Large Scale Metal Wire + Arc Additive Manufacturing of Structural Engineering Parts

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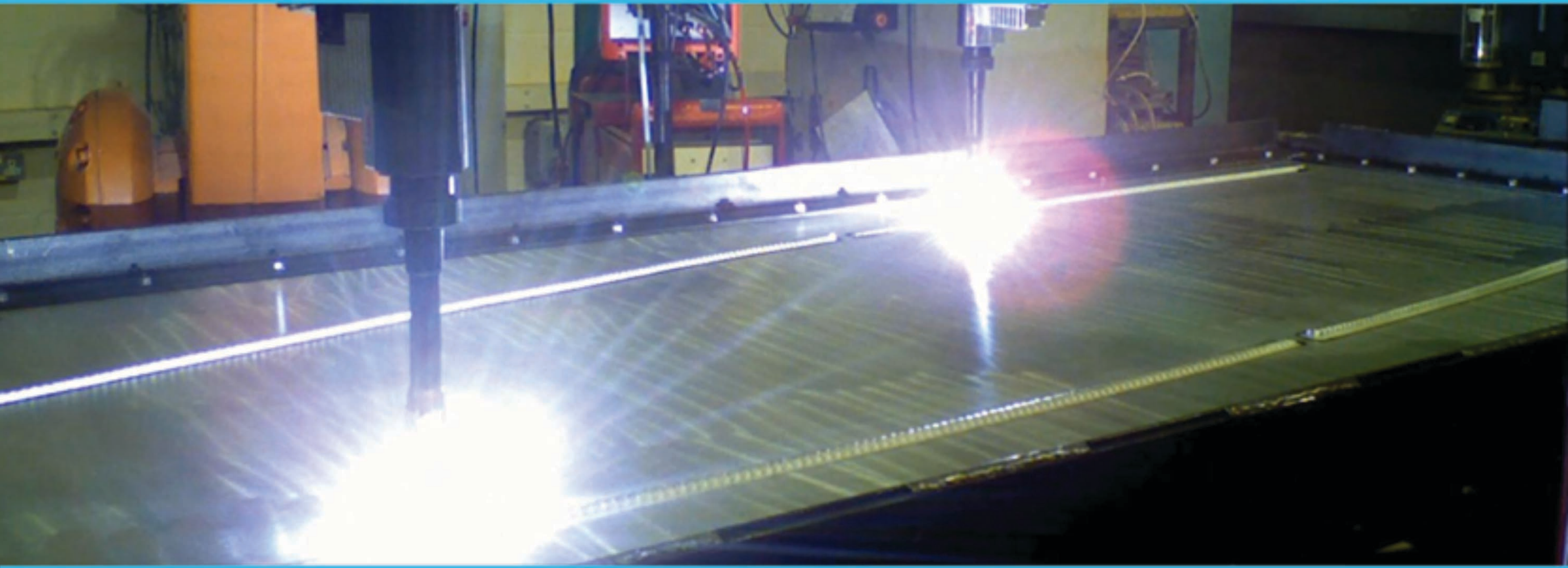

WAAM

www.waammat.com

Professor Stewart Williams + WAAMMat team

Welding Engineering and Laser Processing Centre

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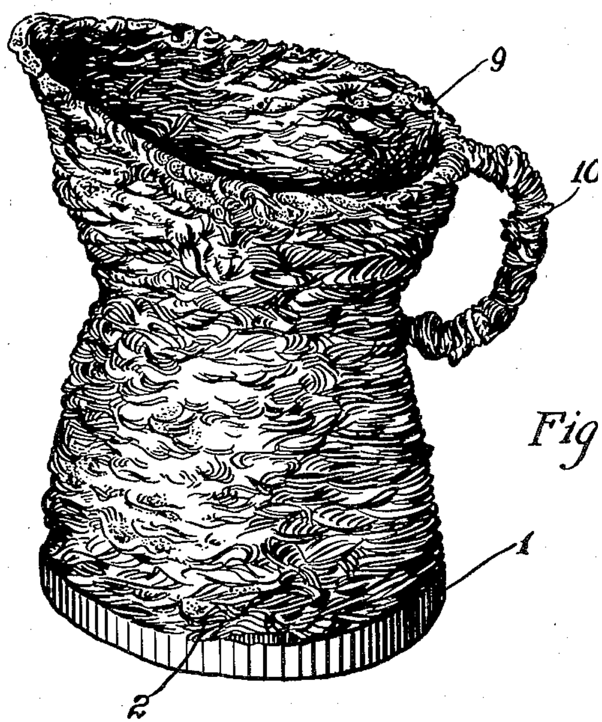
Topics

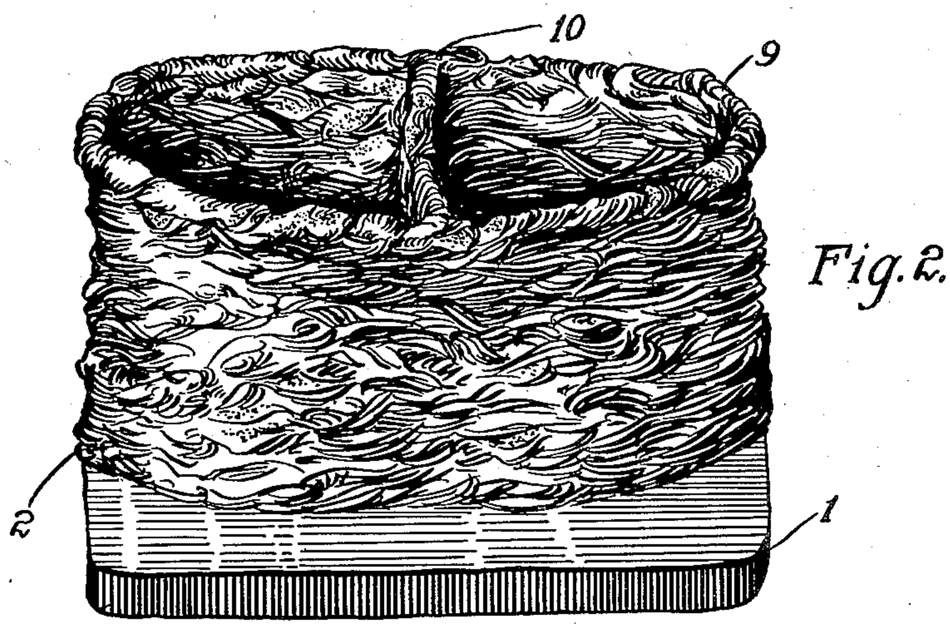
- Brief summary of Wire + Arc Additive Manufacture process in relation to other AM processes
- WAAM Materials
- WAAM Systems
- Future plans

Metal Additive Manufacture - Background

This has been around awhile!

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

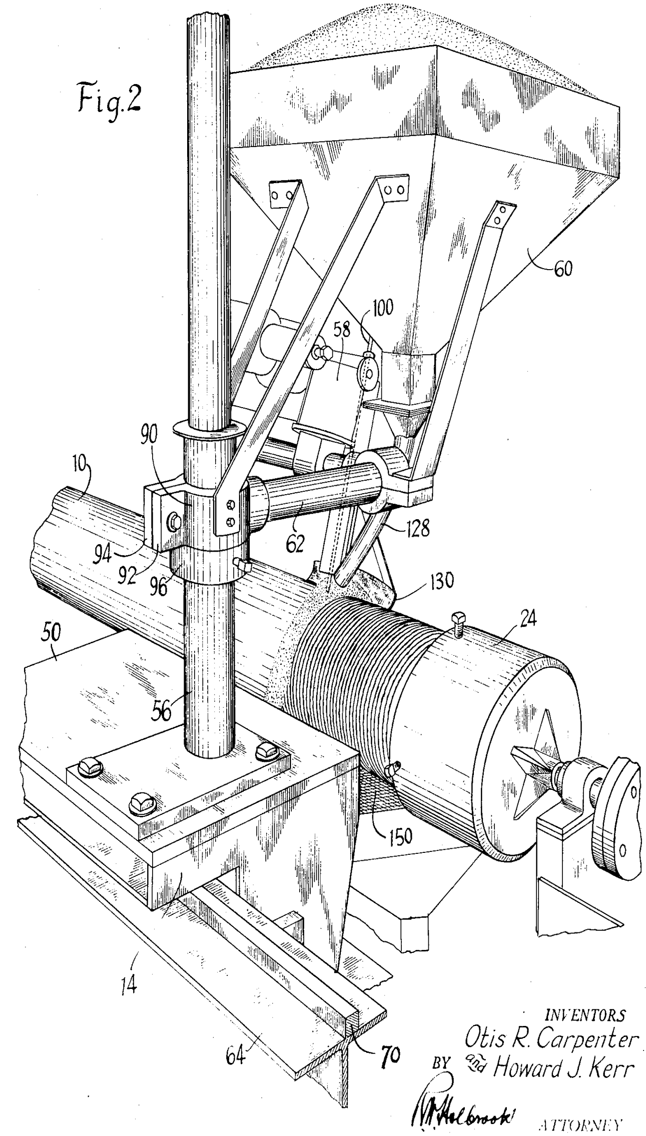


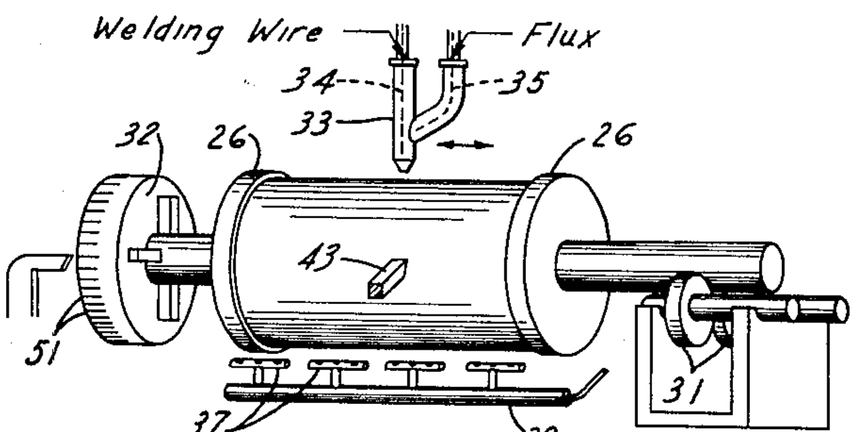


Metal Additive Manufacture - Background

This has been around awhile!

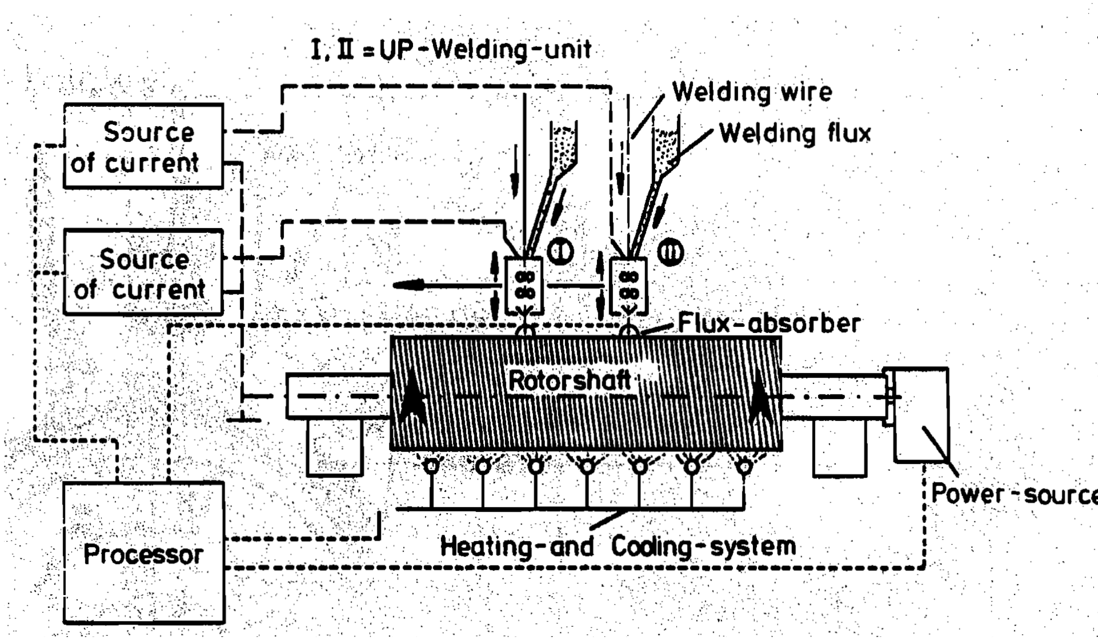
- 1947 Carpenter – weld based cladding using SAW
- 1964 White – Roller coating using SAW
- 1971Ujiie (Mitsubish) = Pressure vessel fabrication using SAW, electroslag and TIG, also multiwire with different wires to give functionally graded walls
- 1974 Thyssen produced components of any dimension and shape made only of weld metal instead casting, forging or rolling using SAW

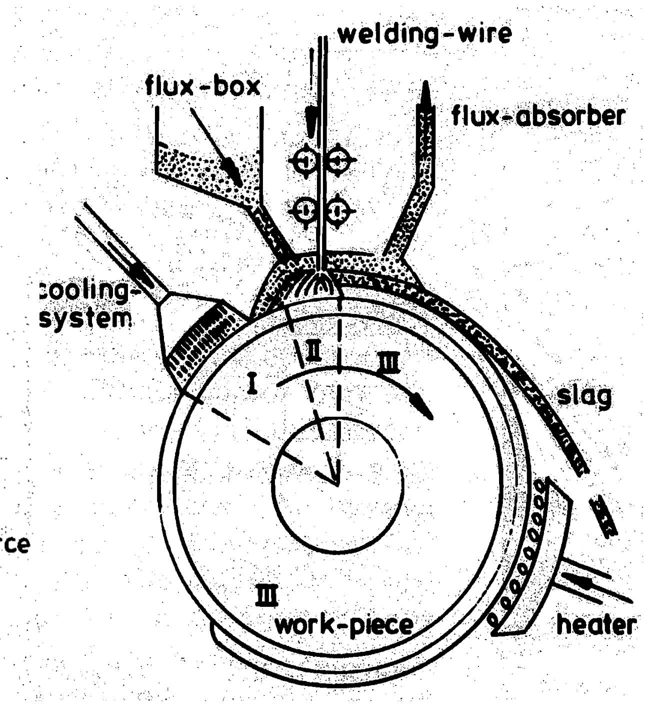




Metal Additive Manufacture - Background

- 1983 Kussmaul used Shape Welding to manufacture high quality large nuclear structural steel (20MnMoNi5 5) parts – deposition rate 80kg/hr – total weight 79 tonnes





Wire + Arc Additive Manufacture (WAAM) Process

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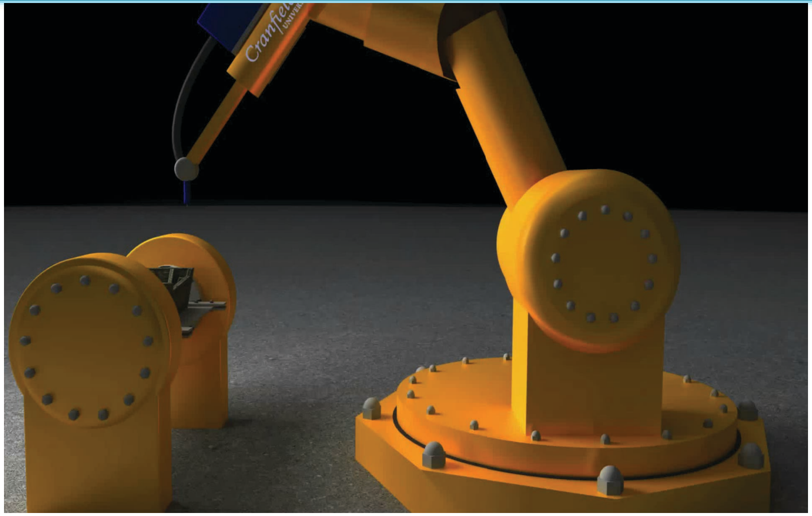

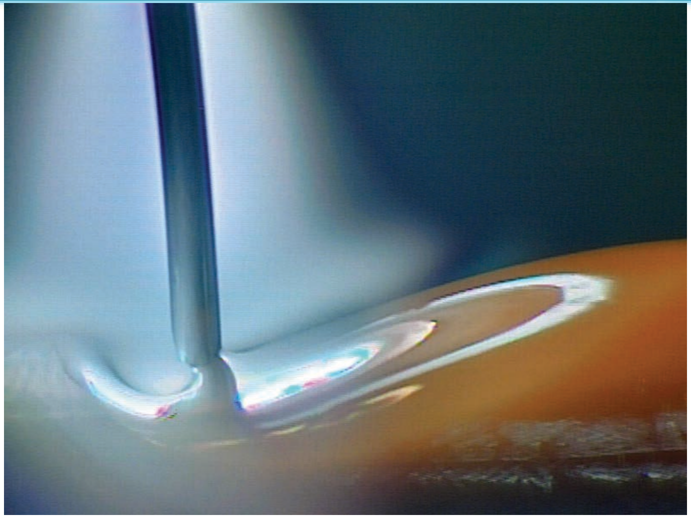

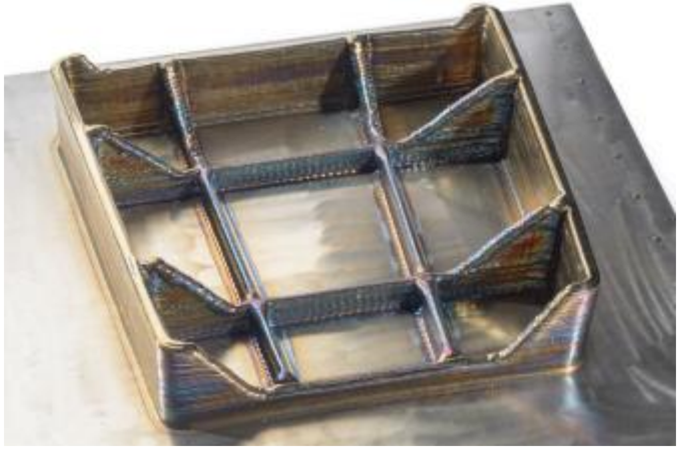

Deposition time 24 hours

Additive manufacturing landscape

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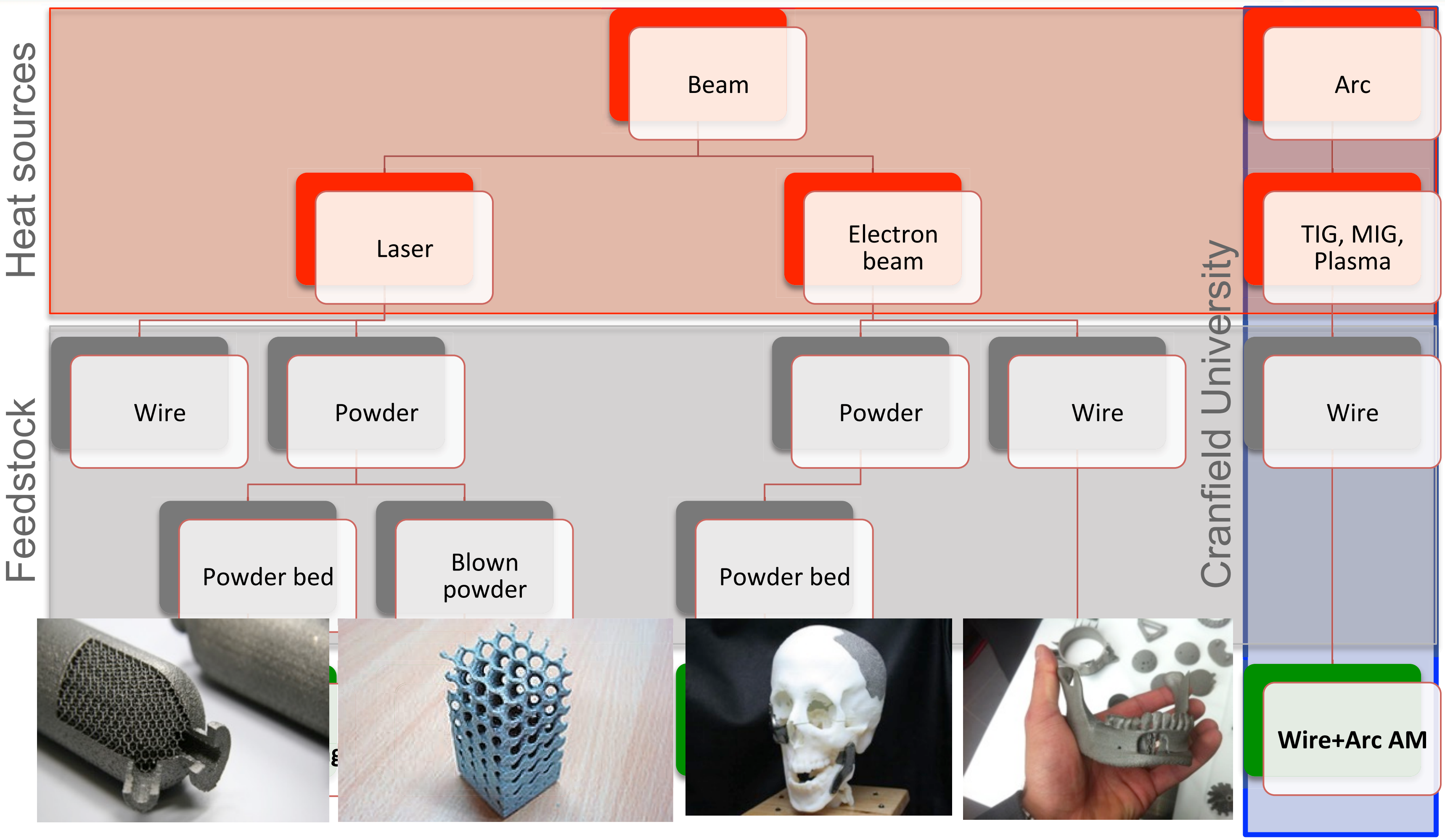
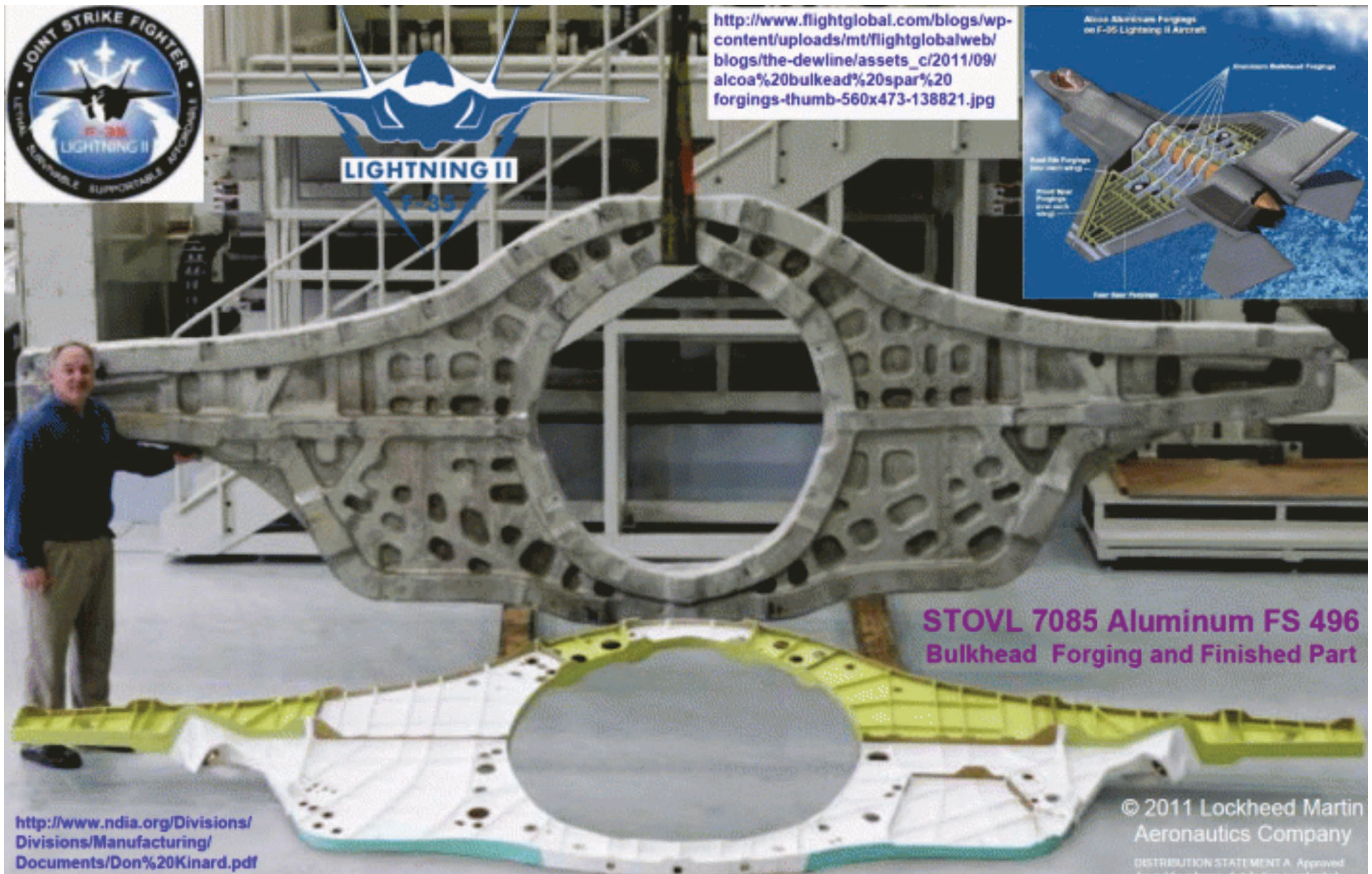


Where we are aiming - HELP!



Aluminium:

- 14 months for forging
- 4 months for machining
- 90% waste

Titanium:

- 10 times worse problems

Basics of metal AM systems – What process or hardware should you use?

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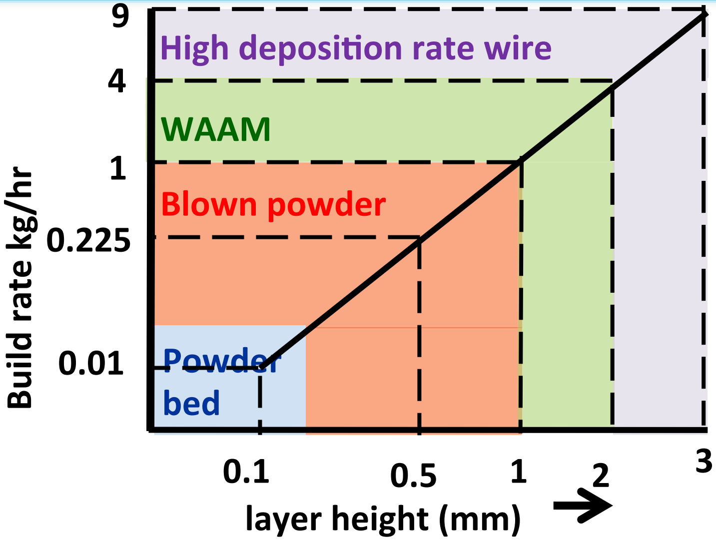
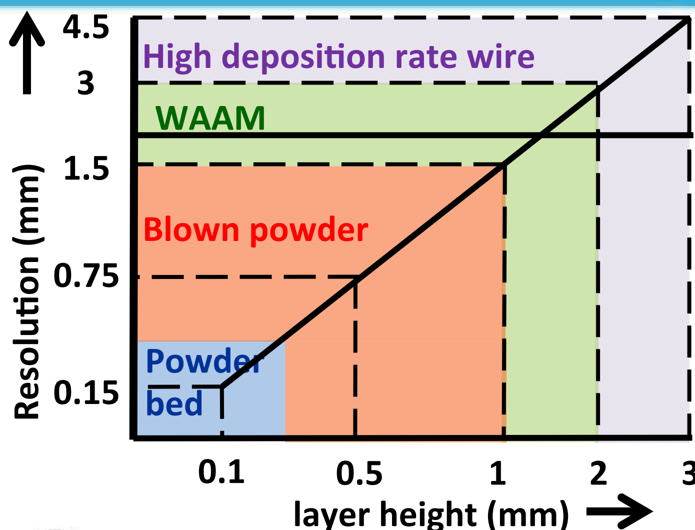
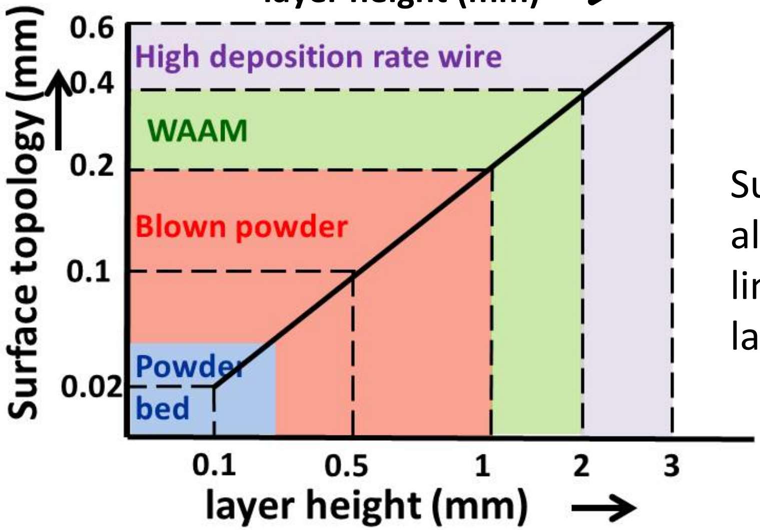


For a single axisymmetric energy source build rate depends on the square of the layer height



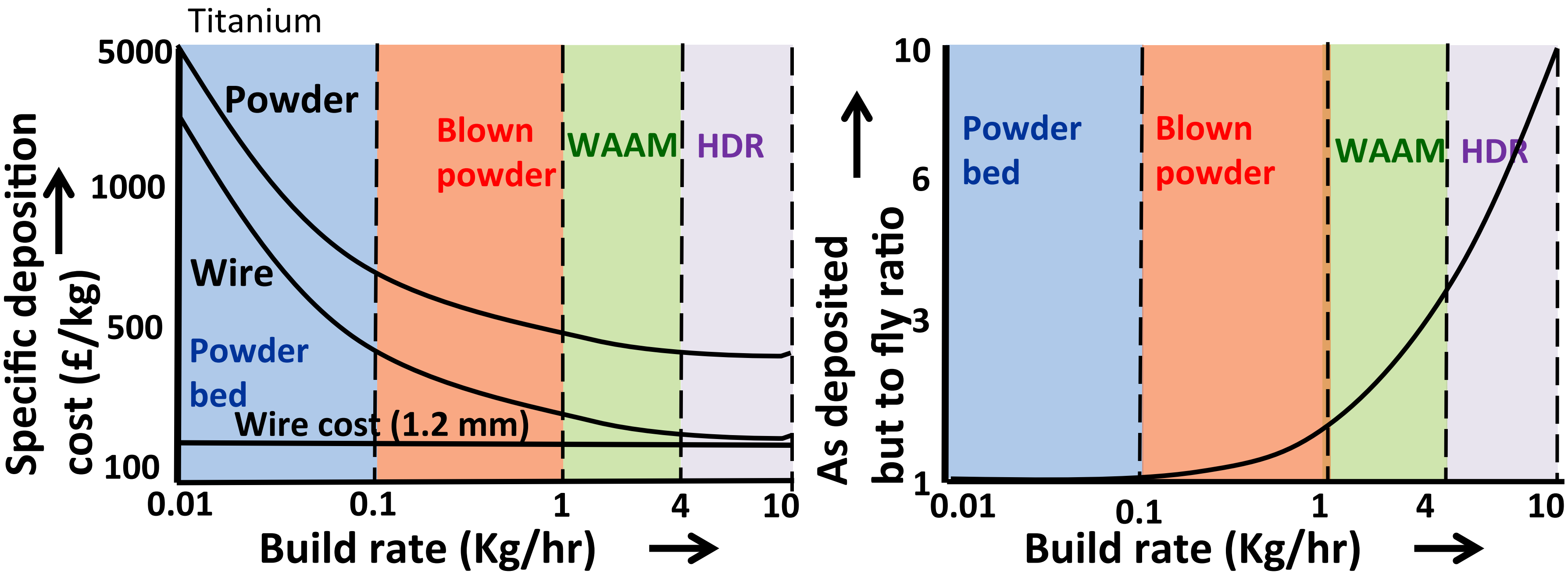
Optimum for finish machining ± 1mm

Resolution depends linearly on the layer height



Surface finish also depends linearly on the layer height

Basics of metal AM systems – Cost of depositing material



Specific cost approaches the material cost for high build rates

Optimum cost saving based on build rate

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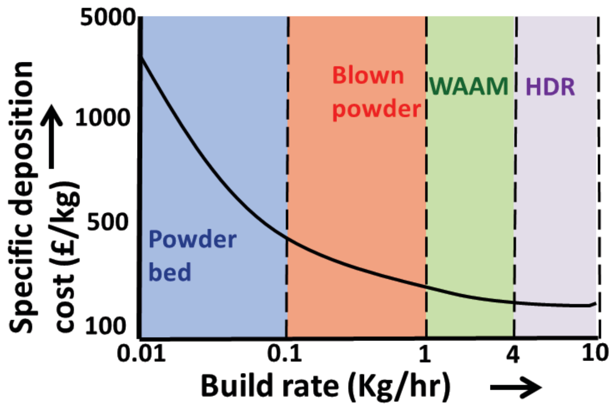

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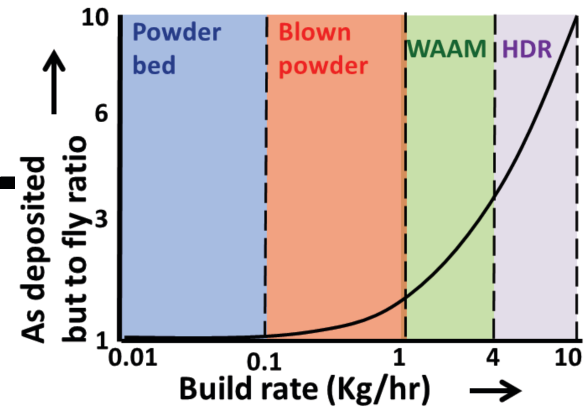

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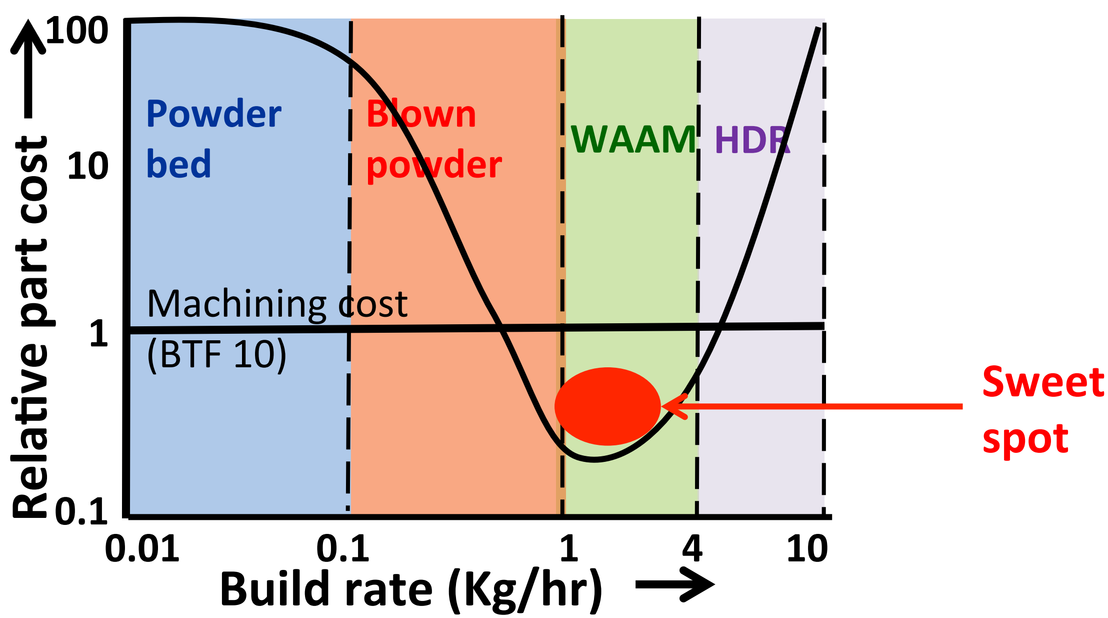
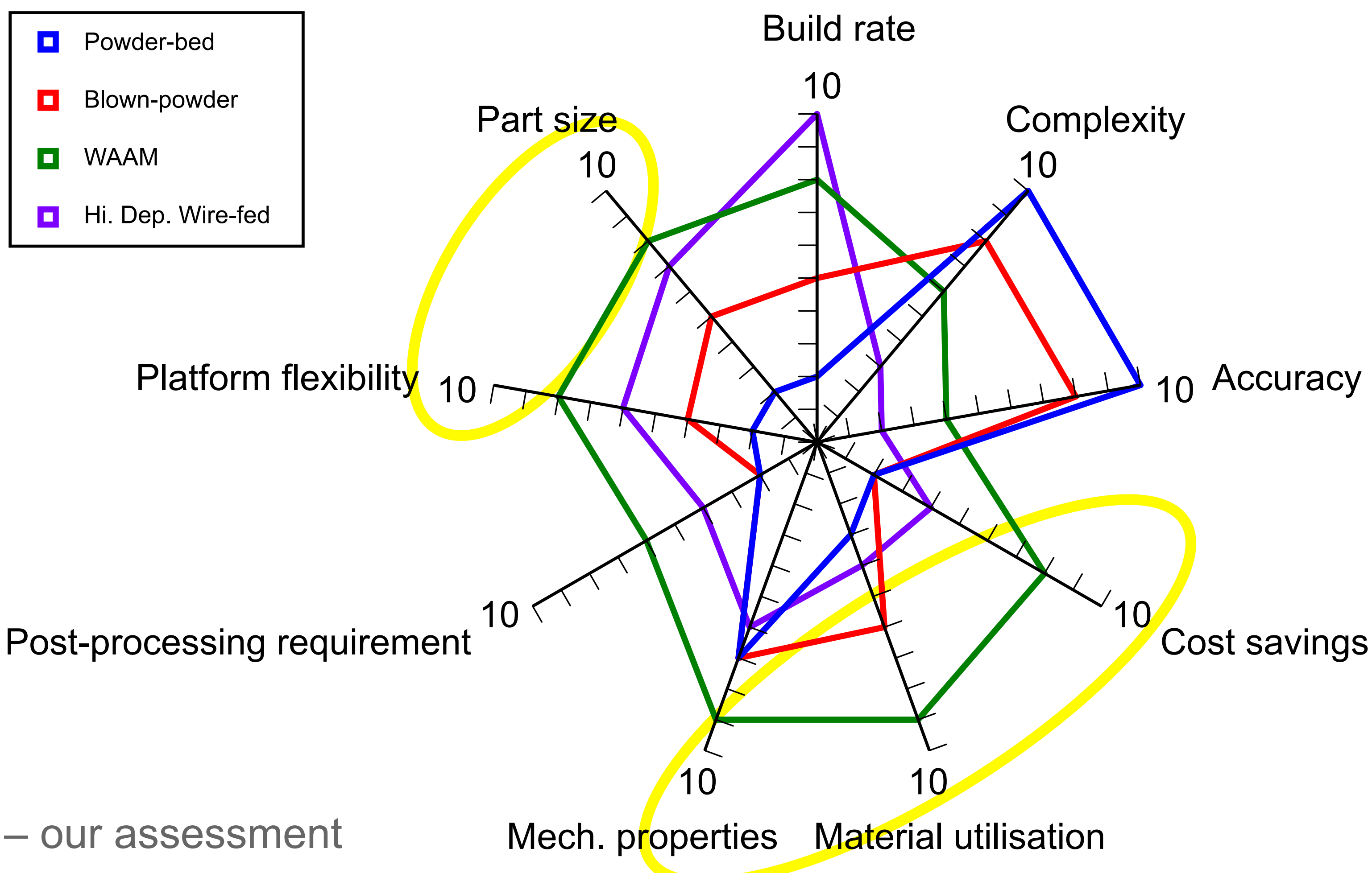


Example for 1-3 m part with BTF of 10 for machining and weight of 30 kg and minimum feature size of 2 mm

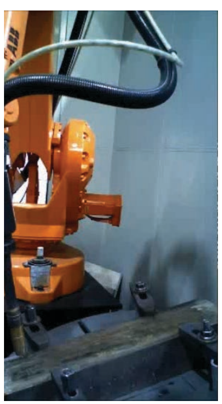
Benefits and limitations

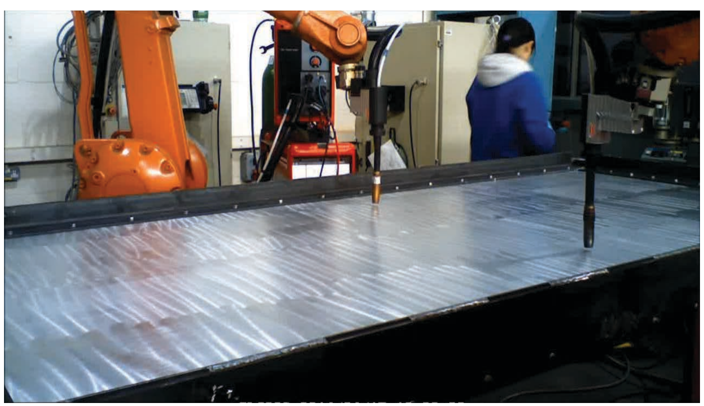


Note – our assessment

Key WAAM process features

- Build rates 0.5 - 4 kg/hour – **typical 1kg/hr titanium**
- Unlimited build volume
- **Buy to fly ratio – typical 1.5 but always <2**
- Fully dense materials with excellent mechanical properties
- Minimum feature size 2 mm
- **No commercial systems available – yet**

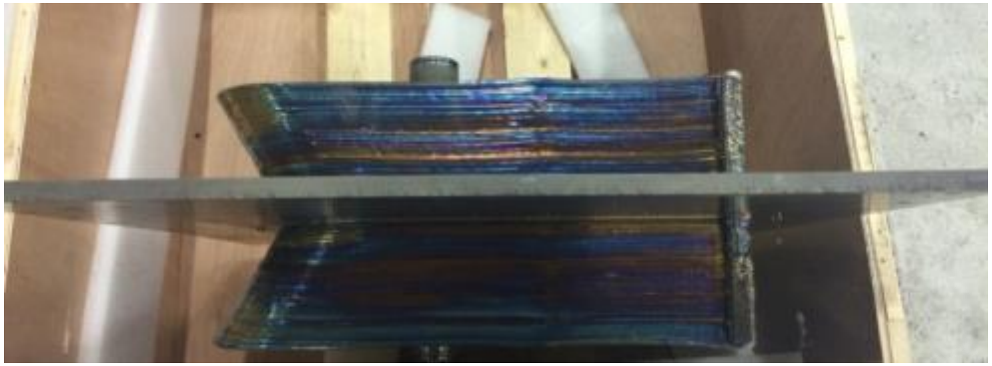


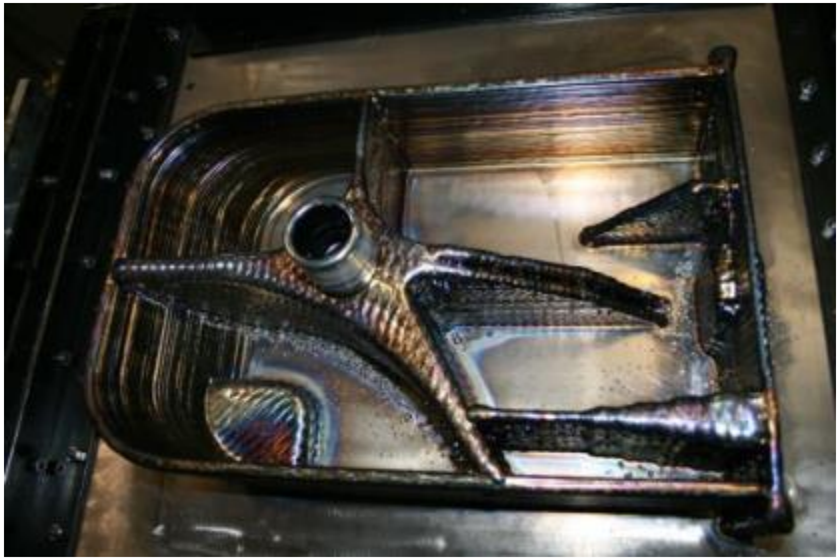


WAAM - Business Drivers

- WAAM business drivers are
  - ✓ Cost and material saving compared to current manufacturing methods
  - ✓ Greatly reduced lead times
  - ✓ Application to large engineering structures
  - ✓ In field applications

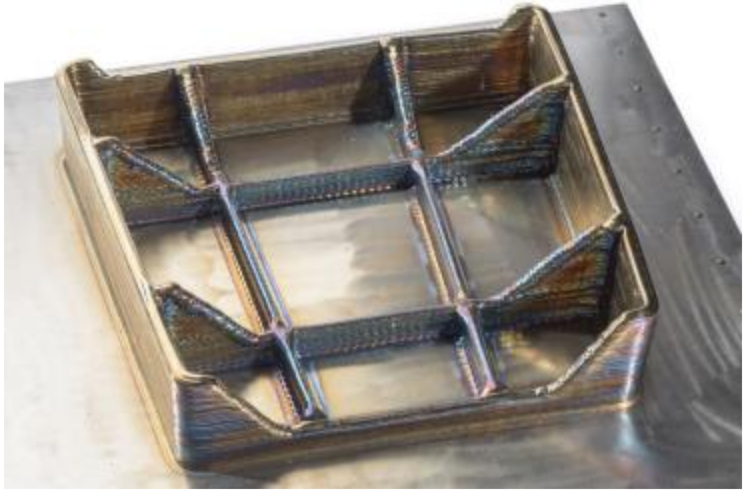
GKN Ti demonstrator part – typical features





WAAM business driver – cost saving case studies - Bombardier rib

Design option	Mass (kg)	BTF	Cost (£k)	Cost red.
Original machined	20	12	16.2	-
WAAM + machining	20	2.3	5	69%

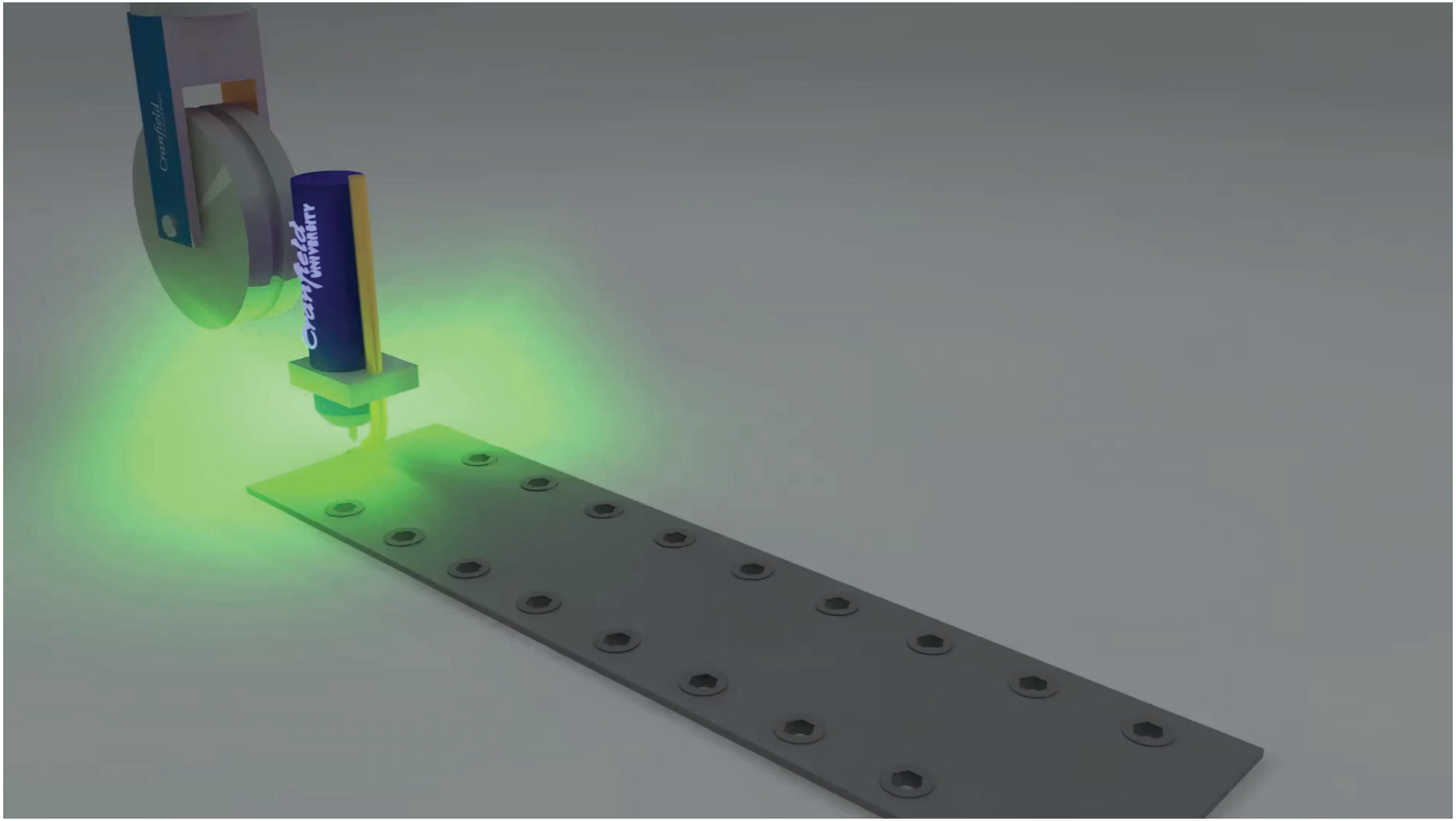


Design option	Mass (kg)	BTF	Cost (£k)	Cost red.
Original, machined	36	12	1.6	-
WAAM + machining	36	2.3	0.7	55%

What we've deposited so far

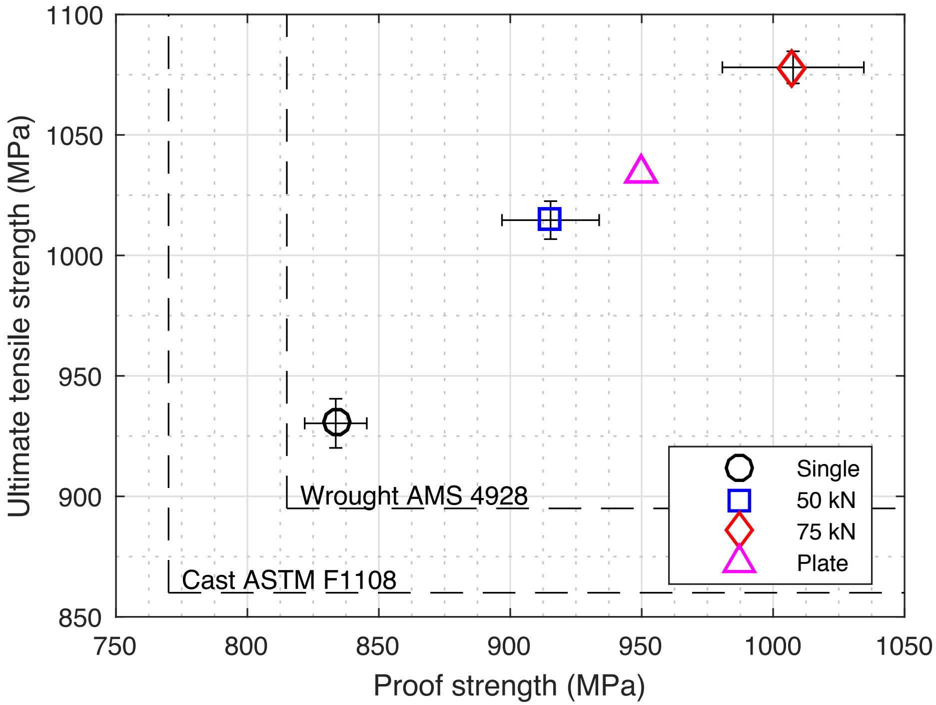
- **Ti-6Al-4V**
  - Grade 5
  - Grade 23
- **Aluminium**
  - 2024
  - 2319
  - 4043
  - 5087
- **Refractories**
  - Tungsten
  - Molybdenum
  - Tantalum
- **Steels**
  - ER60
  - ER80
  - ER90
  - ER120
  - Maraging grade 250
  - Maraging grade 350
  - Stainless (17-4 PH, 316L)
- **Inconel**
  - 625
  - 718
- **Bronze**
- **Copper**

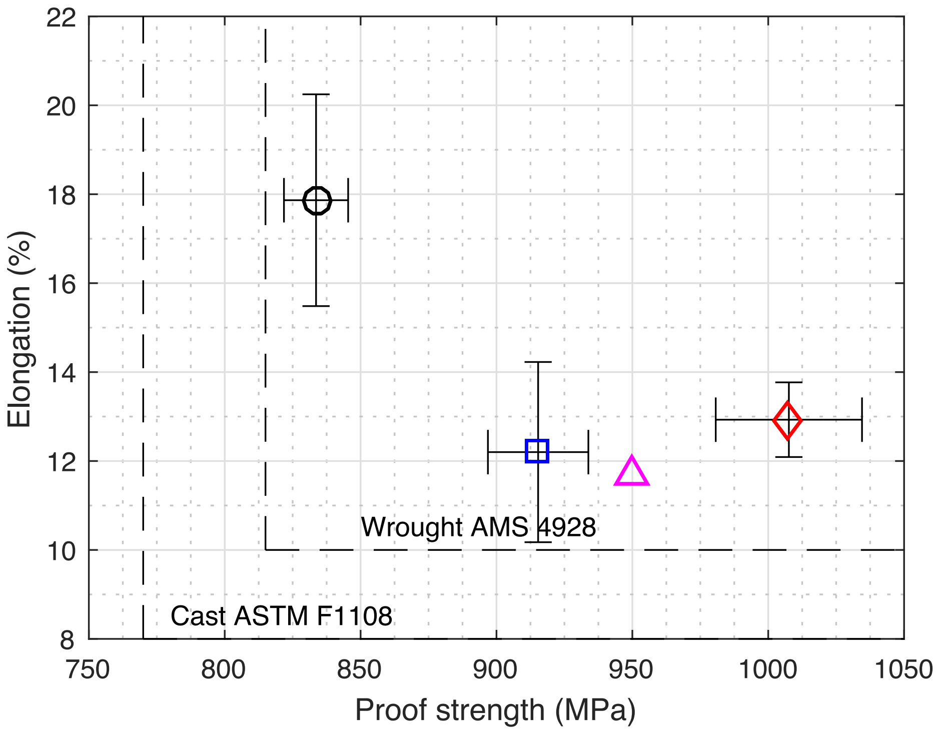
Unique features // High pressure rolling



Ti64 // Microstructure

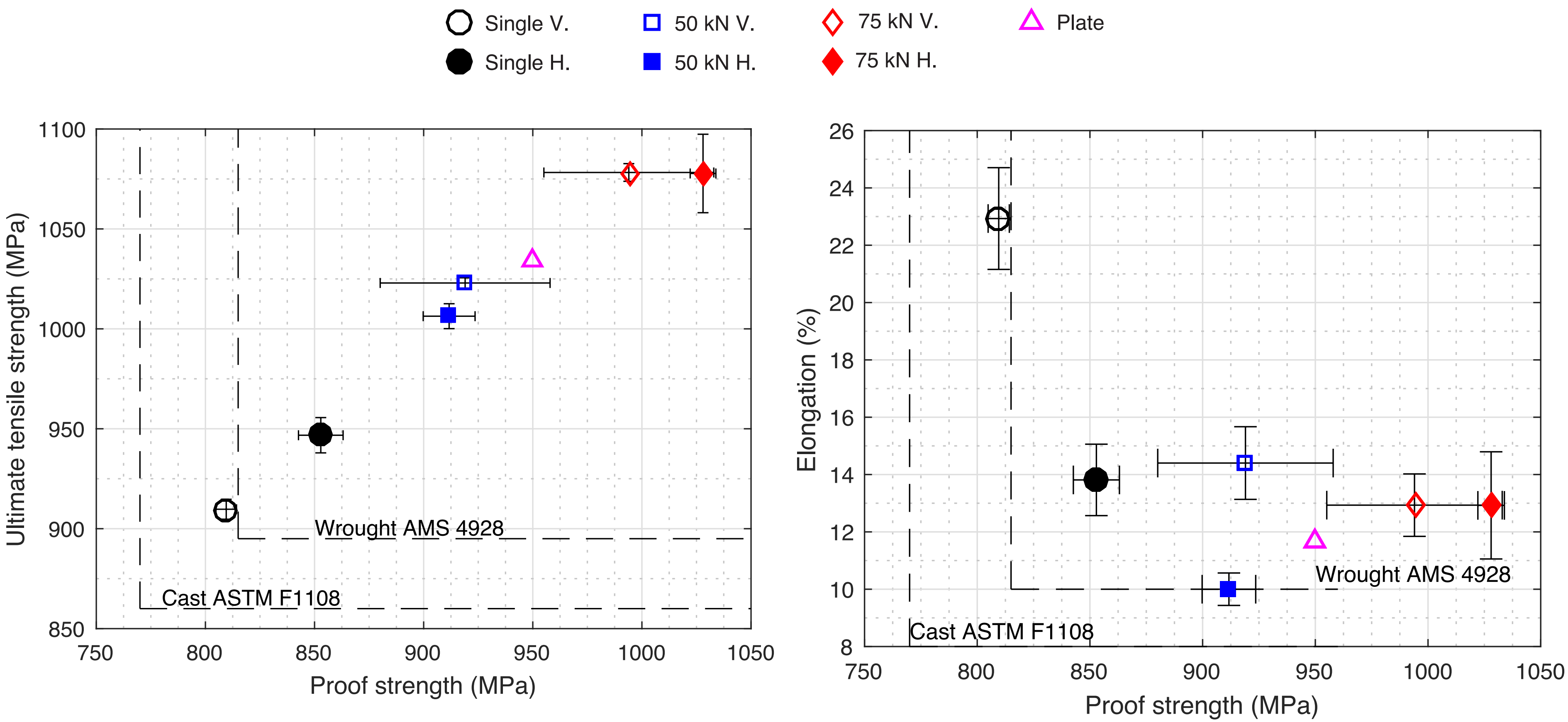
Ti64 // Static properties (average)





- Reduction in prior β grain size
- Reduction in α lamellae thickness
- Possibly some work-hardening effects still left in the structure

Ti64 // Static properties (isotropy)



2319 // Effect of rolling + HT on porosity

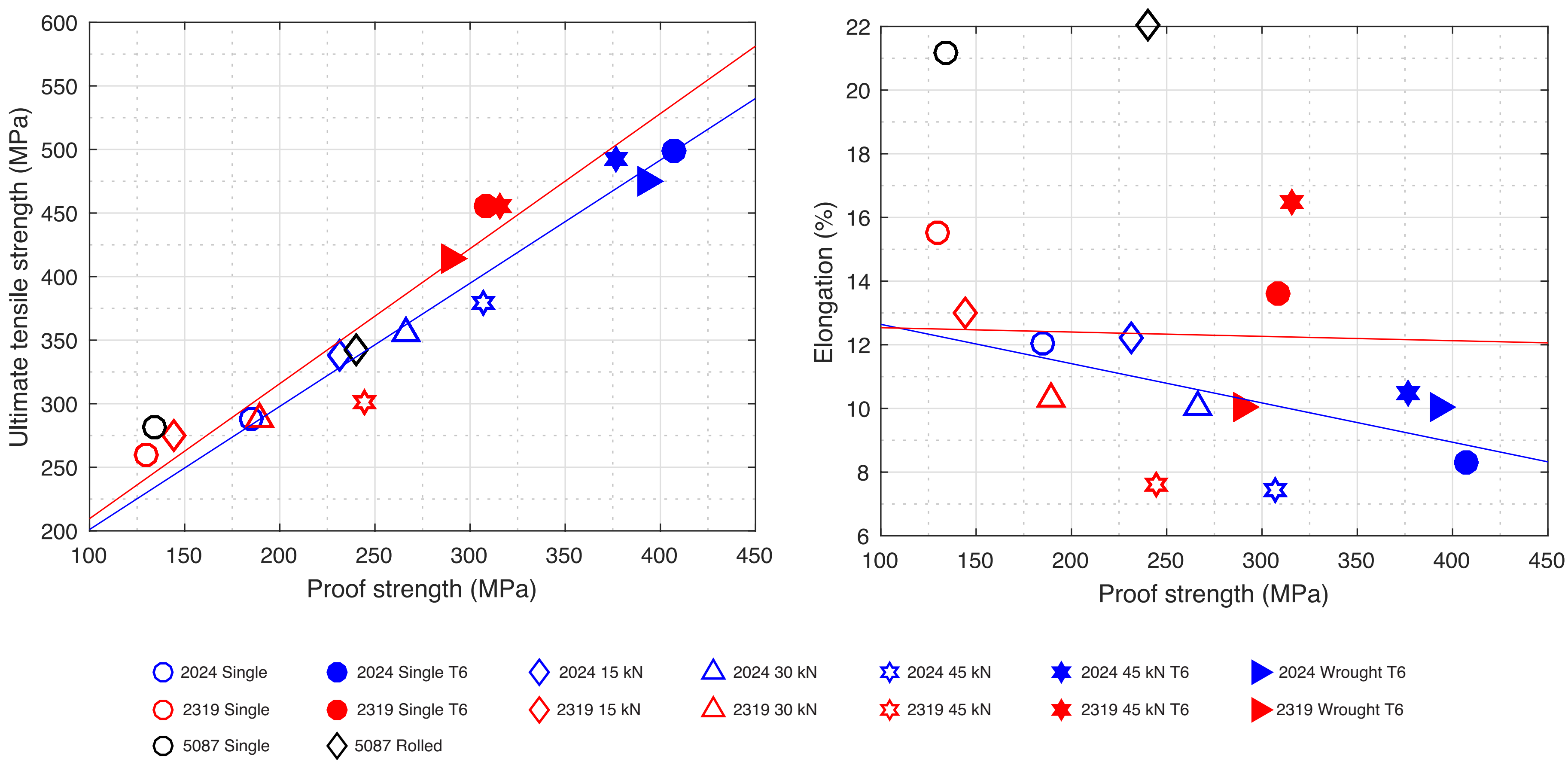
As deposited

ST+AA

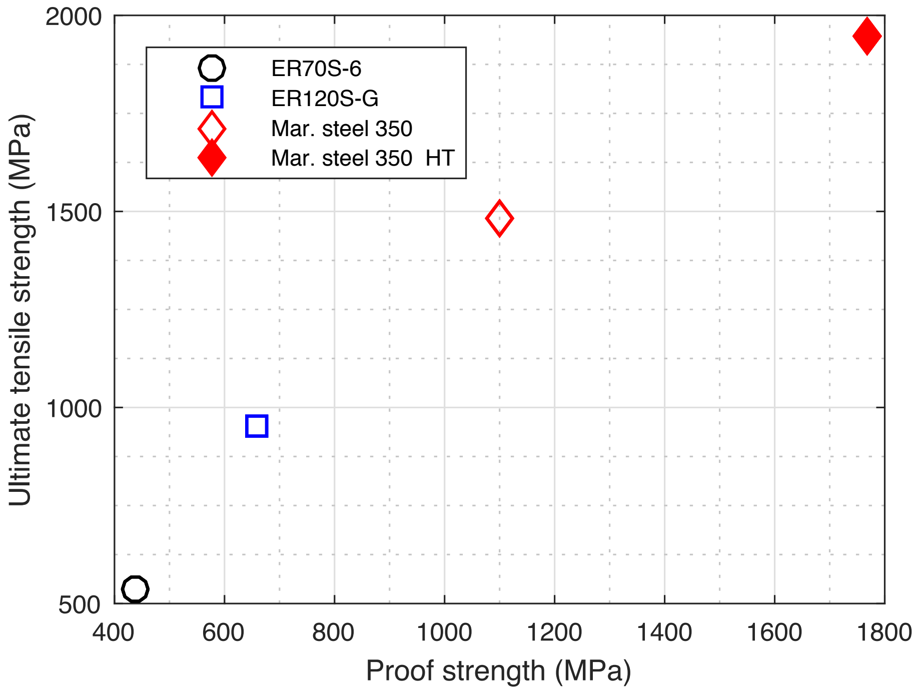
Rolled +
ST + AA

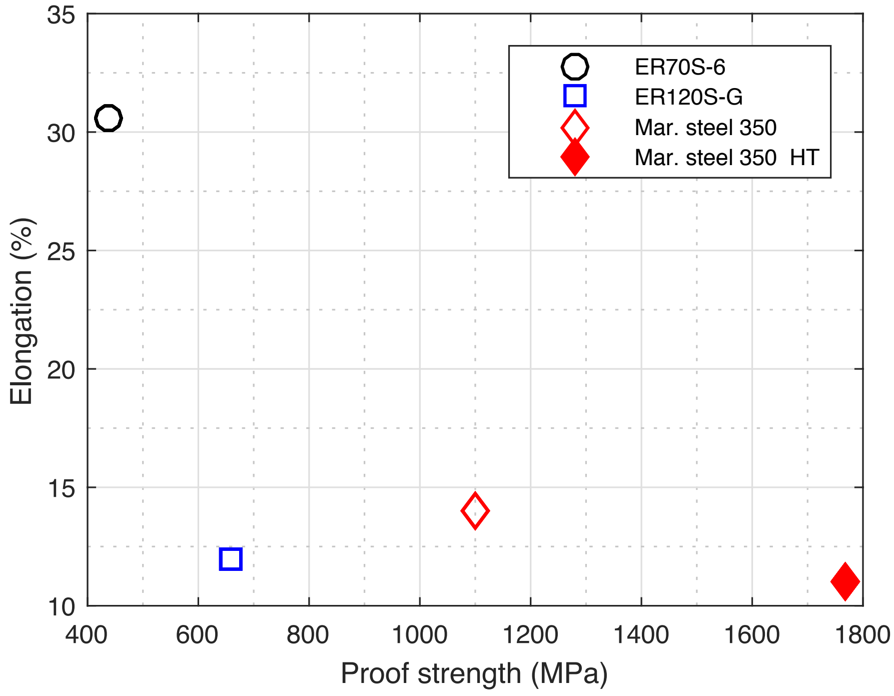
There is no porosity in the rolled + heat treated sample.

Aluminium properties (2024 – 2319 – 5087 (average))



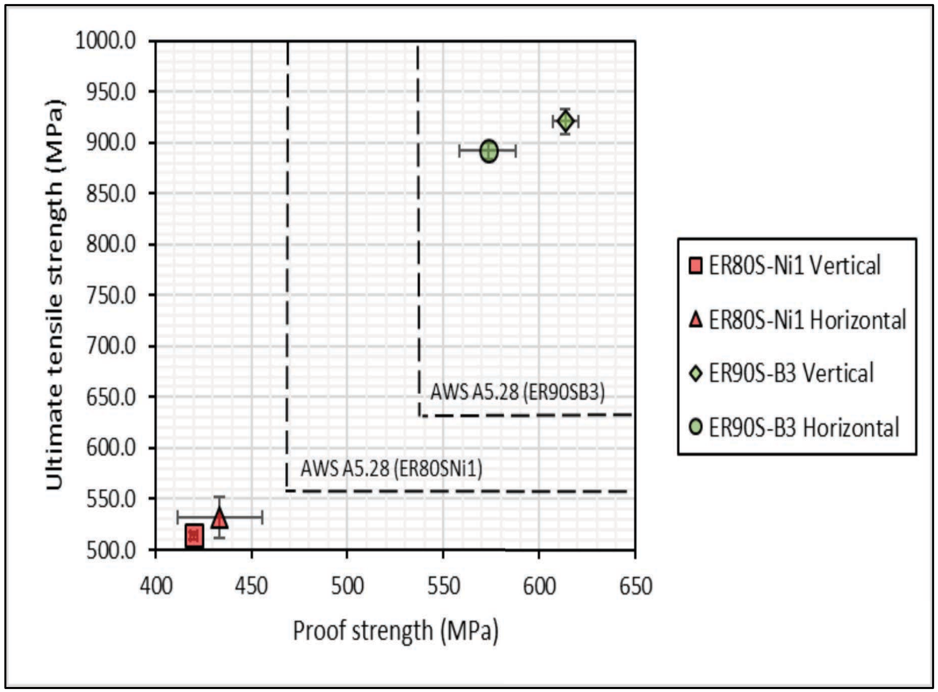
Steel (average)

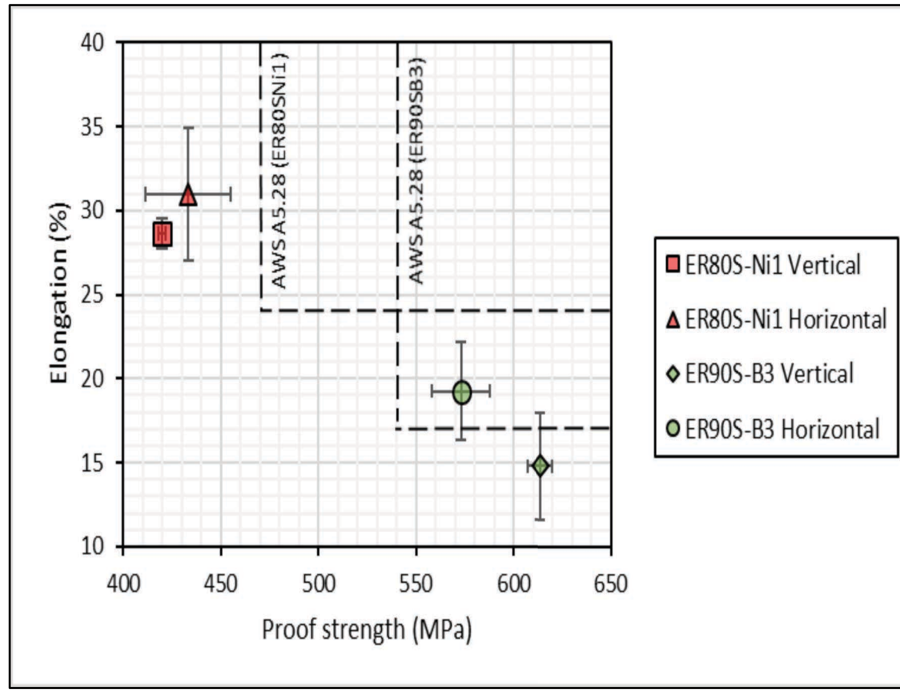




Low alloy steels-Tensile testing

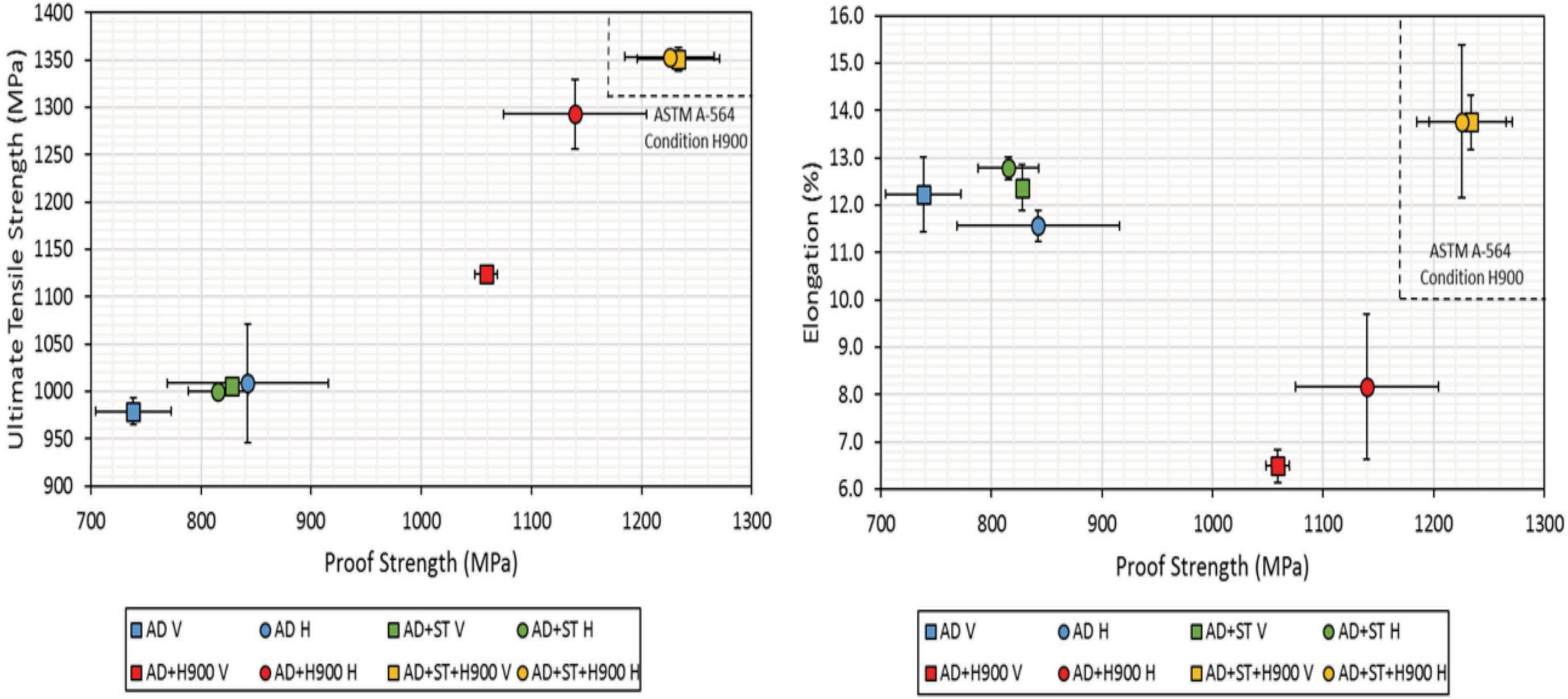
Direction-specific results of tensile test. Error bars indicate 95% confidence intervals





Stainless steel 17-4 PH -Tensile test results

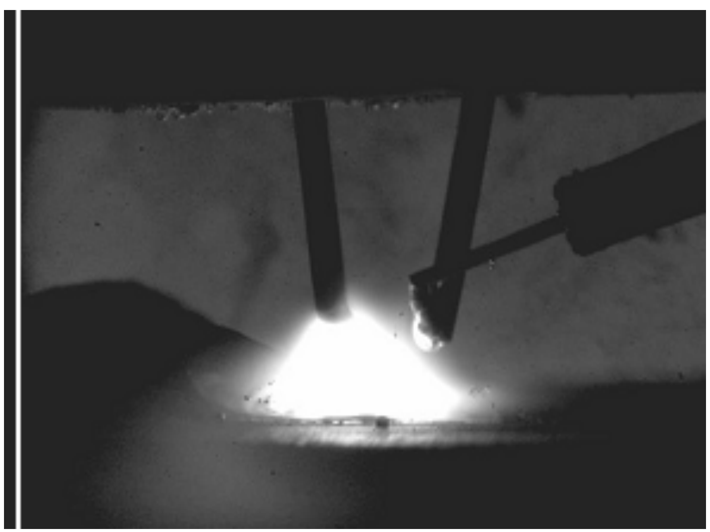
Direction-specific results of tensile test. Error bars indicate 95% confidence intervals



WAAM Process features (4) – deposit composition control using multiple feeds

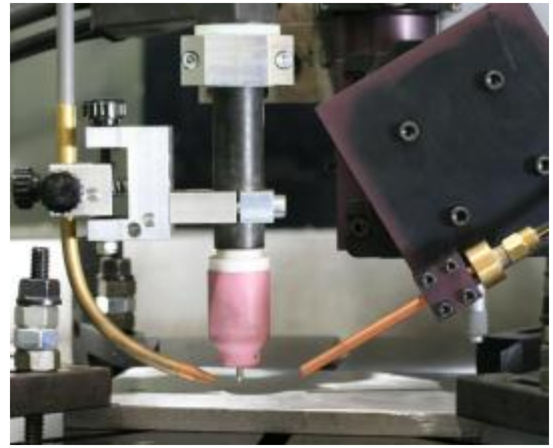
Multi wire approach

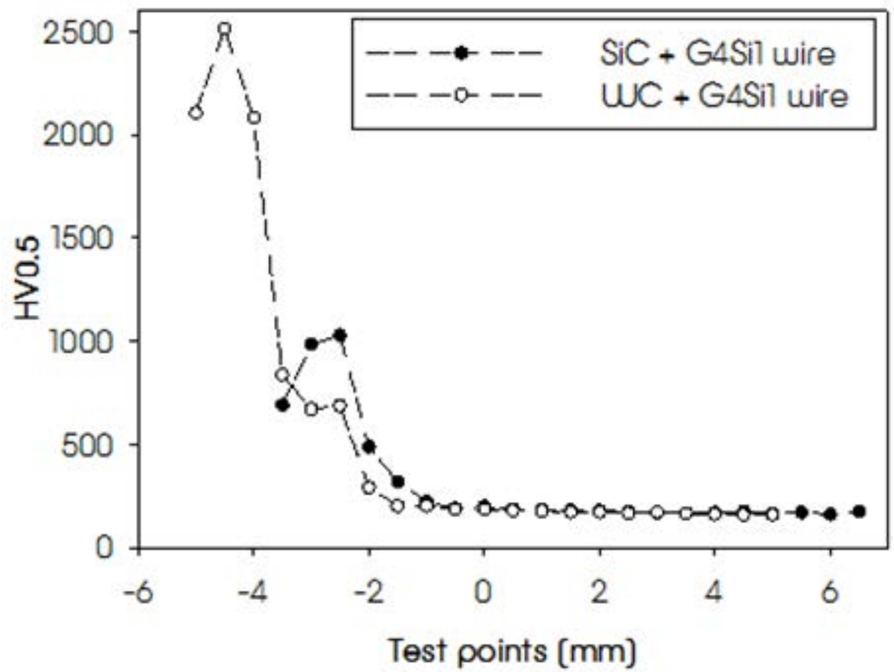
Aluminium hardness
1 wire Al6%Cu– 100HV
2 wire (Al4.5%Cu1.5%Mg) – 120HV



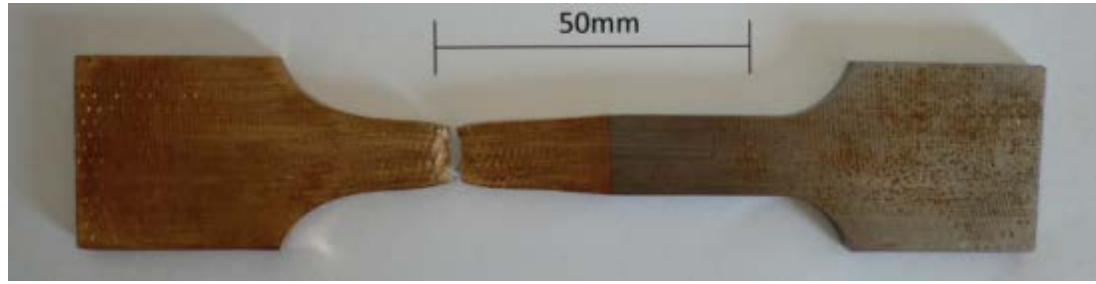
3 wire (Al8%Cu1.5%Mg – 140HV)

Wire + Powder

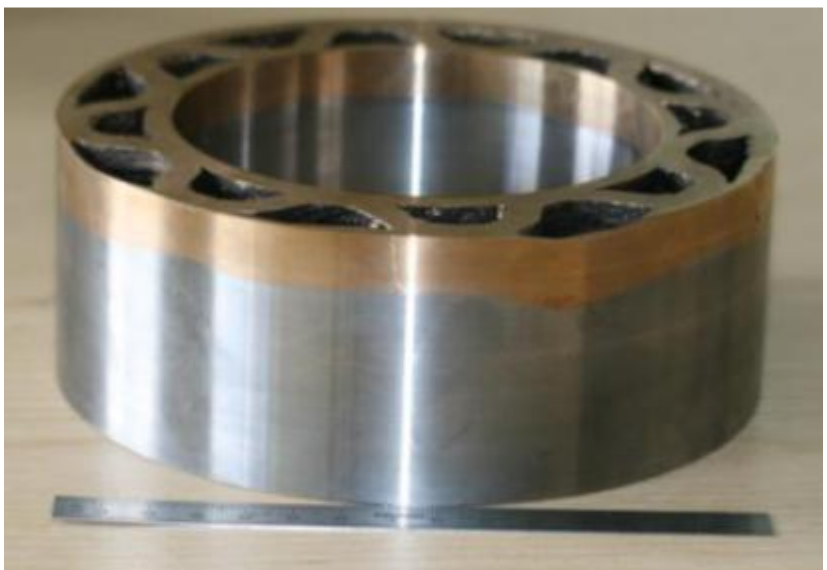




WAAM process features (5) - mixed materials - copper and steel



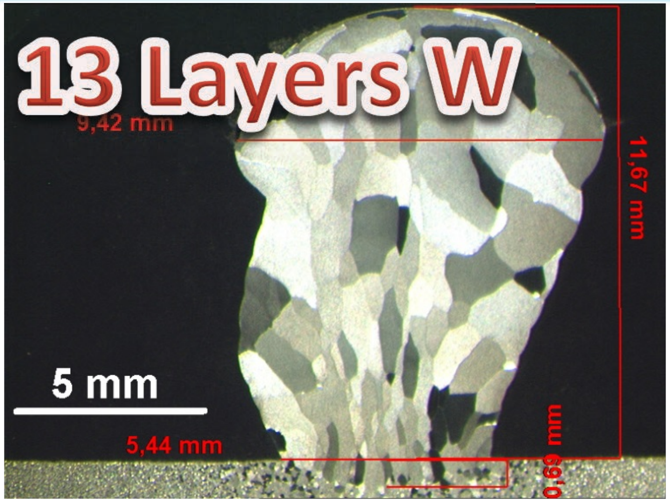
Yield 140 MPa, UTS 300 MPa, elongation 12%, failure in bronze

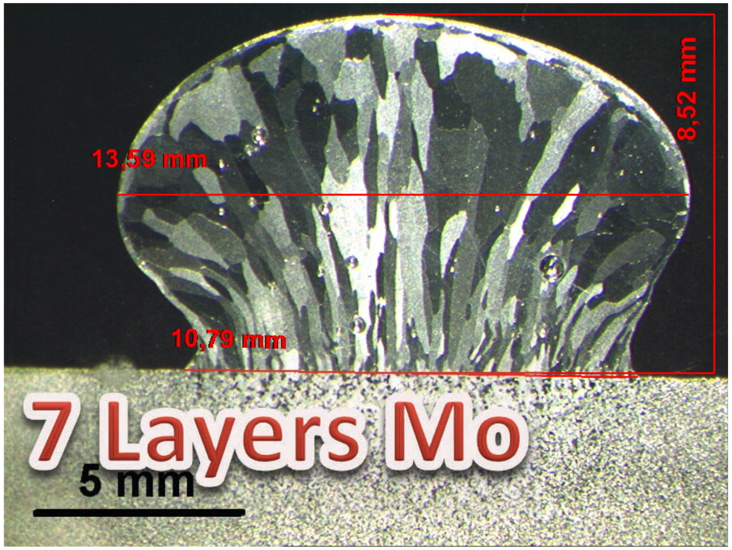


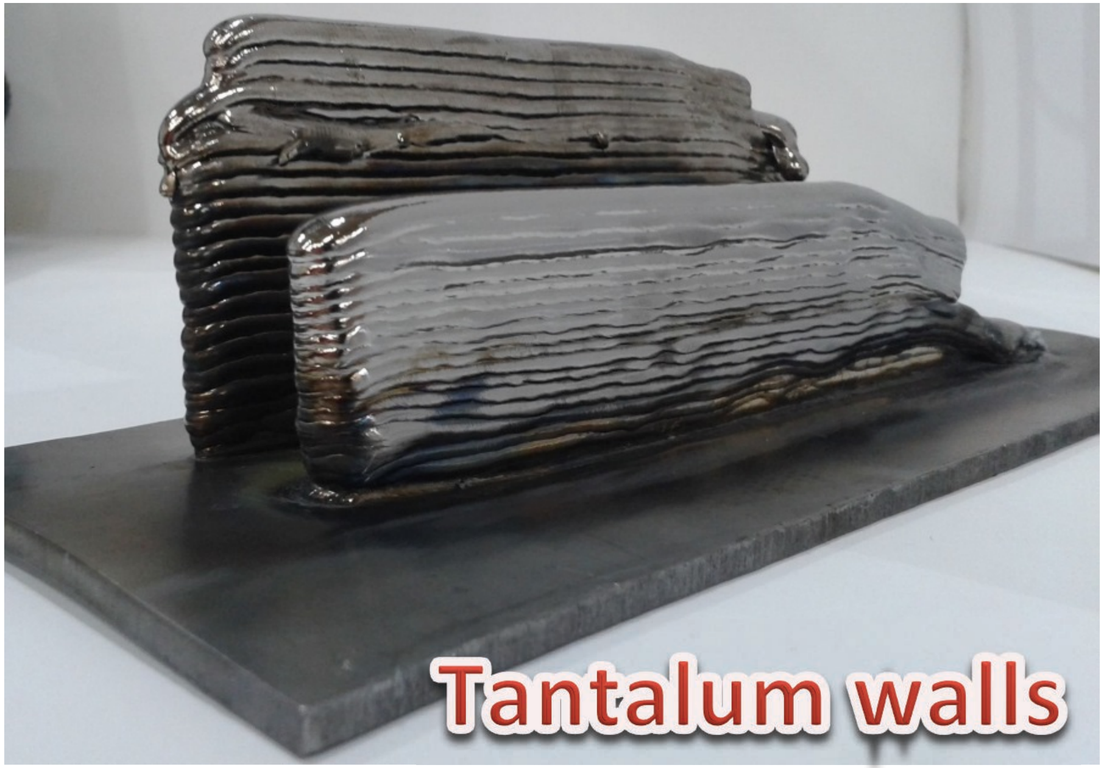
Steel/bronze (CuSi3%) parts

Copper on steel with WC ceramic added

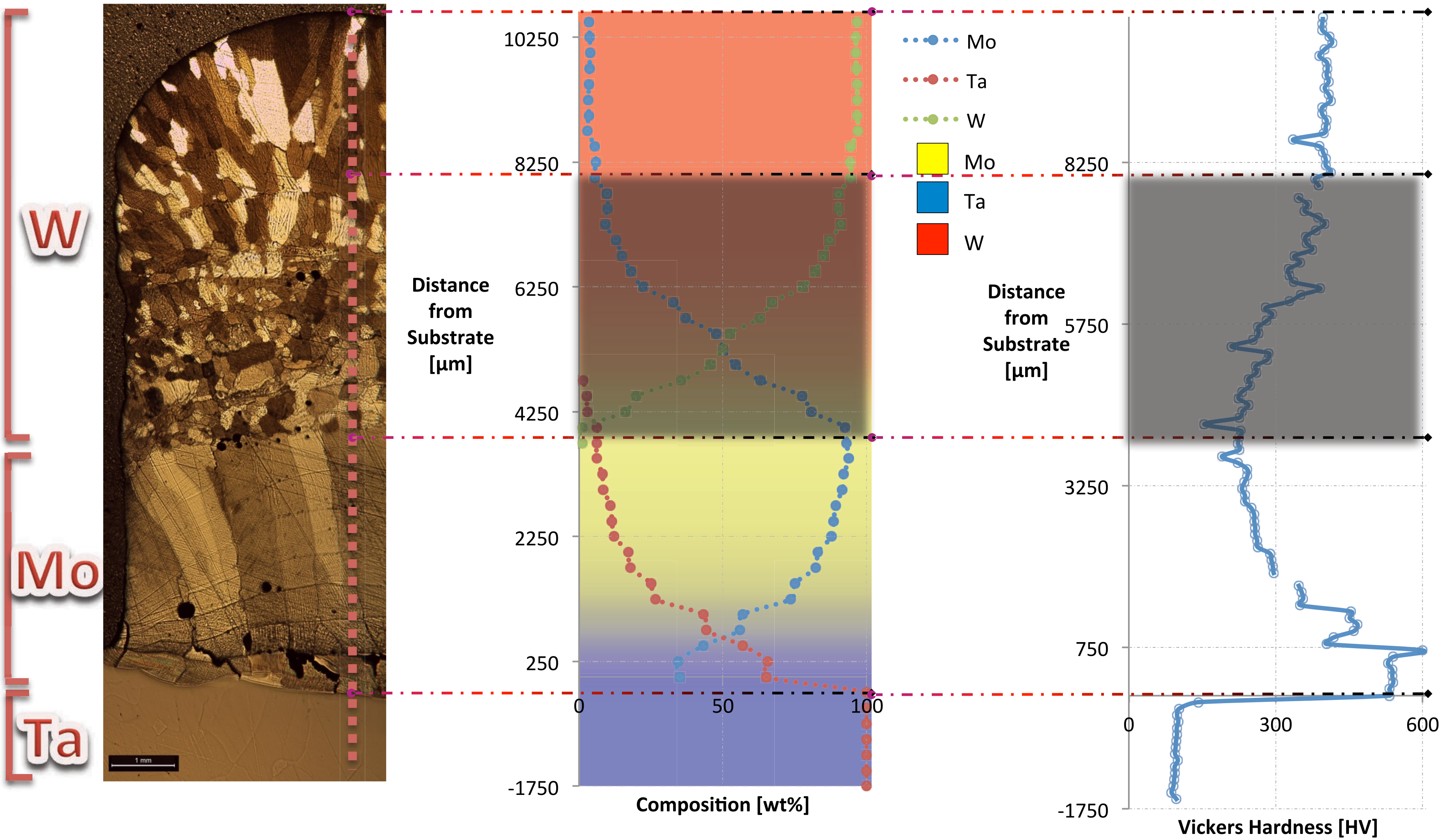
Refractory metal WAAM



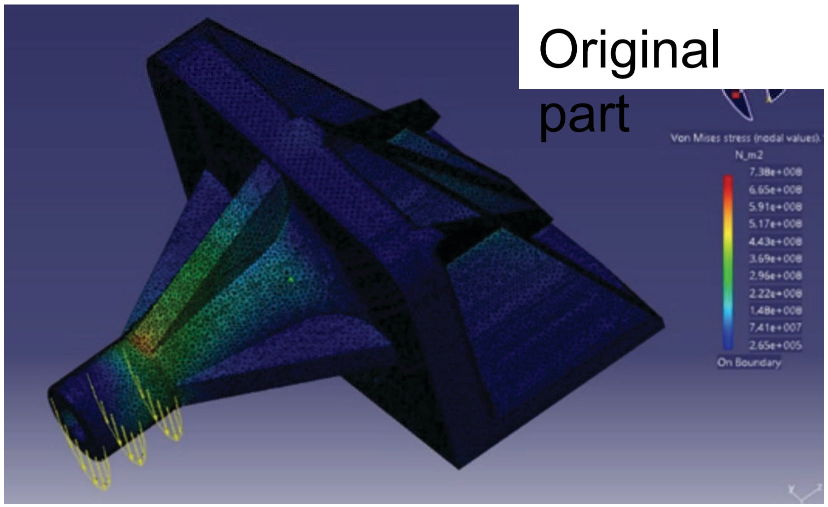




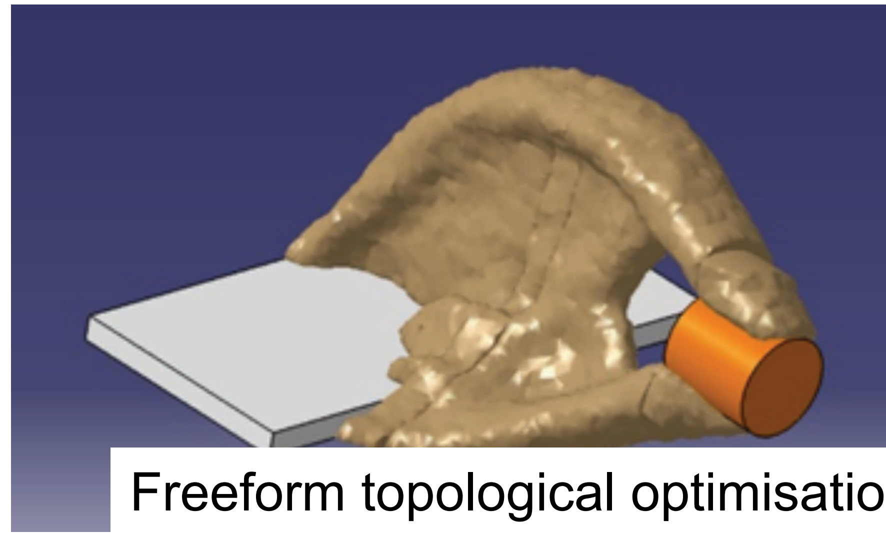
Graded Structure Ta/Mo/W (Chemical Analysis and Hardness)



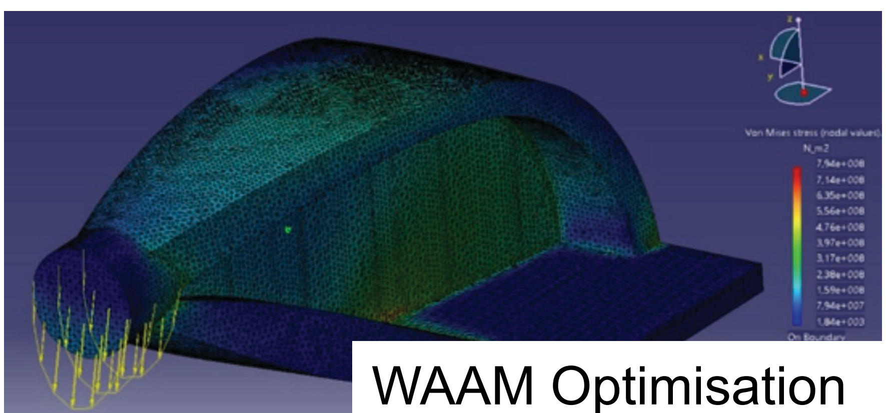
Topological Optimisation for WAAM



Original part



Freeform topological optimisation



WAAM Optimisation

Weight saving
7.5 kg – 3.9 KG – 33%
Also much to make than the original

The systems

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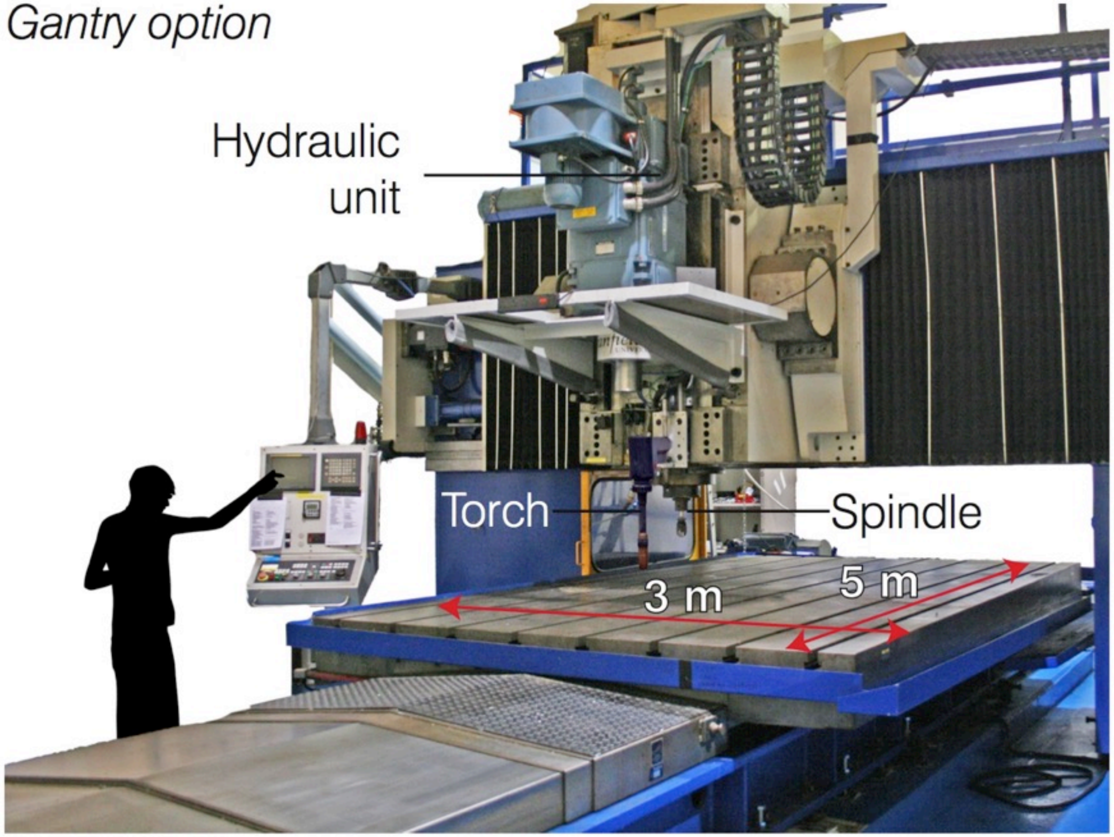
Robot option

Tent + part rotator option

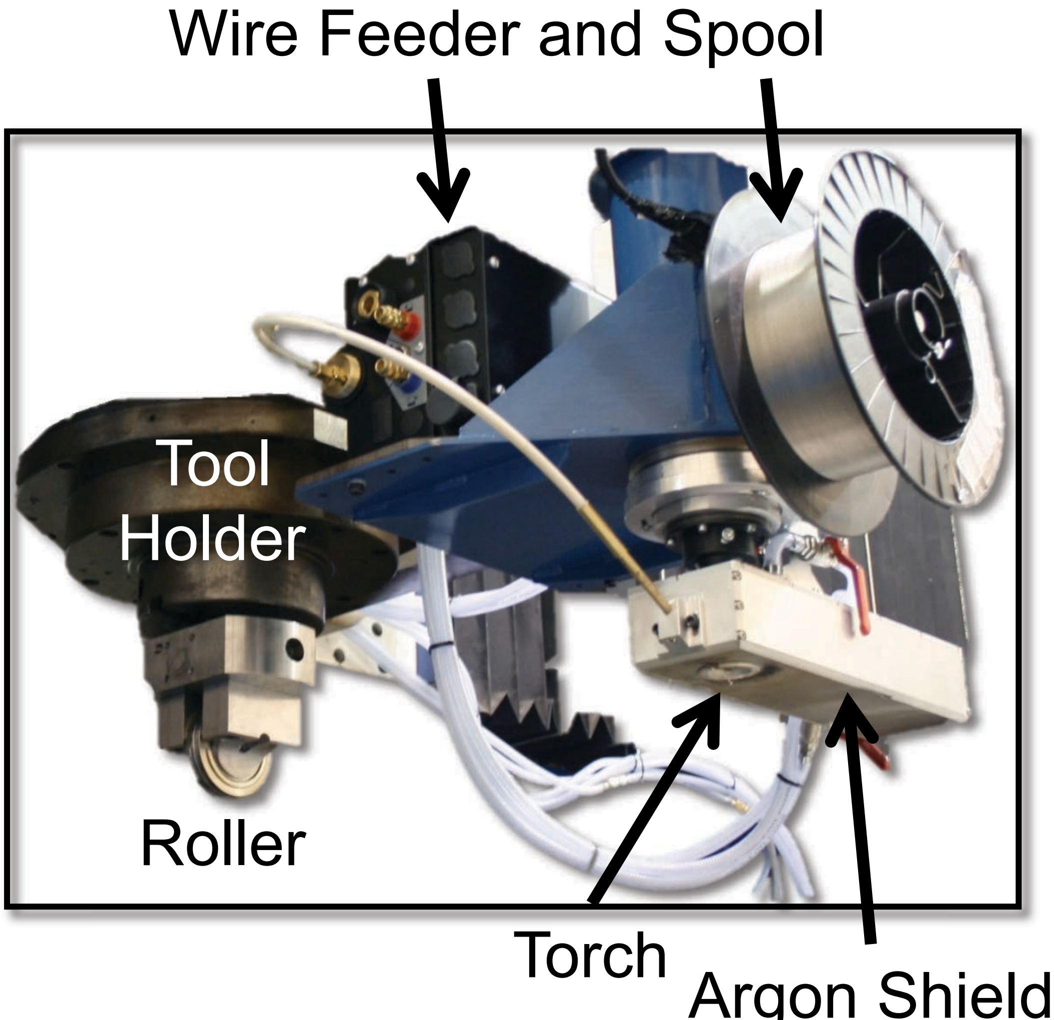
Gantry option

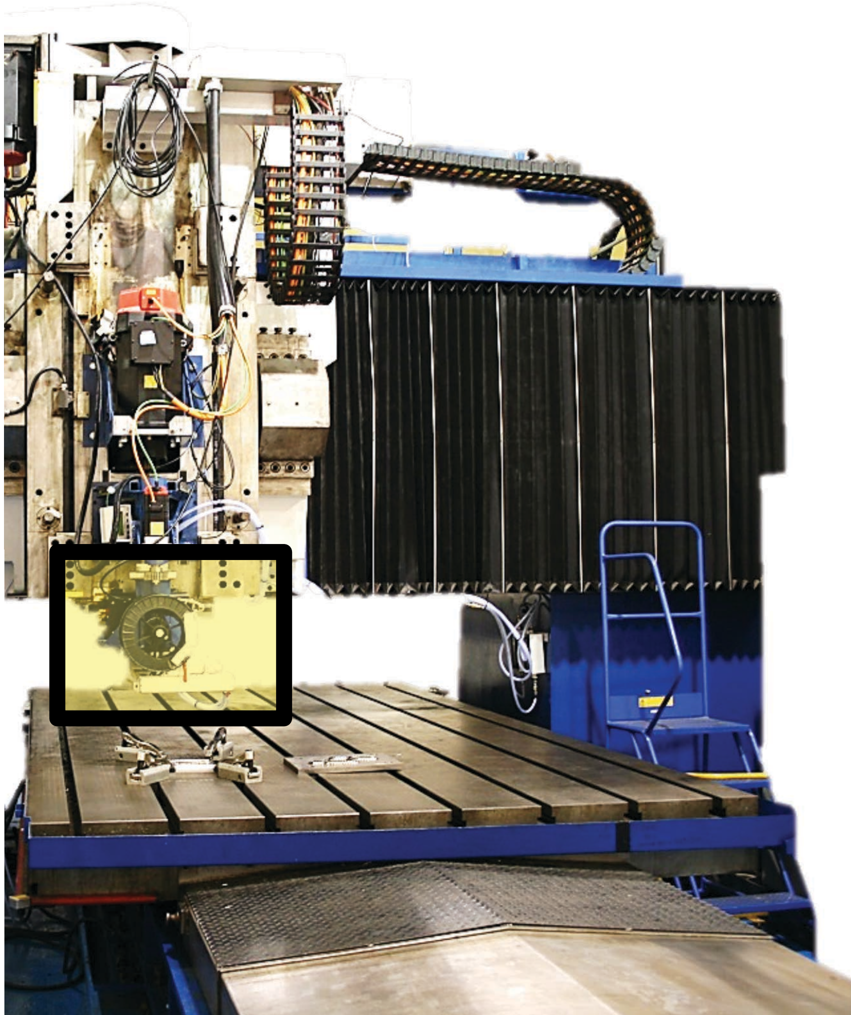


3 Axis CNC milling system with WAAM

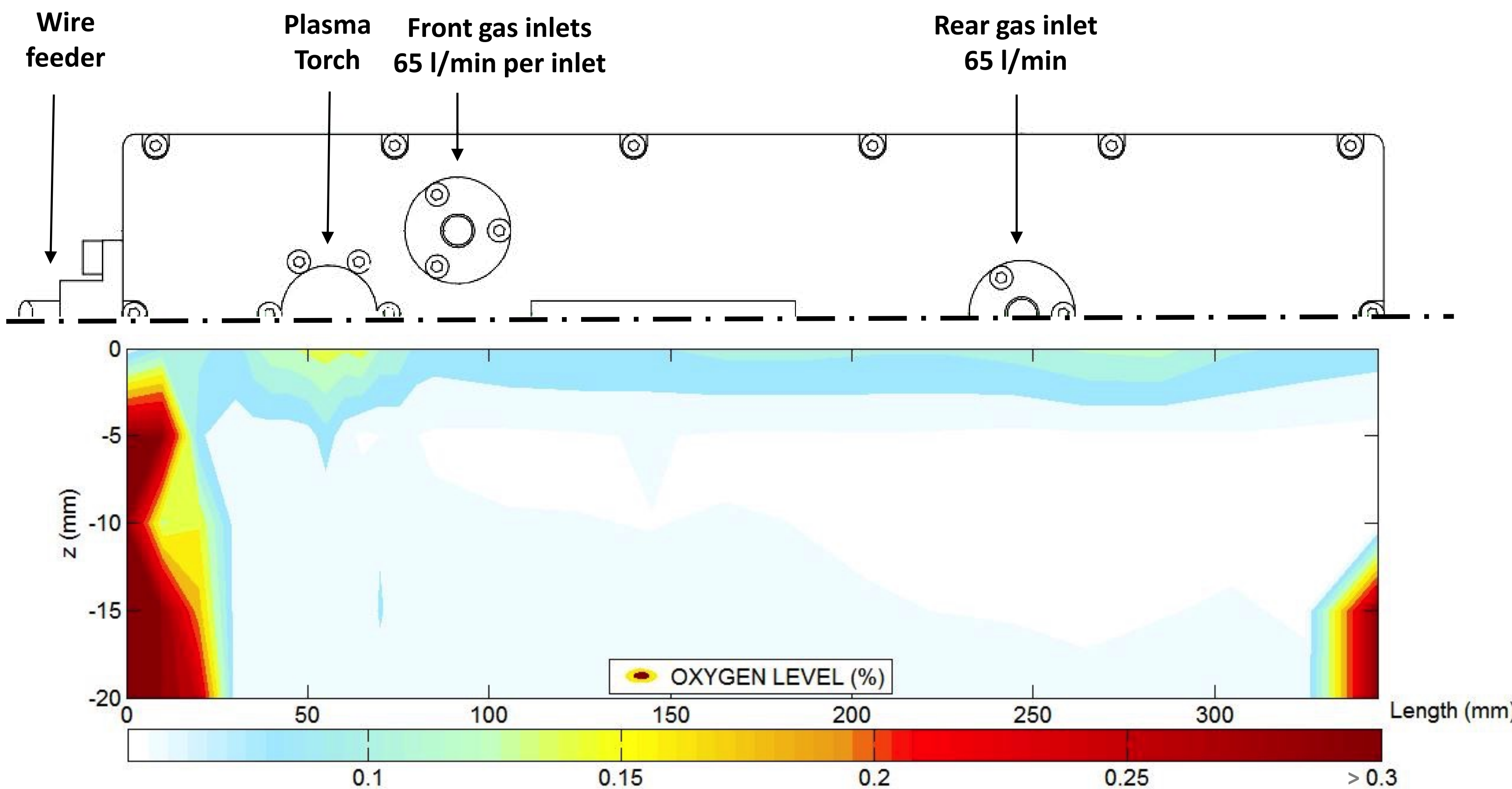
Open architecture systems

Rolling Assisted WAAM



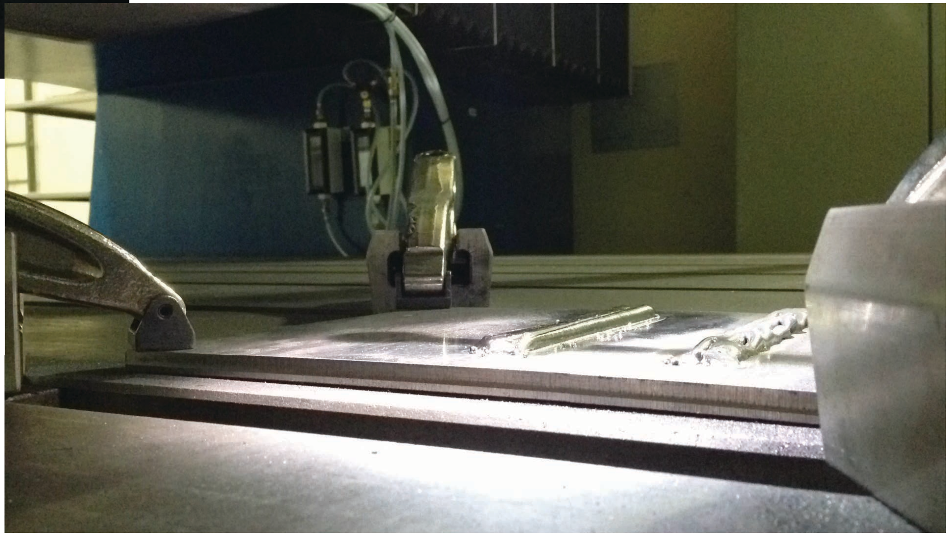


Research results - Local shielding

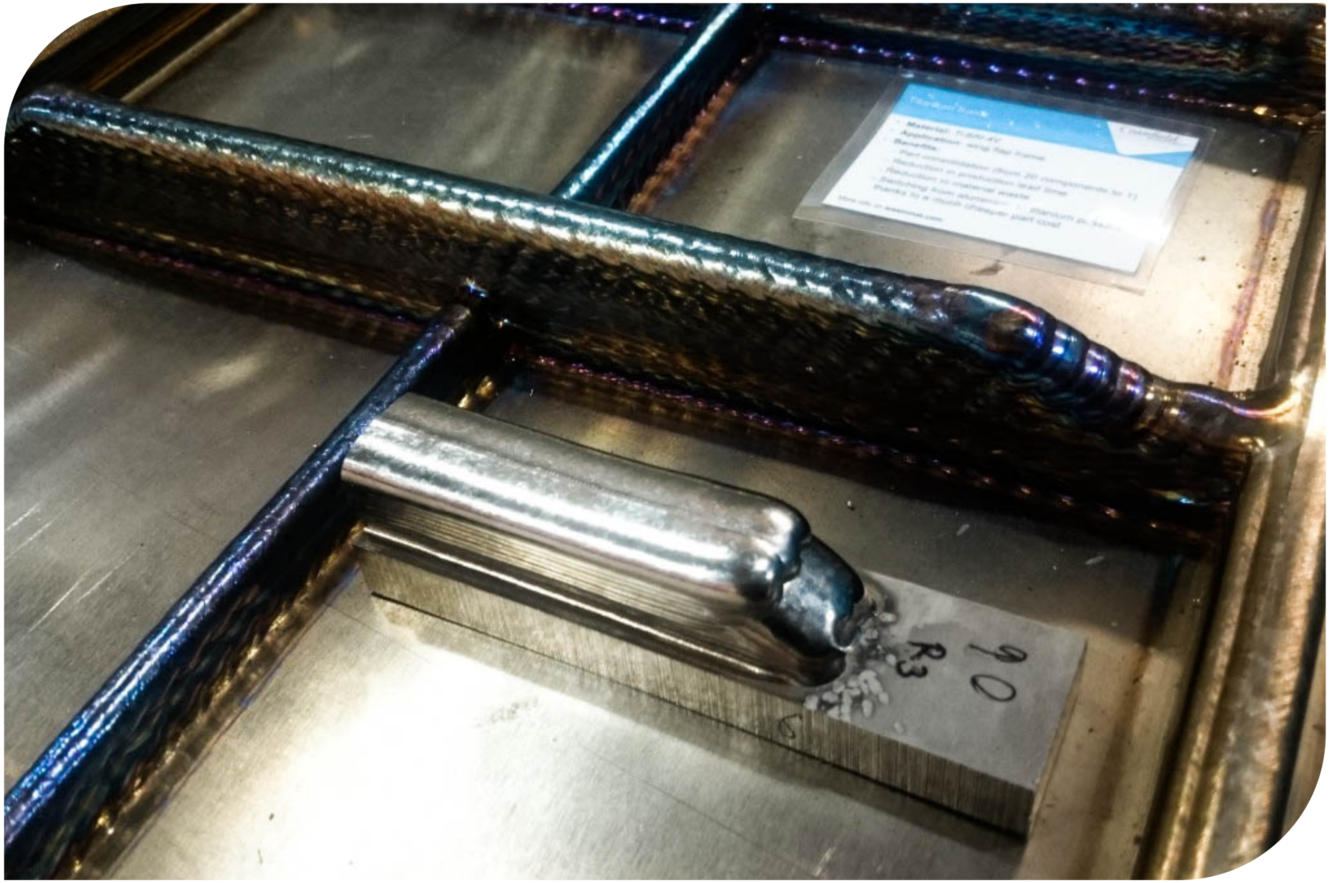


Oxygen contour plot of the AP/PWP Local Shielding Device

Unique features - local shielding solution

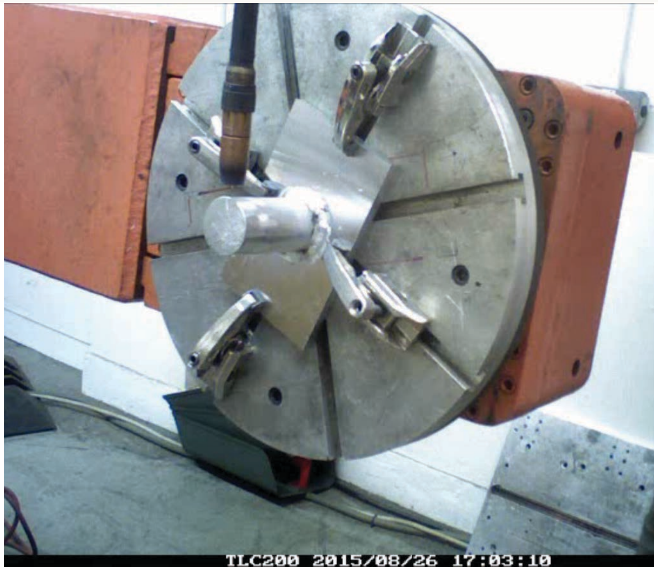


Research results - Local shielding



Visual aspect comparison of parts built in a chamber and using the AP/PWP Local Shielding Device

Coordinate motion deposition



Thin wall revolving structures: ARA beanie
Building time: 2.5 hours
Wall thickness: around 5mm
Material: Al5087

WAAM Software

WAAM design software → **WAAM path planning software** → WAAM process monitoring and control software

Two major challenges:

- Avoiding defects, especially lack of fusion defects
- Achieving and maintaining the specified layer height

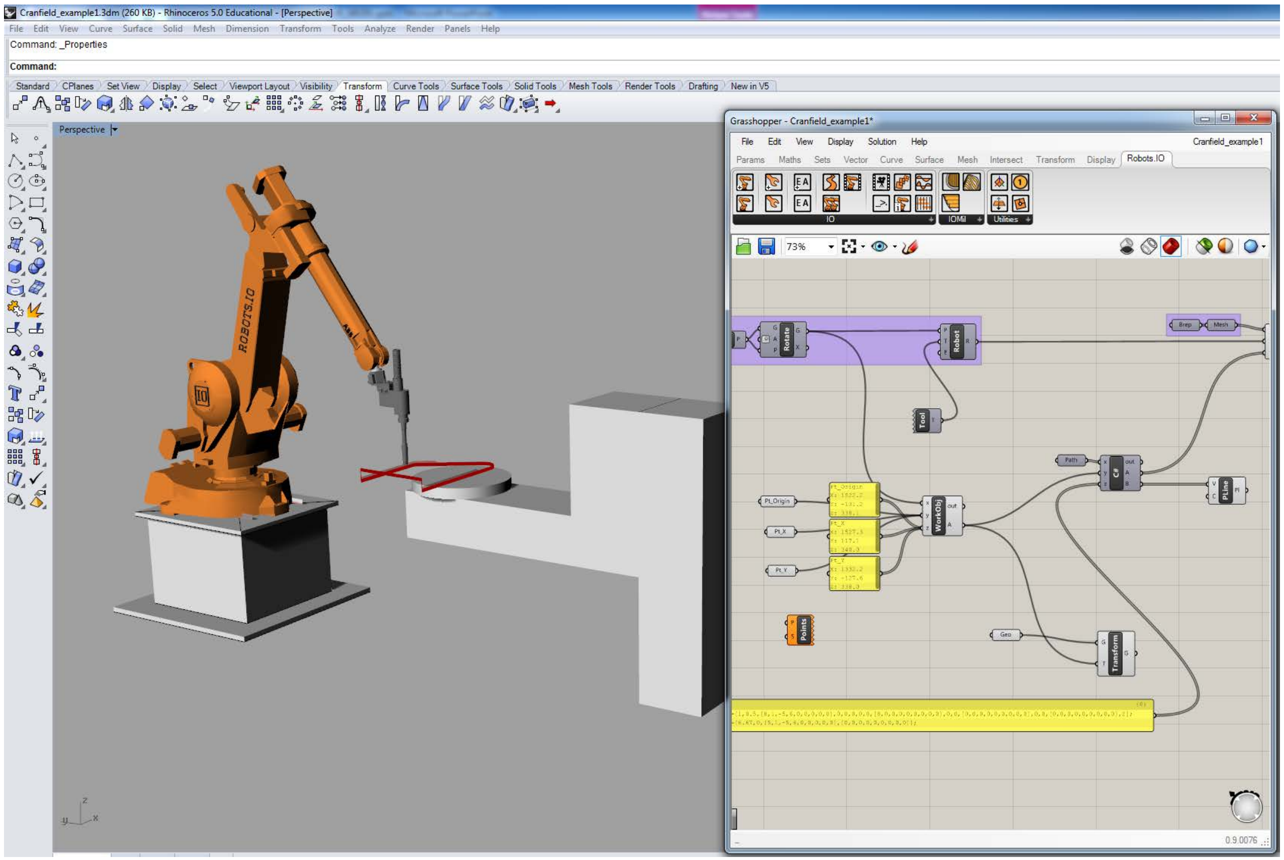
Reverse machining strategies or powder bed additive path planning are not suitable.

Four main functions of the automatic WAAM path planning software

- Intelligent partitioning
- Build path strategies
- Process parameter database

→ Manufacturing strategy

Two routes

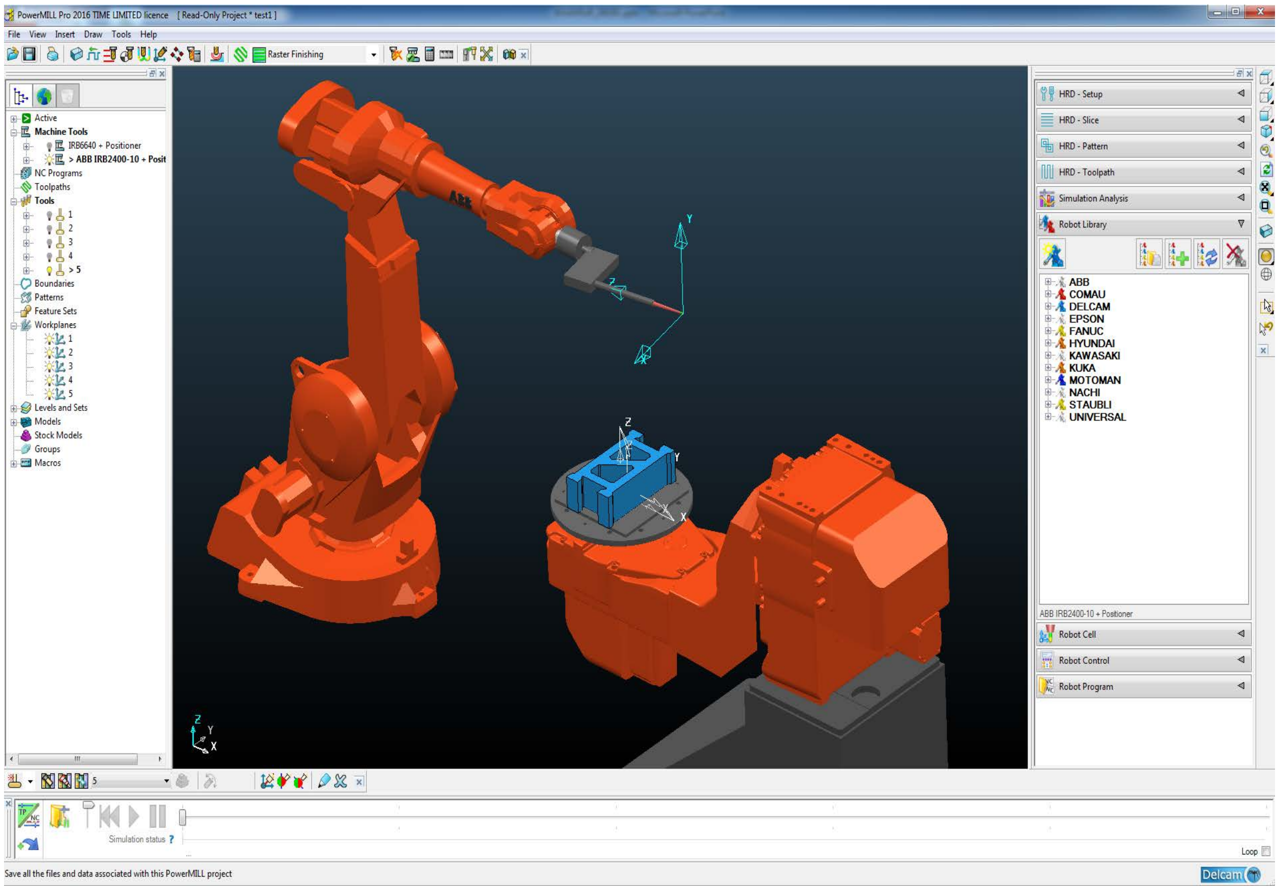


Cranfield WAAMSoft

- Internal process development mainly
- Development of a feature based WAAM software
- Development of automatic path planning method
- Can be customised and supplied to WAAMMat partners if requested
- Development of process data base

Rhinoceros cad platform + Grasshopper development + Robot simulation environment

Two routes



Delcam Commercial Software

- Commercial software provider
- CAD + CAM +CAR
- Software maintenance and training

- Cranfield will support the software development
- Will provide updated process data base
- Will provide developed path planning methods and algorithms

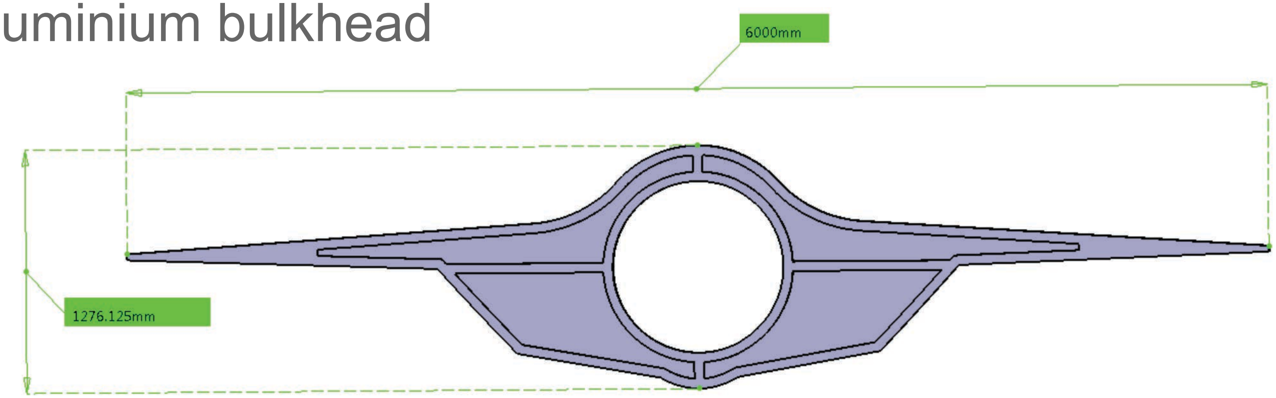
PowerShape + PowerMill + Robot Plugin + 'Build style' development environment

Where are we heading?

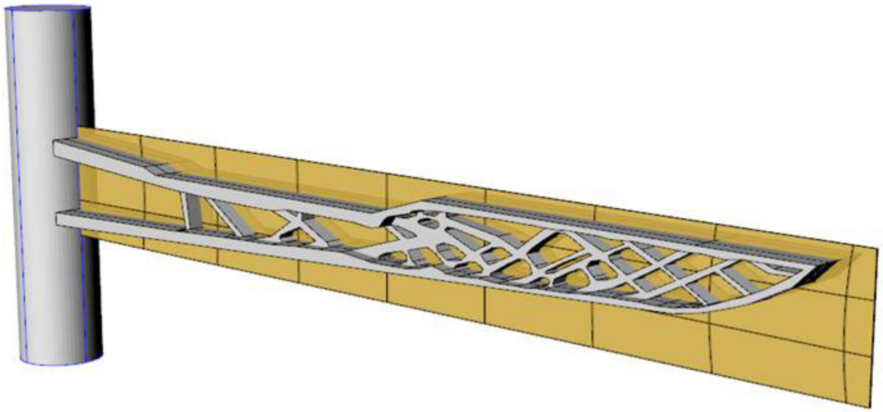
This summer

World's largest metal AM parts:

- 6 m aluminium bulkhead



- 7 m steel cantilever beam (1500 kg)



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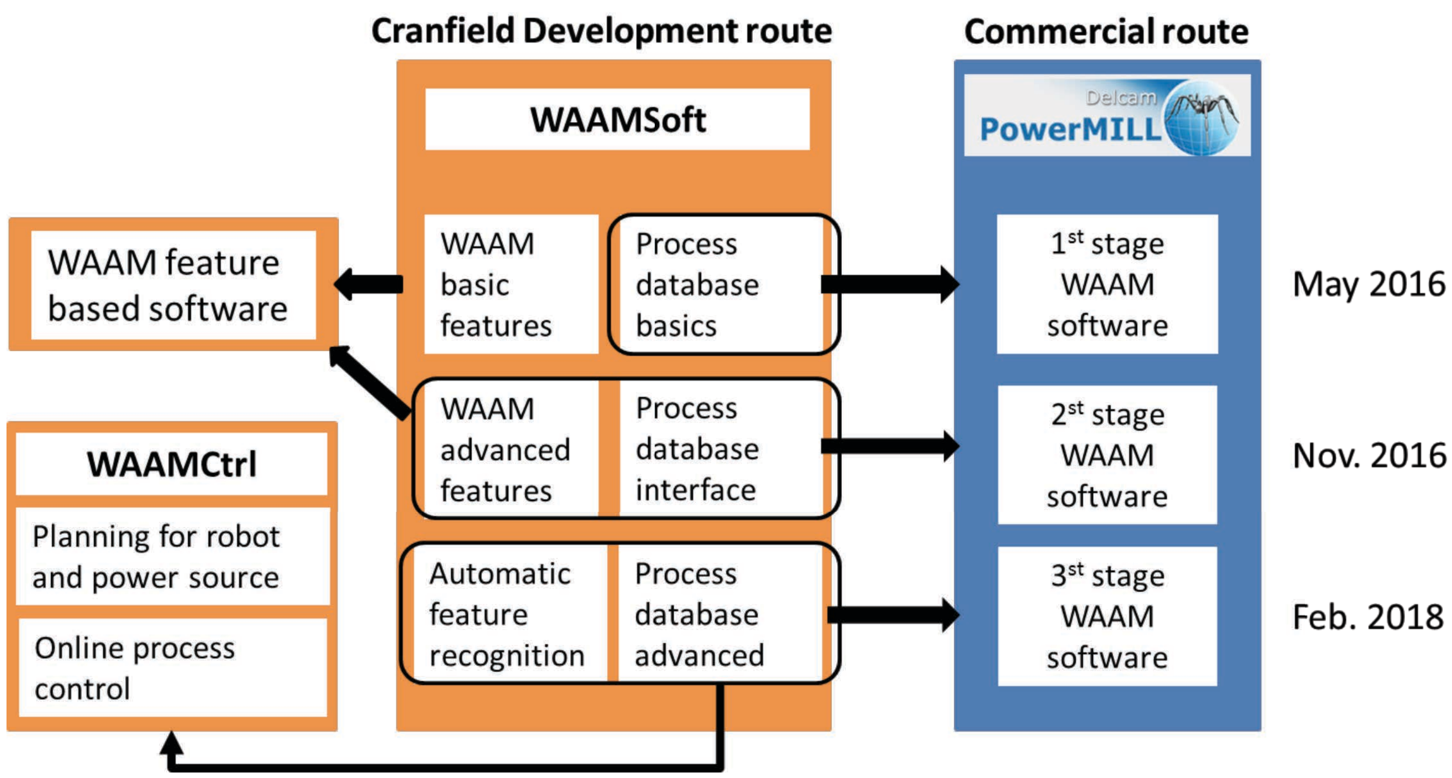
Next 3 years

- Software
- Control

→ Tool path automation → Commercialisation of the technology



Selected beta audience

Available to everyone

Next 3 years

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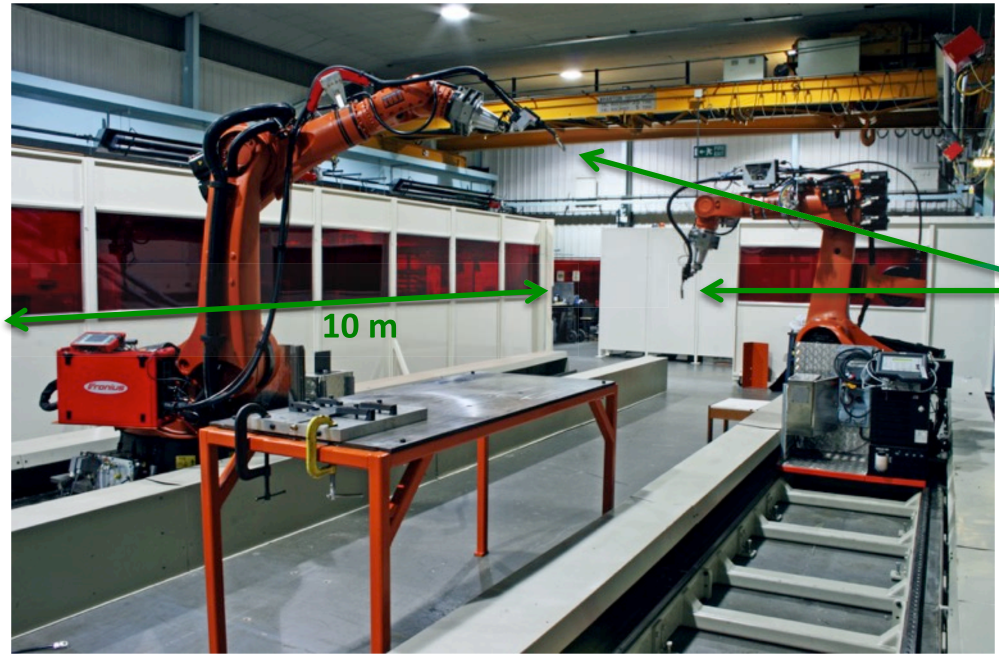
- **Qualification** for aerospace (civil + defence)
- **Parallel** processing



- Deposition
- Local shielding
- Cold work
- Metrology
- Machining
- NDT

- **High-strength** aluminium > 500 MPa
- **Mixed** materials, graded structures (f.i. aluminium MMCs)

Next 5 years

- **Commercialisation**:
  - **Robotic** manipulation
    - Medium size ~ $1m^3$ → £100k
    - Large size ~ 6-10m → £200k up to £700k depending on accuracy requirements
  - **CNC** manipulation
    - Low cost ~ 0.5m x 0.5m x 0.5m → £30k
    - Medium size ~ 2m x 1m x 1m → £300k
    - Extended capability including cold-work ~ 6m x 3m x 1m → £2M
  - **+ whatever**: the software being developed should be able to drive any manipulation system – great for retrofitting

Beyond 8 years

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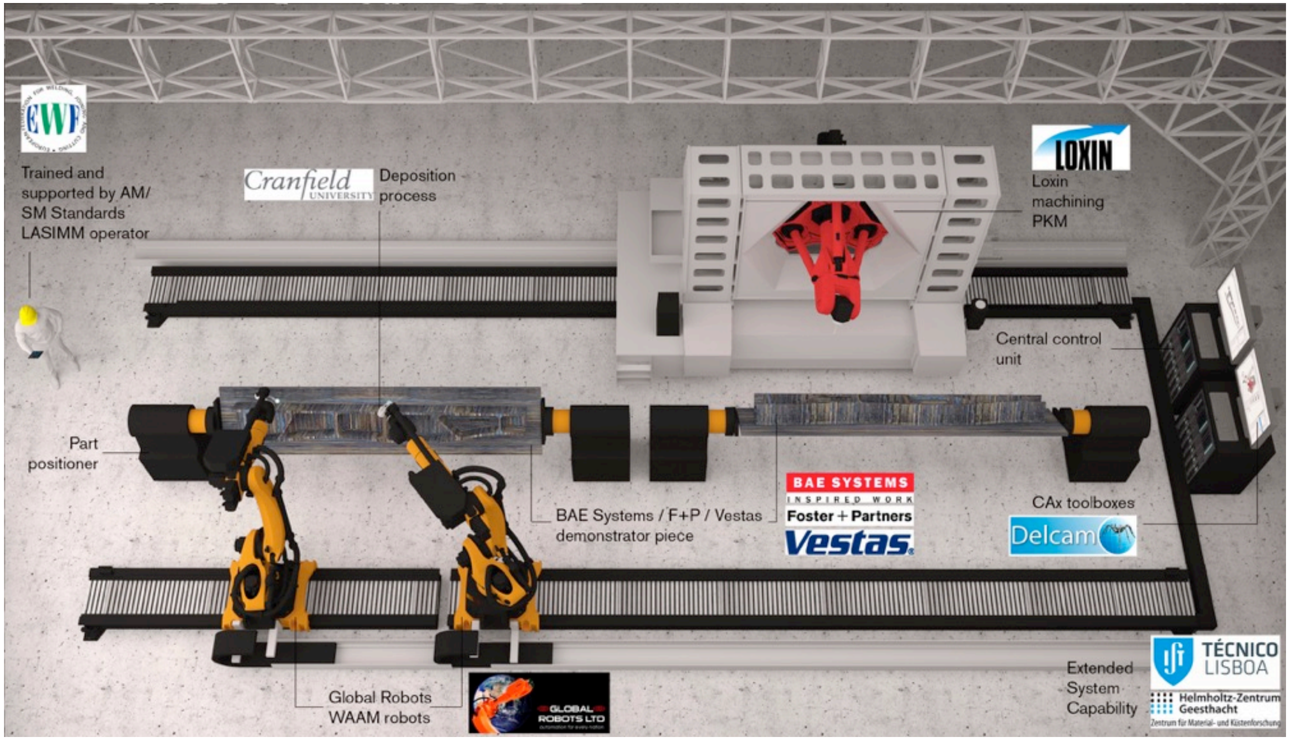
- Very **large** parts – Ti (local shielding), Al, Steel



LASIMM
6M€ EU project
3 years
Starts this October

- Full **industrial implementation** as No. 1 process

New website – launched April 1st.

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THANK YOU FOR YOUR ATTENTION ☺

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WAAMSoft: Demonstration