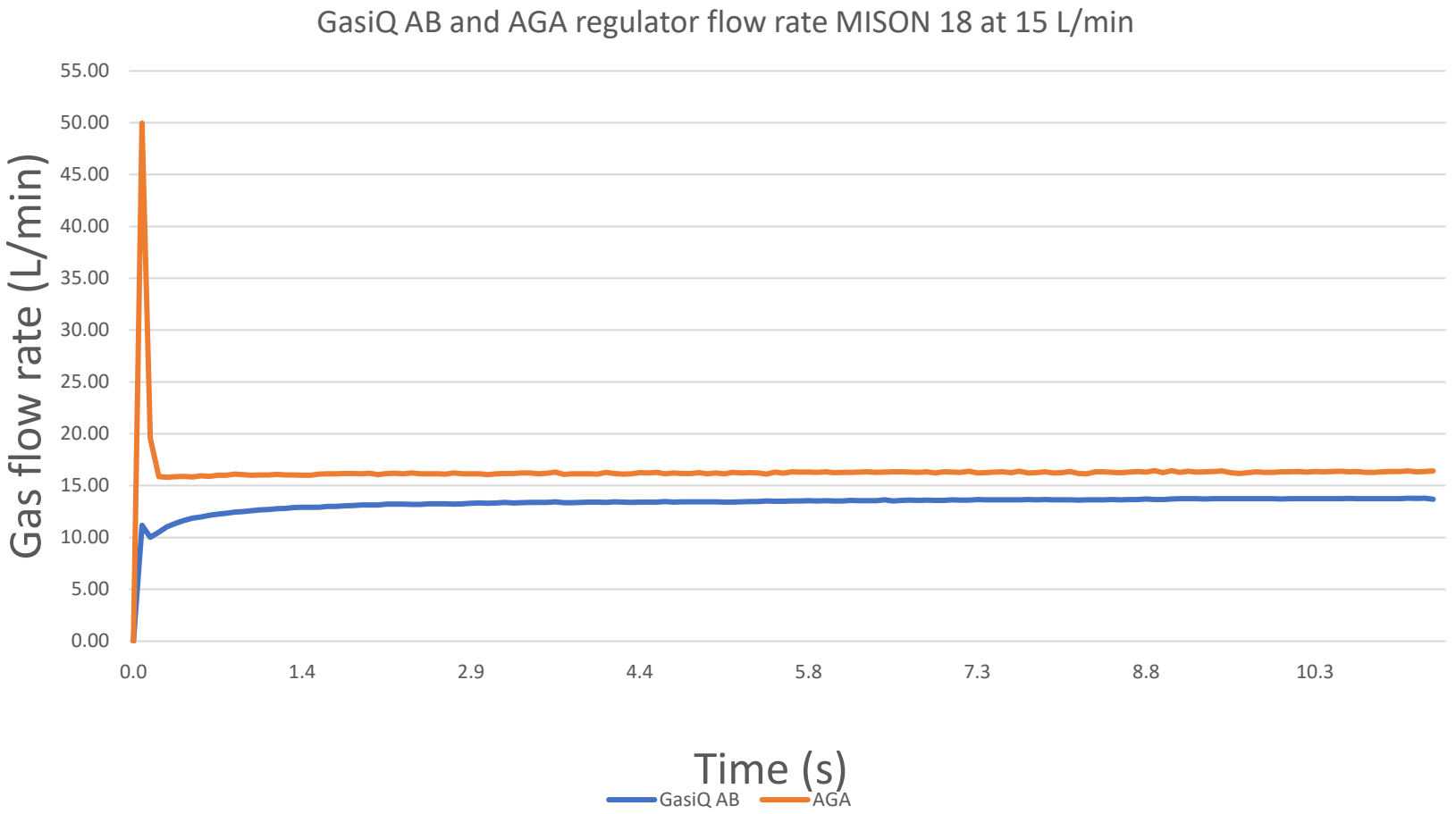
Gas regulator from GasiQ

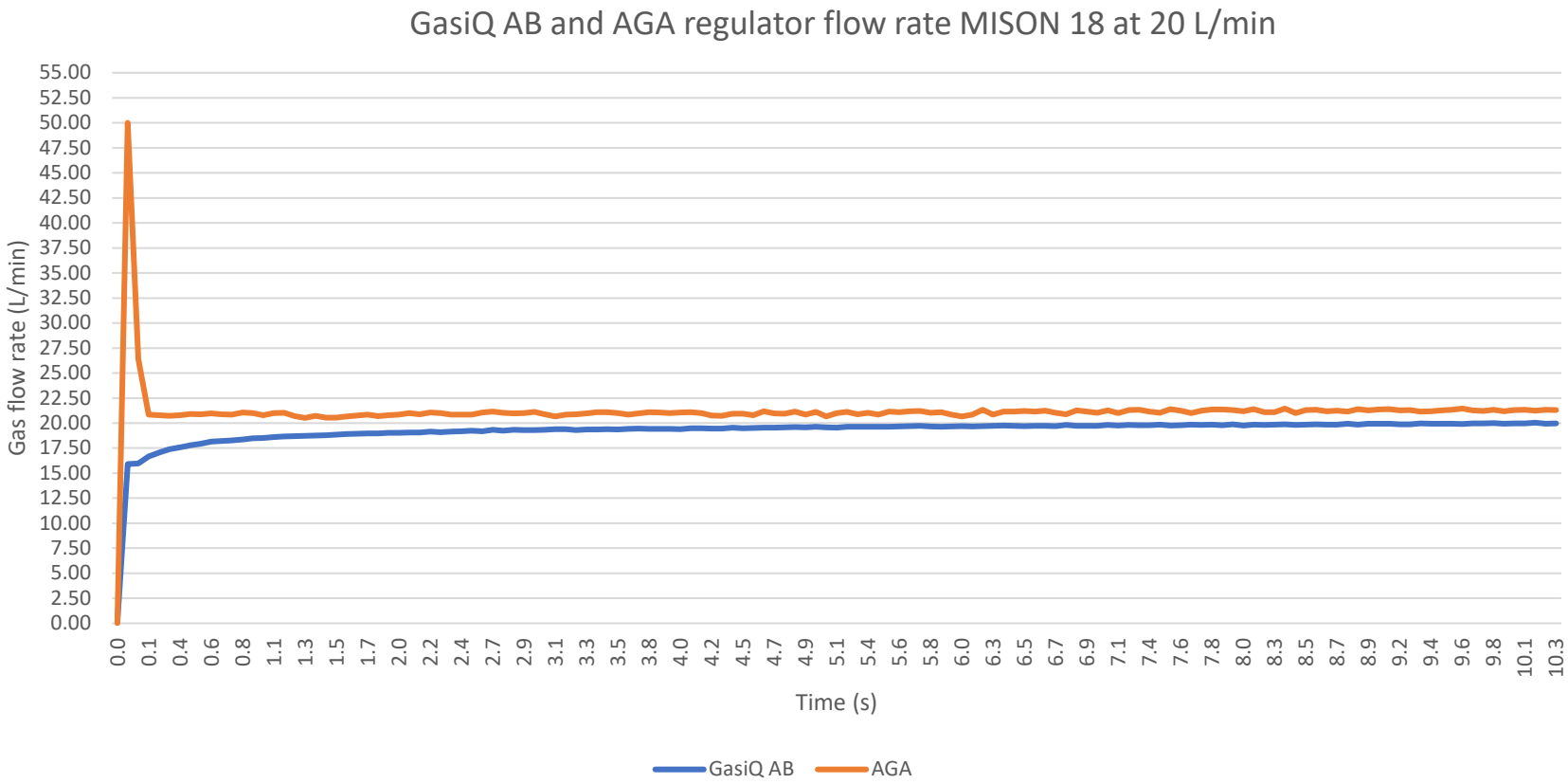
Flow rate (L/min)

Time (sec)

Measurement


GasiQ AB and AGA regulator flow rate MISON 18 at 10 L/min
Gas flow rate (L/min)
38
35
33
30
28
25
23
20
18
15
13
10
8
5
3
0
0.0
0.8
1.5
2.3
3.0
3.8
4.5
5.3
6.0
6.8
7.5
8.3
9.0
9.8
GasiQ AB
AGA
Time (s)


GasiQ AB and AGA regulator flow rate MISON 18 at 15 L/min
Gas flow rate (L/min)
55.00
50.00
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
0.0
1.4
2.9
4.4
5.8
7.3
8.8
10.3
Time (s)
GasiQ AB
AGA

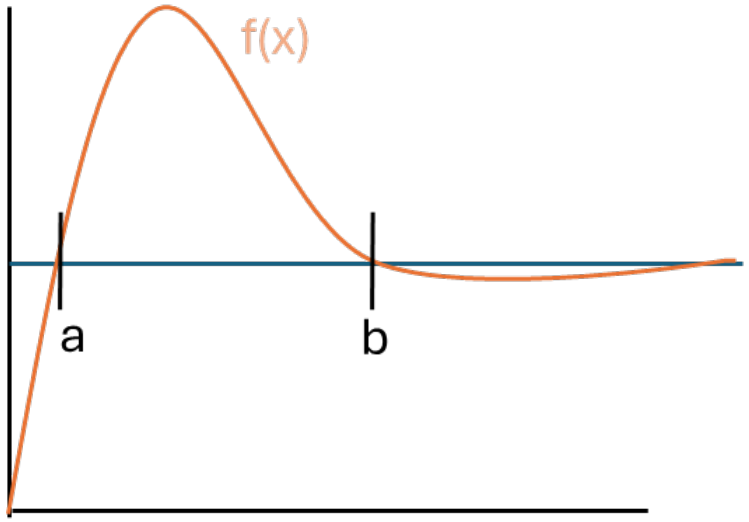

GasiQ AB and AGA regulator flow rate MISON 18 at 20 L/min
Gas flow rate (L/min)
55.00
52.50
50.00
47.50
45.00
42.50
40.00
37.50
35.00
32.50
30.00
27.50
25.00
22.50
20.00
17.50
15.00
12.50
10.00
7.50
5.00
2.50
0.00
0.0 0.1 0.4 0.6 0.8 1.1 1.3 1.5 1.7 2.0 2.2 2.4 2.7 2.9 3.1 3.3 3.5 3.8 4.0 4.2 4.5 4.7 4.9 5.1 5.4 5.6 5.8 6.0 6.3 6.5 6.7 6.9 7.1 7.4 7.6 7.8 8.0 8.3 8.5 8.7 8.9 9.2 9.4 9.6 9.8 10.1 10.3
Time (s)
GasiQ AB
AGA

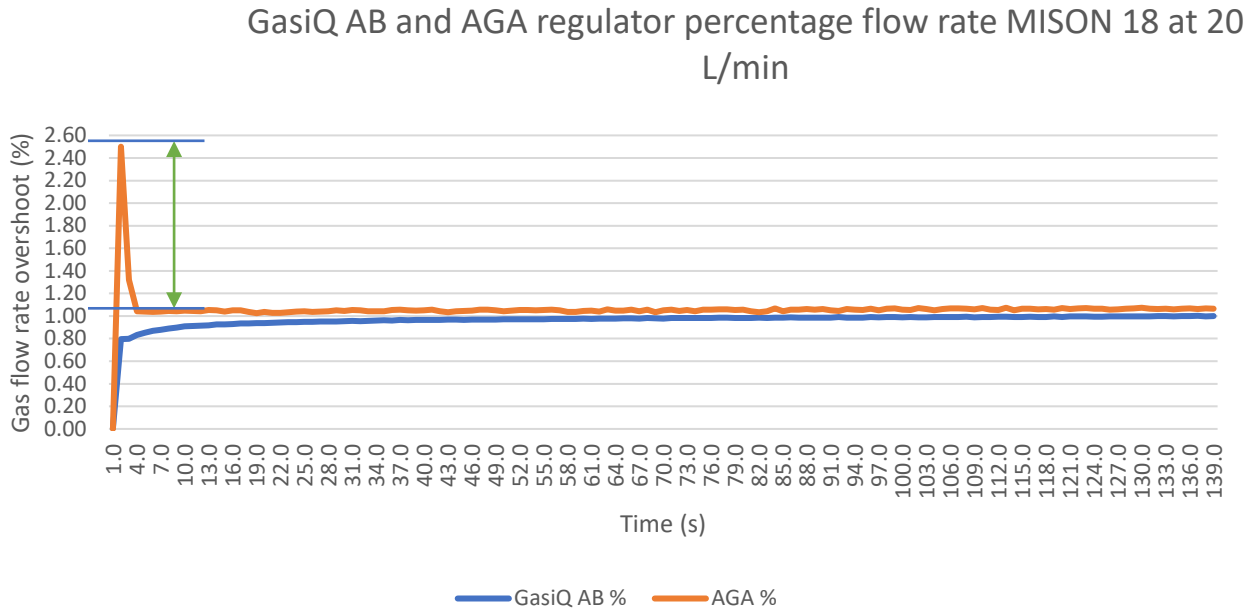
Result evaluation

- Result analysis through percentage overshoot (%)

- Integral of curve to find the total gas volume lost.

$$\text{Area} = \int a^{b} (f(x)dx) - t(b-a)$$





Extracted data

Percent overshoot comparison of different GasiQ Optimator and AGA regulator, in Linde MISON 18 Ar/mix.

Flow rate	Optimator overshoot	AGA overshoot
10	-34.4%	323 %
15	-24.1%	303 %
20	2%	230%

Average volume lost per start stop of Linde MISON 18 Ar/mix, per regulator.

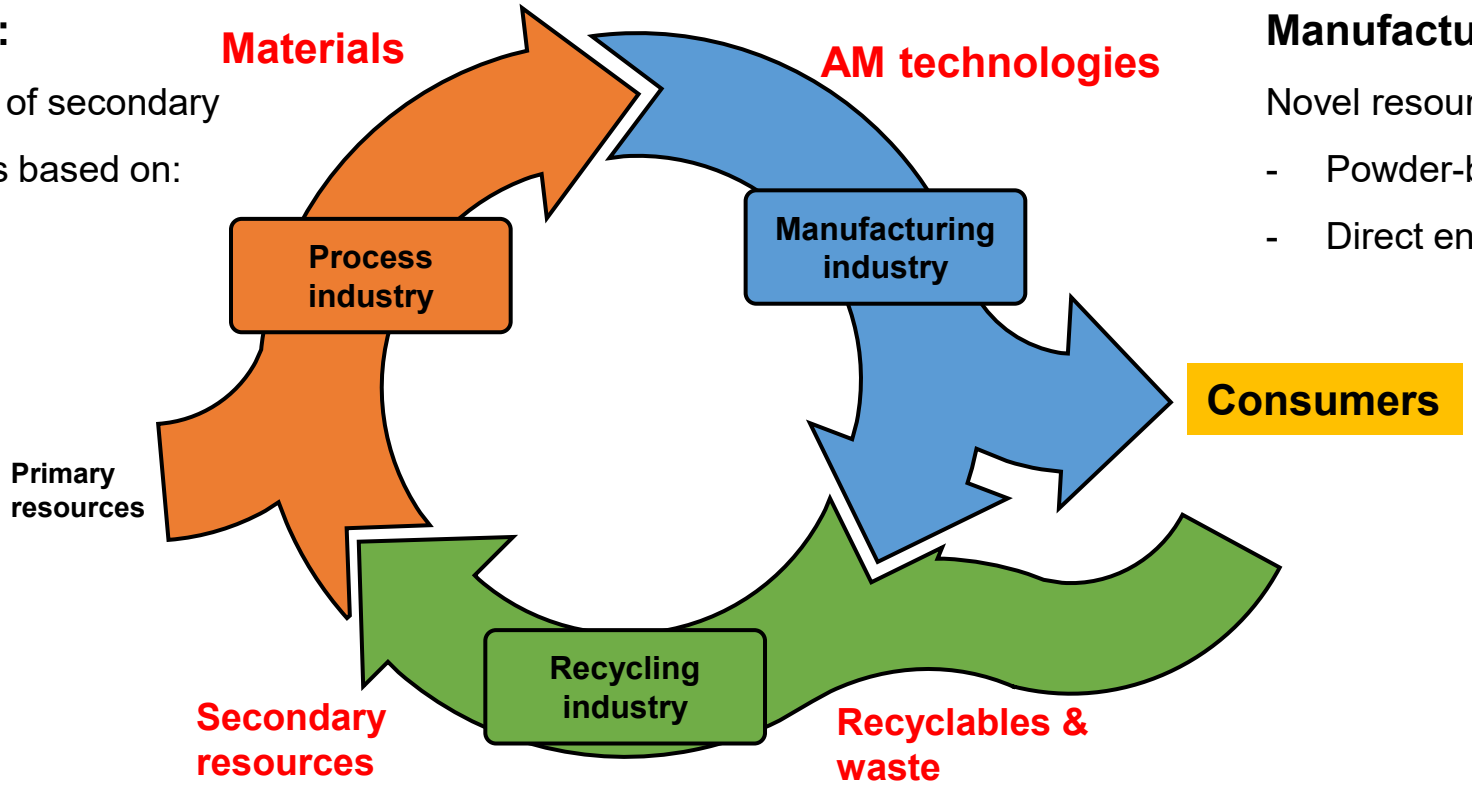
Flow rate	Optimator Volume lost (L)	AGA Volume lost (L)
10	none	0.071L
15	none	0.089L
20	≈0L	0.086 L

Circular manufacturing

Material process industry:

Innovations to increase the use of secondary resources - Innovative materials based on:

- better processability in AM
- better inherent recyclability
- better resource efficiency



Manufacturing industry:

Novel resource-efficient processes based on:

- Powder-bed fusion (PBF)
- Direct energy deposition (DED)

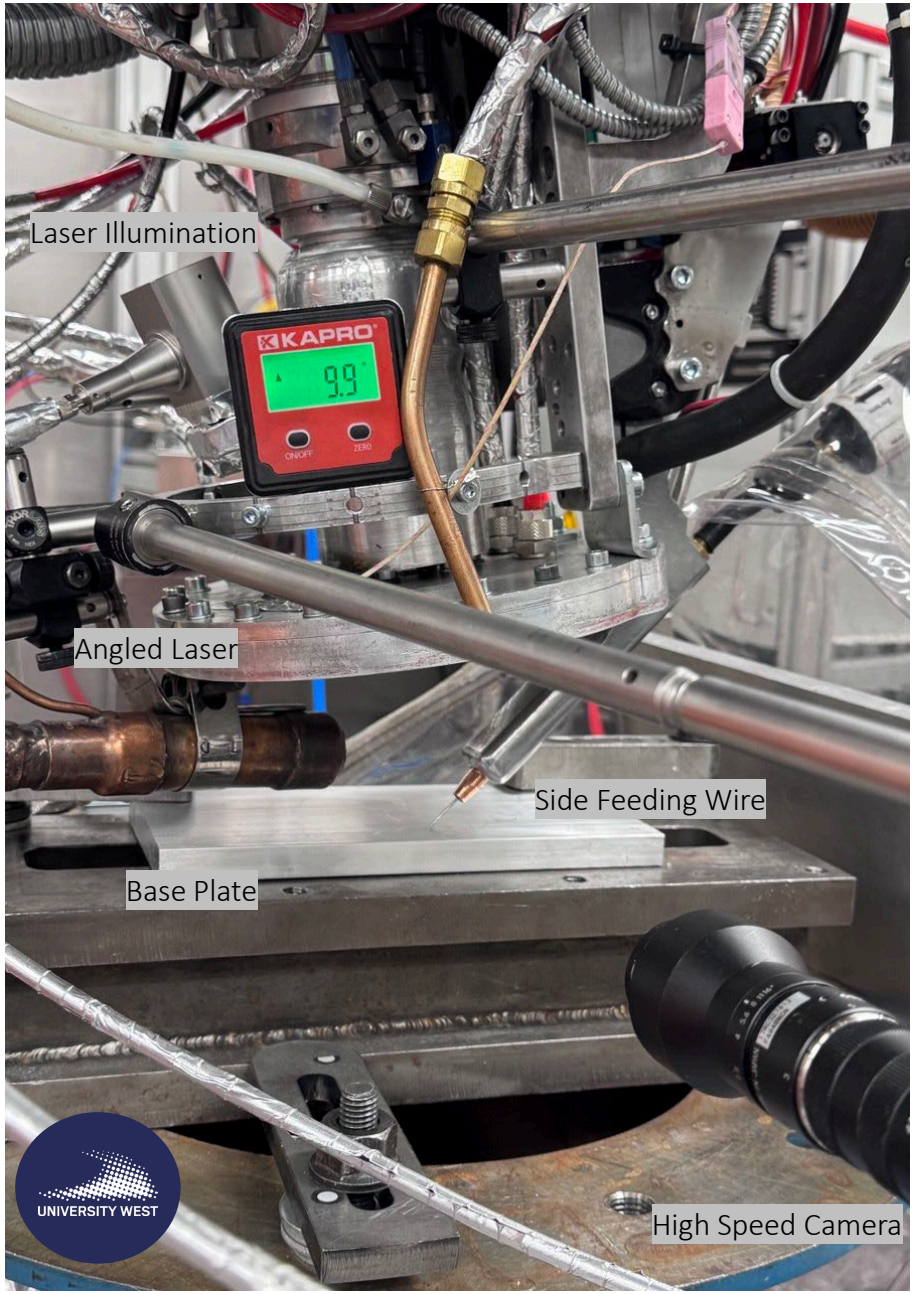
Recycling industry:

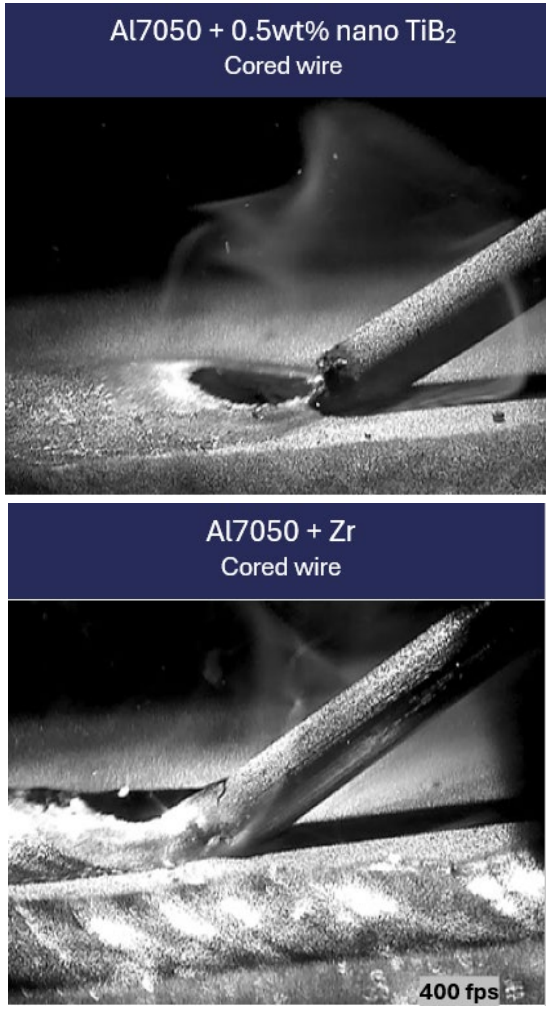
Innovative direct recycling routes for high-value materials and multi-materials and functionally graded materials

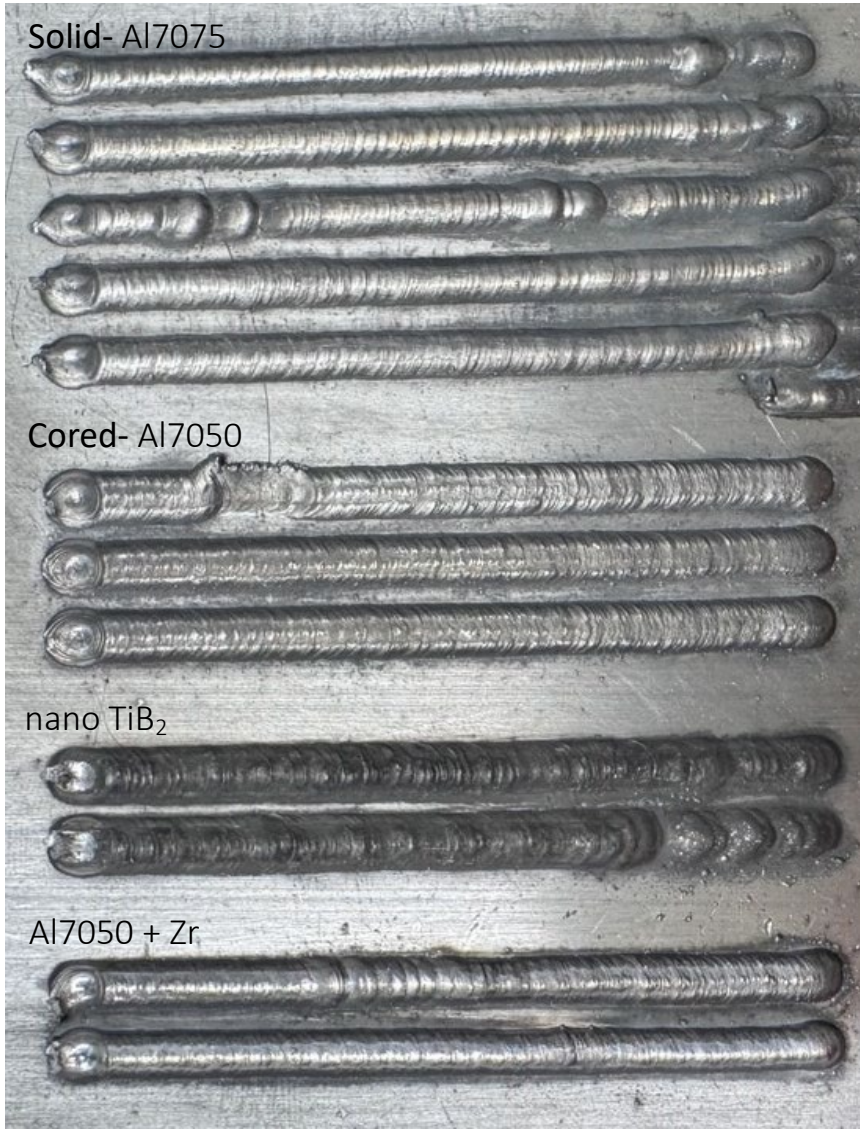
Keep high value of materials

HEU-project: REPAM

Impact of wire composition

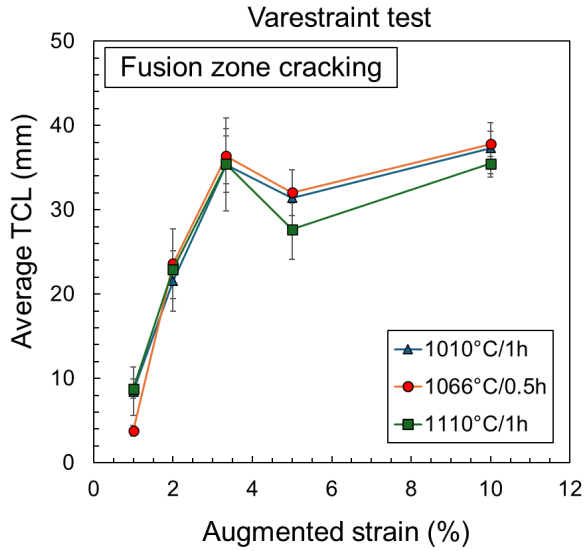




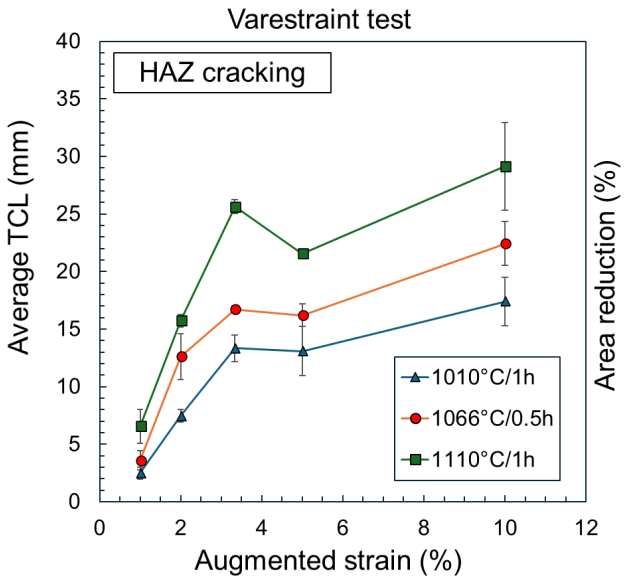


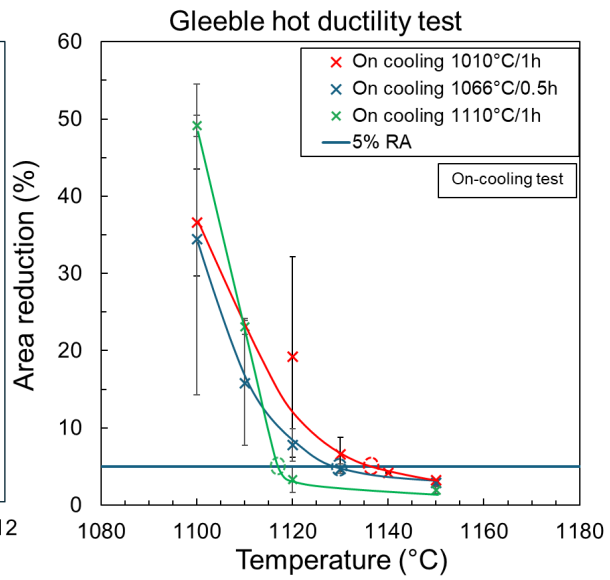
Effect of pre-weld solution annealing on fusion zone solidification cracking of Alloy G27

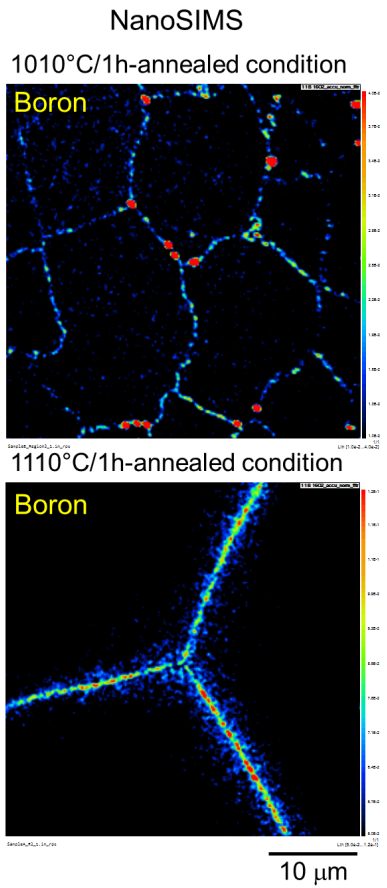
Solution annealing	Grain size before testing
1010°C/1h	12 μm
1066°C/0.5h	85 μm
1110°C/1h	200 μm



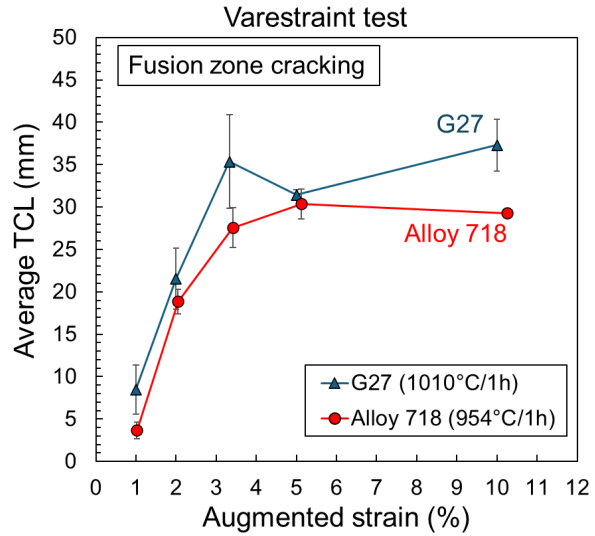
Effect of pre-weld solution annealing on HAZ cracking of G27



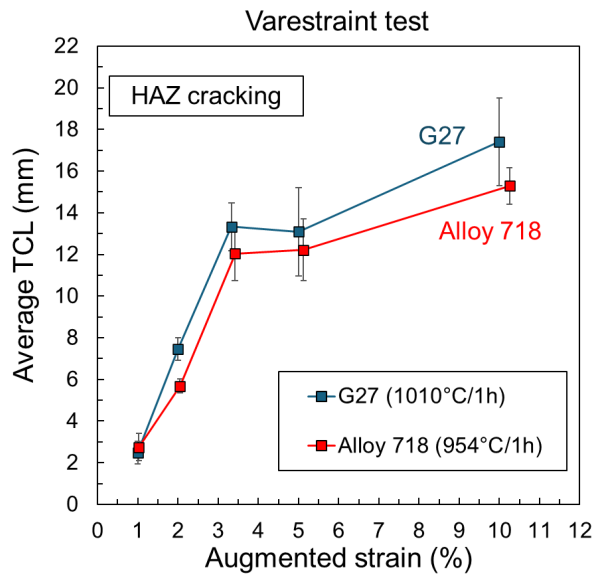




Solidification cracking of G27 vs. Alloy 718

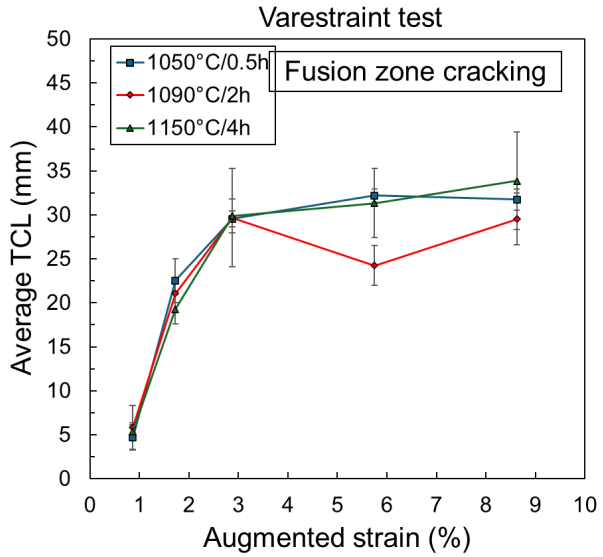


HAZ cracking of G27 vs. Alloy 718

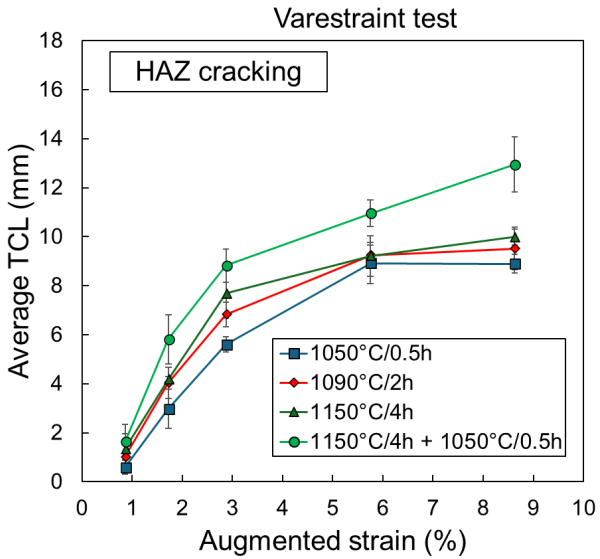


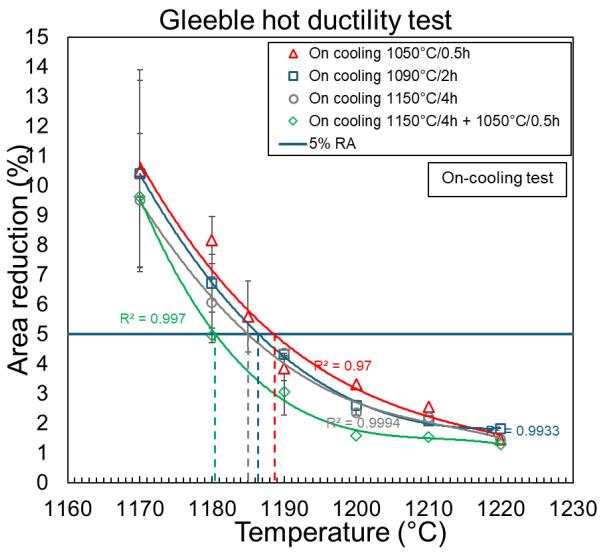
Effect of pre-weld solution annealing on fusion zone solidification cracking of VDM Alloy 780

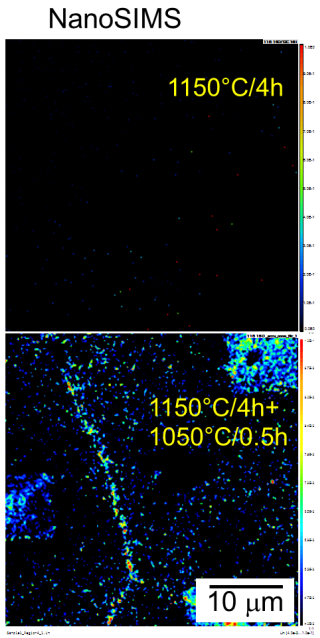
Solution annealing	Grain size before testing
1050°C/0.5h	85 µm
1090°C/2h	110 µm
1150°C/4h	160 µm
1150°C/4h + 1050°C/0.5h	160 µm



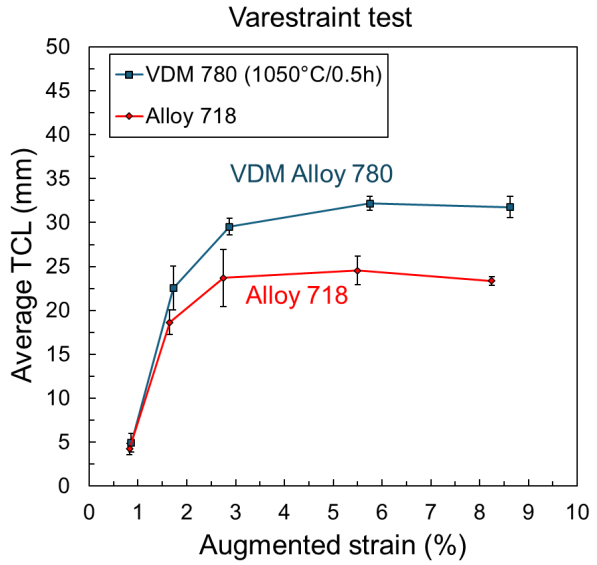
Effect of pre-weld solution annealing on HAZ cracking of VDM Alloy 780



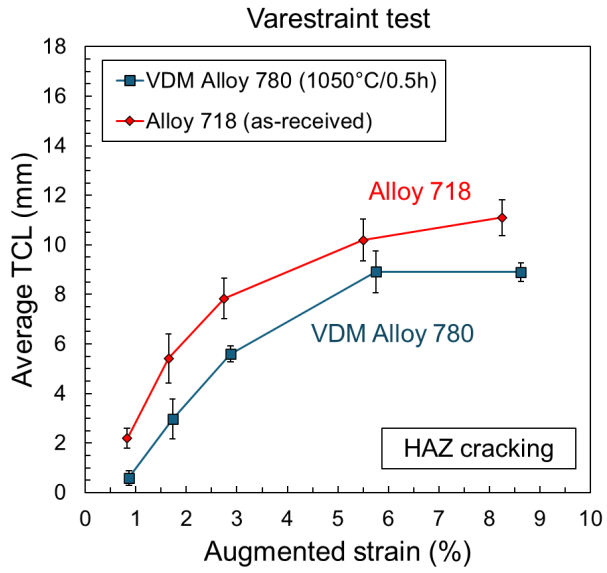




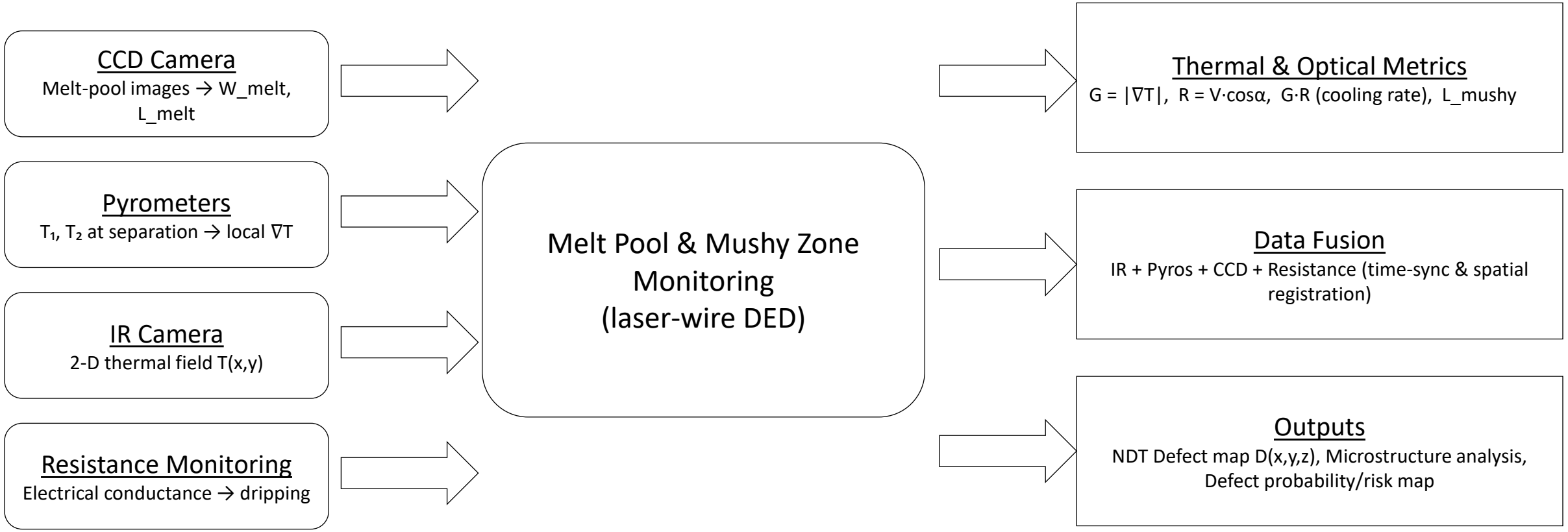
Solidification cracking of VDM Alloy 780 vs. Alloy 718



HAZ cracking of VDM Alloy 780 vs. Alloy 718

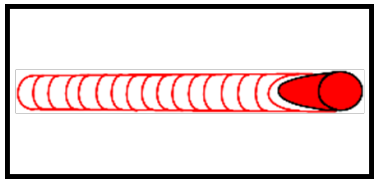


DED-LB/w of Haynes 282: In-situ Monitoring for defect Mapping

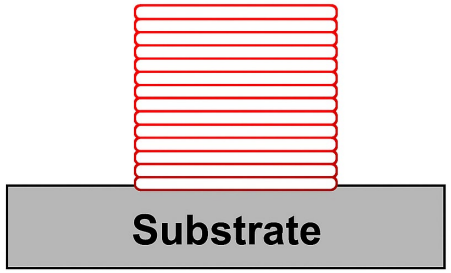


Goal: To Develop a defect-aware process window for H282 with in-situ monitoring capable of flagging and correcting defects in real time.

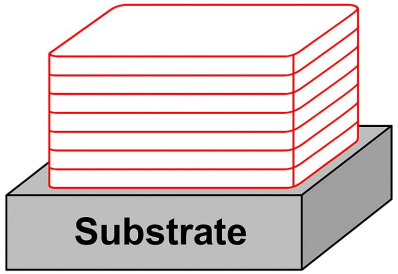
Multi-Sensor Setup



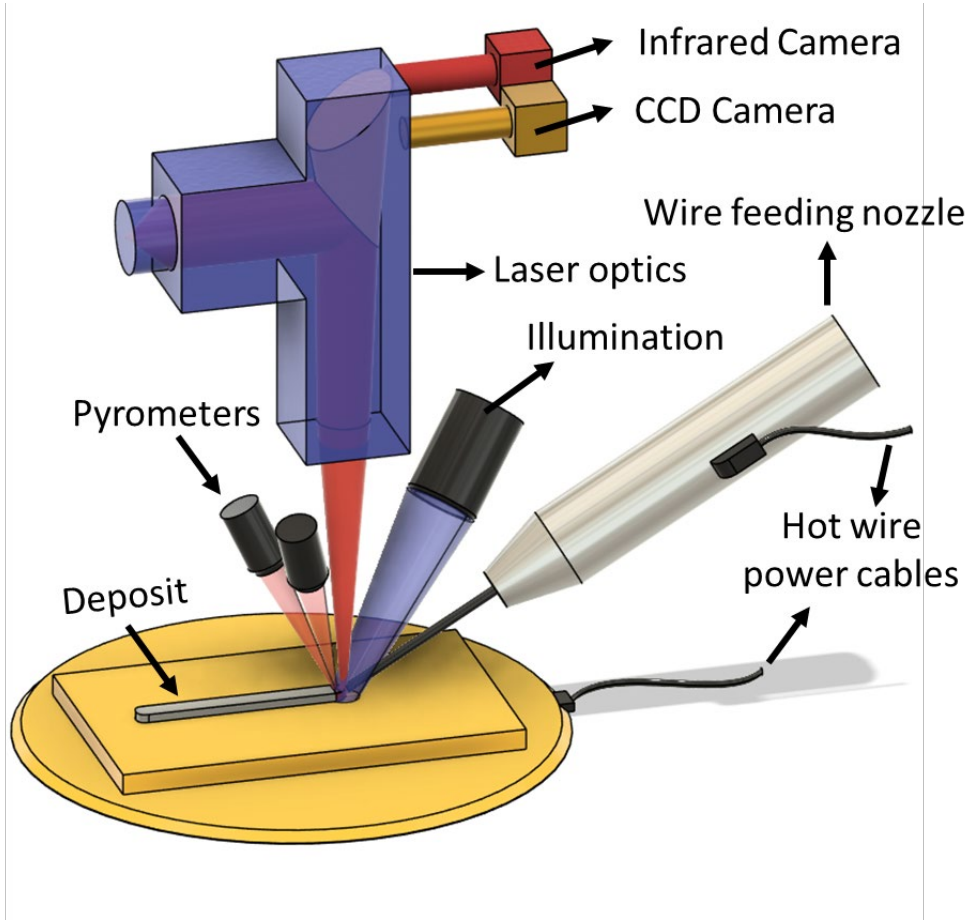
Stage 1: Single Tracks



Stage 2: Multi Layer/thin Structure



Stage 3: 3D block



Sensor	Signal Captured	What We Infer from the Signal
Resistance monitoring	Electrical Conductance	Dripping Events
CCD camera	Melt Pool images	Representative of heat content, Quantifies heat buildup
Pyrometer 1 & 2	T_1, T_2 at separation D	Thermal gradient at mushy (G&R)
IR camera	2-D thermal field; mushy-zone length	L_{mushy}, G&R

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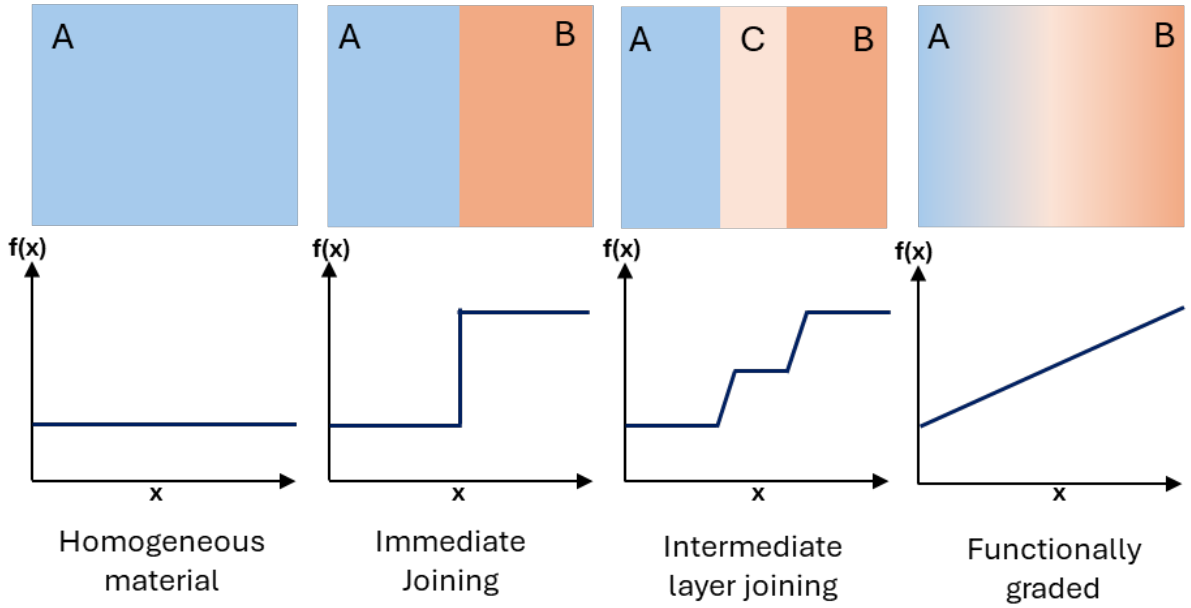
Project Title: Developing Metal-Metal (Alloy 718-NiCrAlY) Functionally Graded Materials (FGMs) using Directed Energy Deposition Process

Ph.D. student: Dilipkumar Ratnala

Supervisors: Joel Andersson, Shrikant Joshi, Fabian Hanning

Introduction to FGMs:



Functionally Graded Materials (FGMs):

- Reduces the stresses associated with a sharp interface
- Gradual variation in properties, instead of a sudden change

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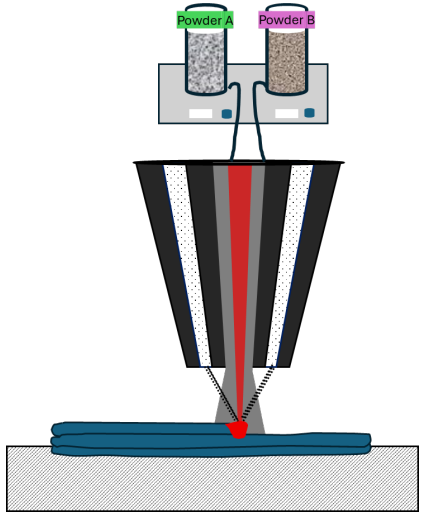
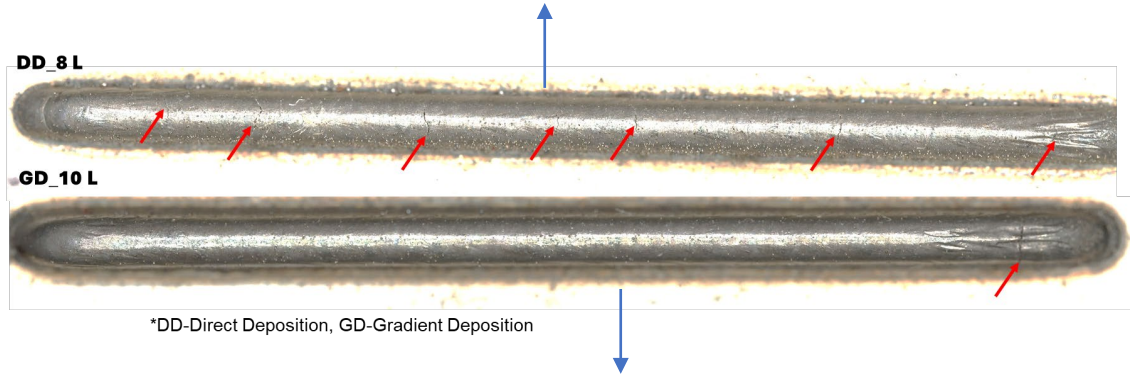
Alloy 718 – NiCrAlY FGMs



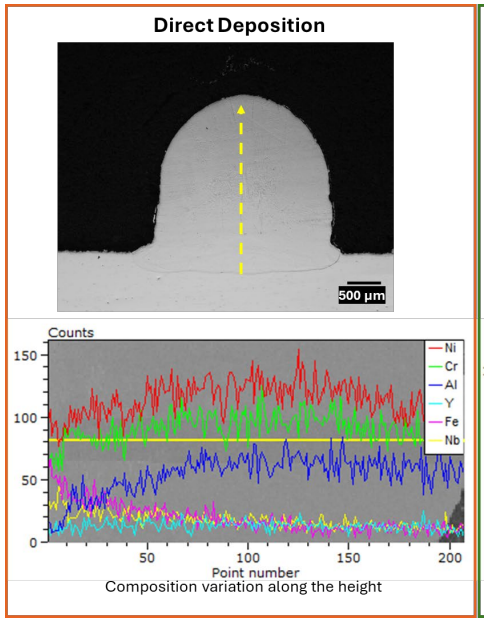
DED-LB/p

Surface cracking in the Direct Deposited sample

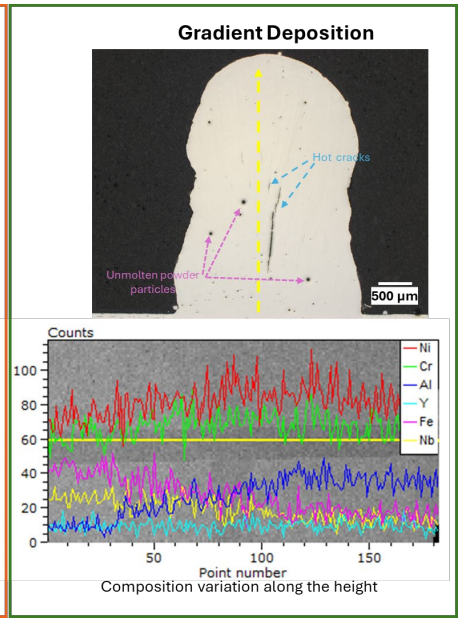


*DD-Direct Deposition, GD-Gradient Deposition

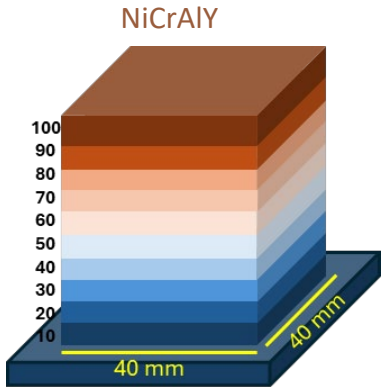
Near eliminated surface cracking in the Gradient Deposited sample

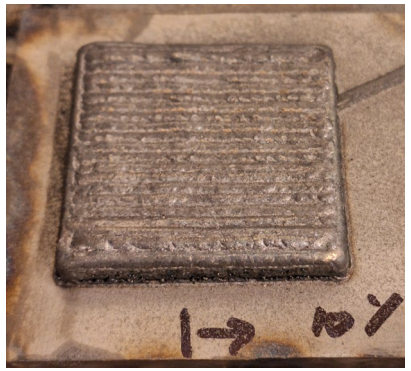


Composition variation along the height



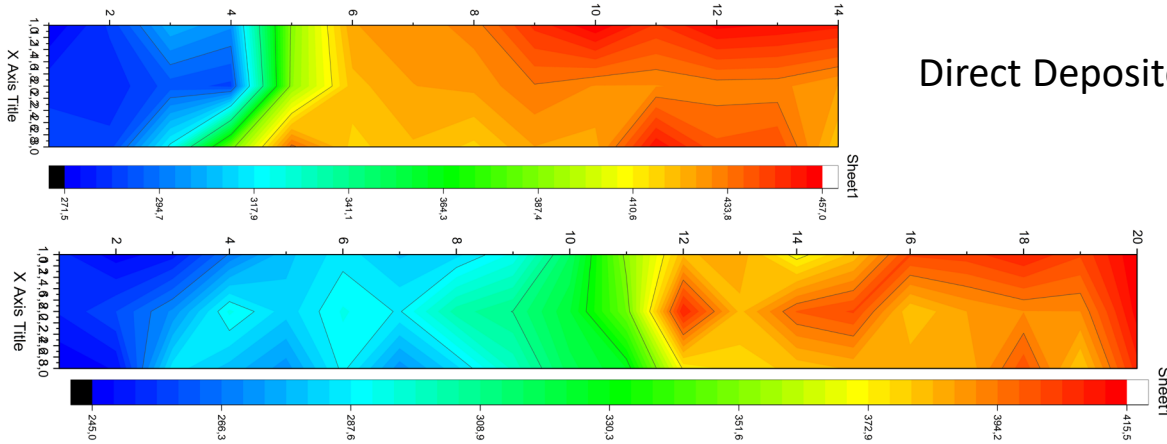
Composition variation along the height





Alloy 718-NiCrAlY FGM

Microhardness



Direct Deposited NiCrAlY (8 layers)

Graded Deposited NiCrAlY (10 layers)

Variation in Microhardness with Gradient

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On-Line FSW QA: Instance Segmentation of Defects and Weld-Width Measurement

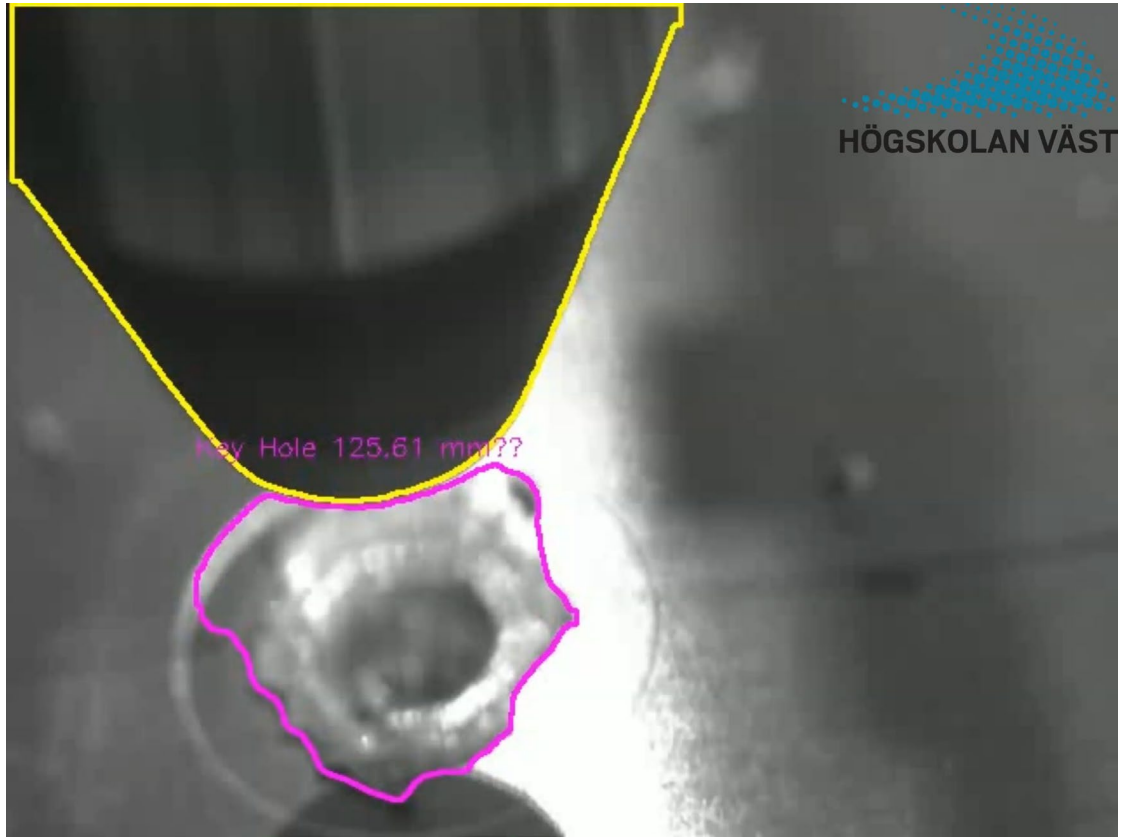

Fig. 1 — Real-time defect segmentation (video)

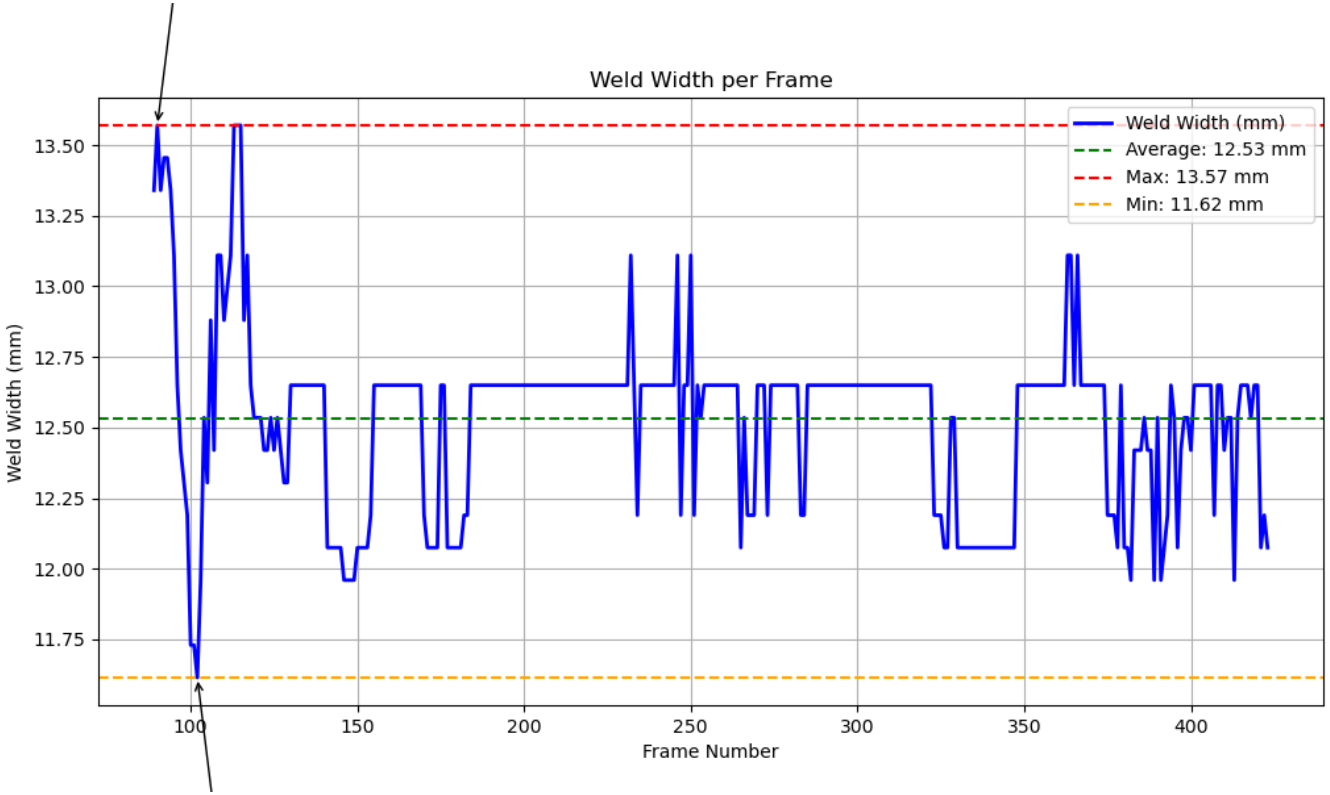

Fig. 2 — Per-frame weld-width measurement (image/plot).

Three core areas of research
with connections related to education on second-cycle

Materials and Manufacturing (Material och Tillverkningsteknik M&T)

- 1-2 year magister/master programme in **Manufacturing Engineering** (thermal spray, welding, machining and AM)
- Bachelor of mechanical engineering
- 2-year master programme in **Welding**, focusing on various joining technologies, welding based AM and material

Production Systems

- 1-2 year magister/master programme in **Robotics and Automation**
- 1-2 year magister/master programme in **AI and Automation**, with planned start 2022 resp 2023.
- Master programme in **Production Management**, with planned start 2022
- Master programme in **Operations Management**, with planned start 2024

Emerging Technology

- 1-year magister programme in **Cyber Security**, with planned start 2022
- 1-year magister programme in **Electrical Vehicles**

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Courses for professionals and contract education

2022

- SPK600 Quality control during Welding
- ATP720 Advanded Manufacturing Processes

2023

- SPK600 Quality control during Welding
- ATP720 Advanded Manufacturing Processes

2024

- SHS600 Sustainability Aspects in Welding
- ATP720 Advanced Manufacturing Processes
- KXXXXX Automation in Welding Production

Updated course list:
www.hv.se/produktionskurser

- Located in the beautiful town of Trollhättan
- Situated close to Goteborg, Sweden's 2nd largest city

Contact:
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Director Production Technology

joel.andersson@hv.se

Ass. Professor Jörg Volpp
Welding & welding-based AM

jorg.volpp@hv.se