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# *Wire Based Additive Manufacture at Cranfield University*

**Professor Stewart Williams + WAAMMat team**

**May 2018**

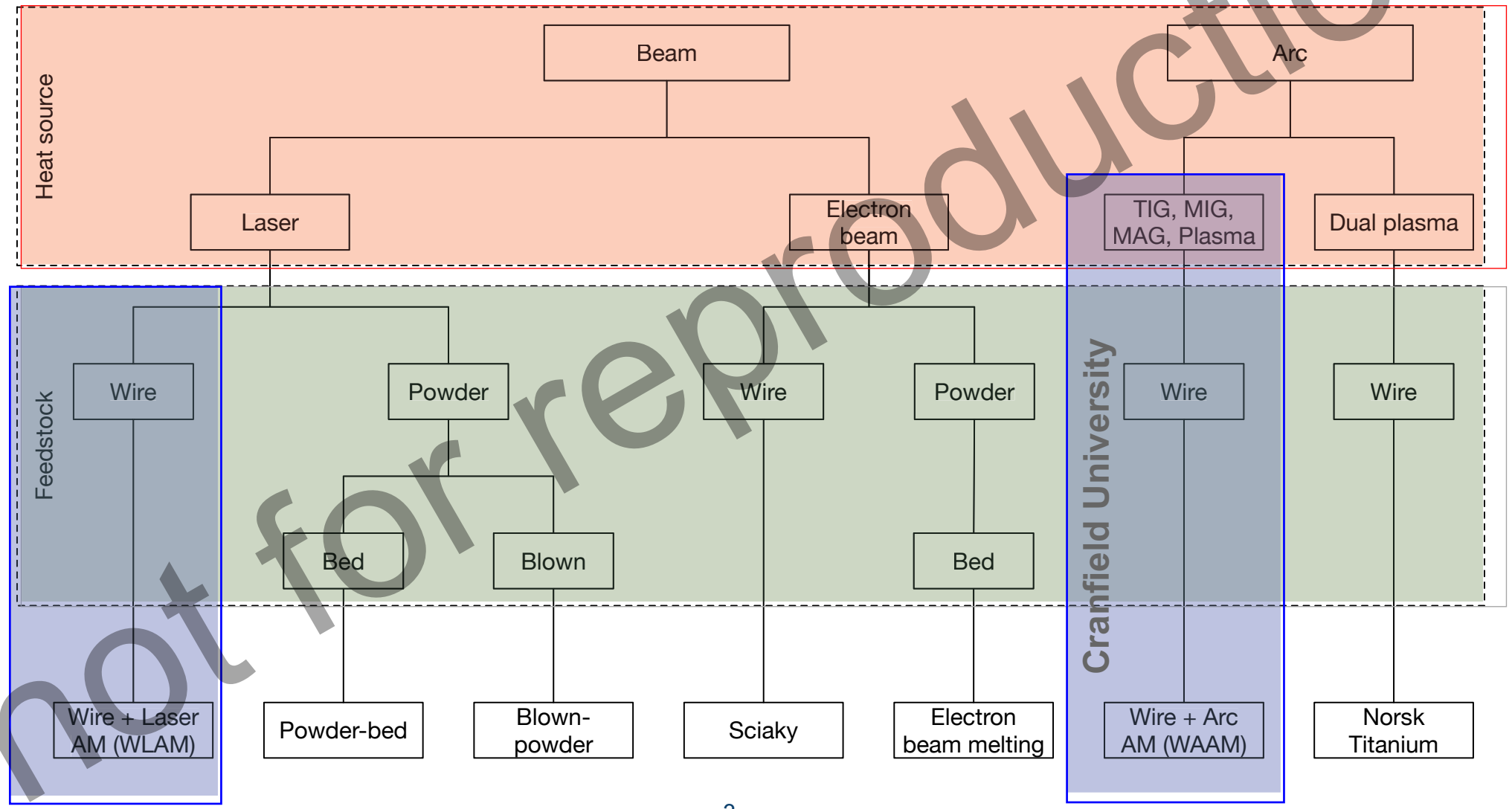
http://waammat.com/

www.cranfield.ac.uk

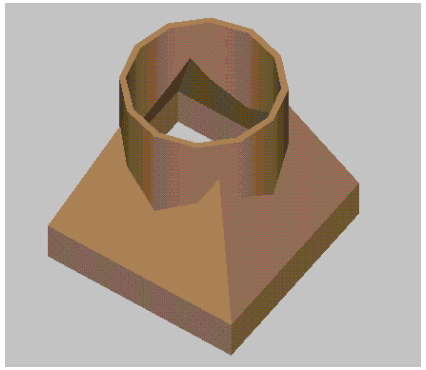
# Talk overview

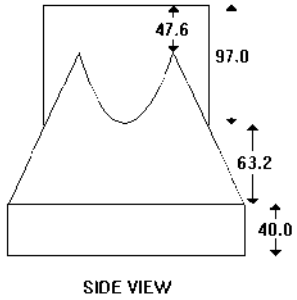
- Wire based AM research at Cranfield University
  - ❑SMD
  - ❑RUAM
  - ❑WAAMMat
- Challenges going forward
- NEWAM programme

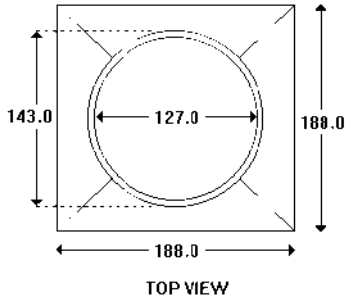
# Metal AM processes

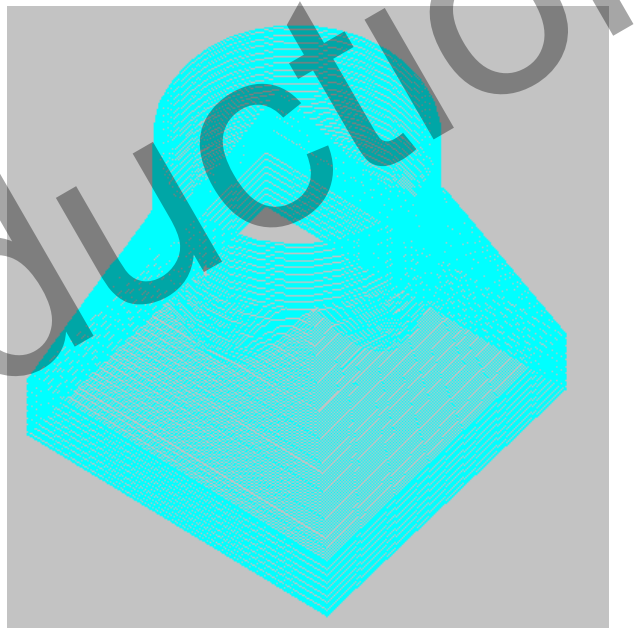


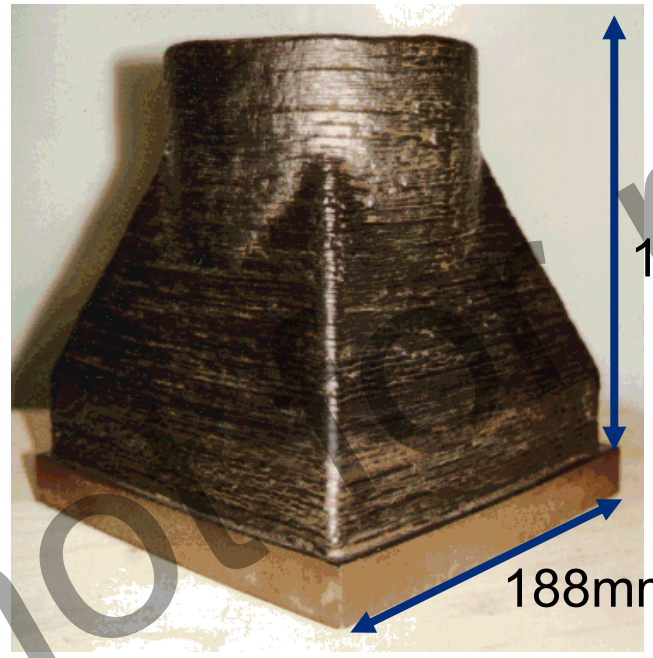
# Shaped Metal Deposition project – 1994 - 2001





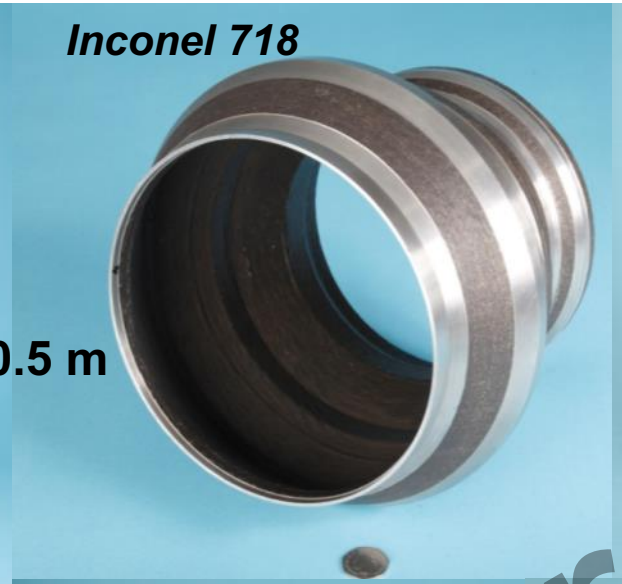






Material – Iconel 718
No of layers - 144
Deposition Time - 2.44hrs
Deposited Weight - 7kg
Max wall thickness variation - 0.3mm
Max height variation - +2mm
Max diameter variation - -2mm

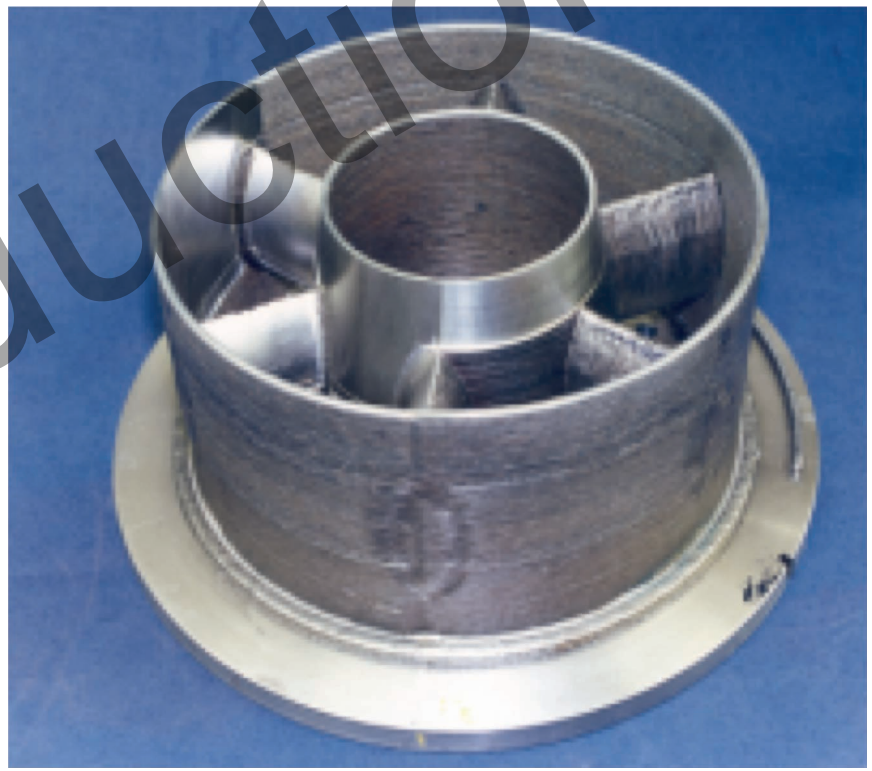
# Shaped Metal Deposition project – 1994 - 2001











Developed for Rolls Royce and taken into full production

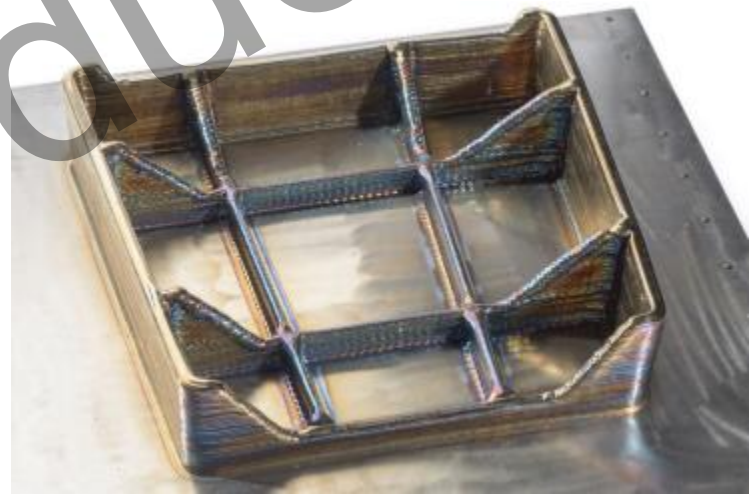
**Still in production today**

# Wire based AM - Business Drivers

- WAAM business drivers are
  - ✓Cost and material saving compared to current manufacturing methods
  - ✓Greatly reduced lead times
  - ✓Application to large engineering structures
  - ✓Enabling new functionality in components

Titanium wing frame

| Design option (MRR = 65 kg/h) | BTF | Cost (£k) | Cost red. |
|---|---|---|---|
| Machined from solid | 69 | 4.9 | - |
| WAAM + machining | 8 | 2.4 | >50% |

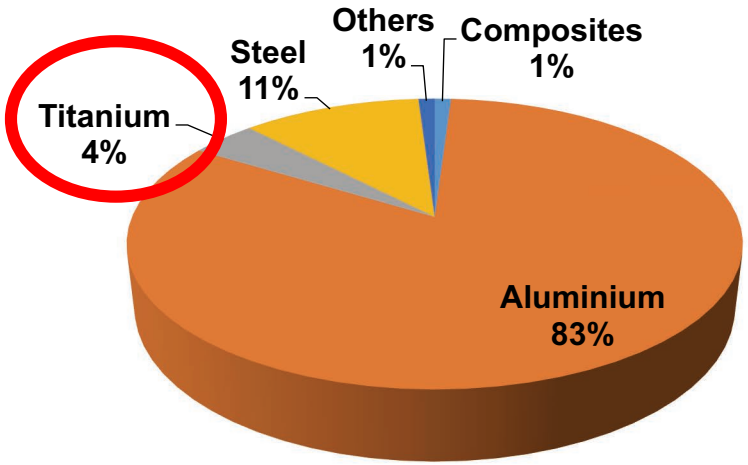


Titanium landing gear rib

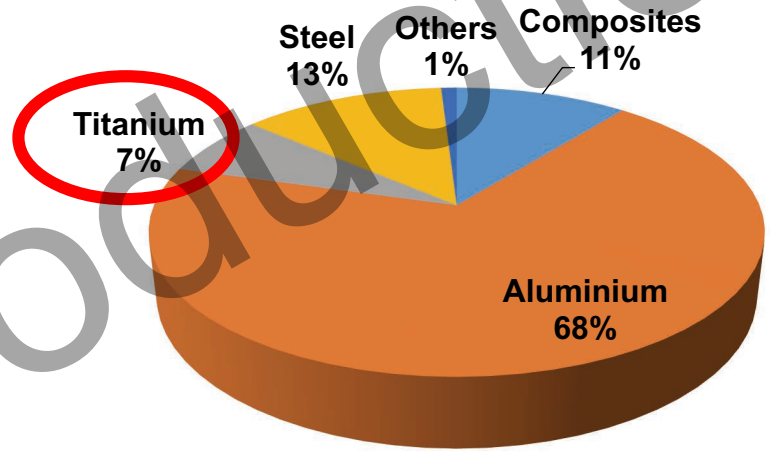
| Design option | Mass (kg) | BTF | Cost (£k) | Cost red. |
|---|---|---|---|---|
| Original machined | 20 | 12 | 16.2 | - |
| WAAM + machining | 20 | 2.3 | 5 | 69% |

# Wire based AM motivation – Change in Material Usage in Civil aircraft

747




777

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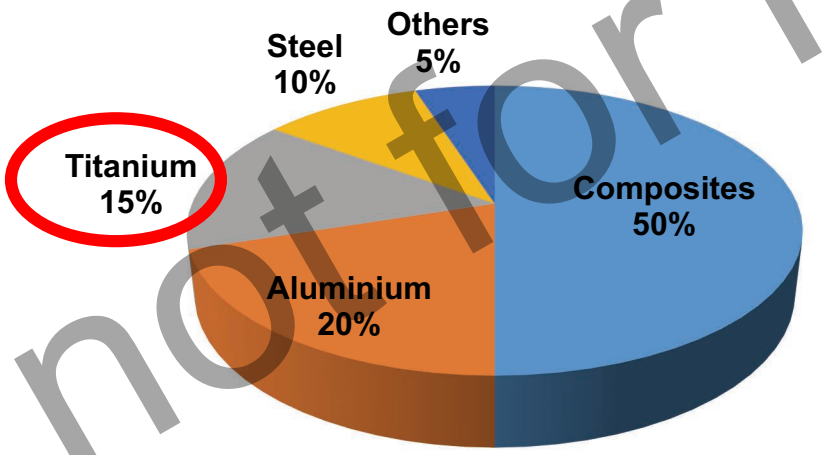
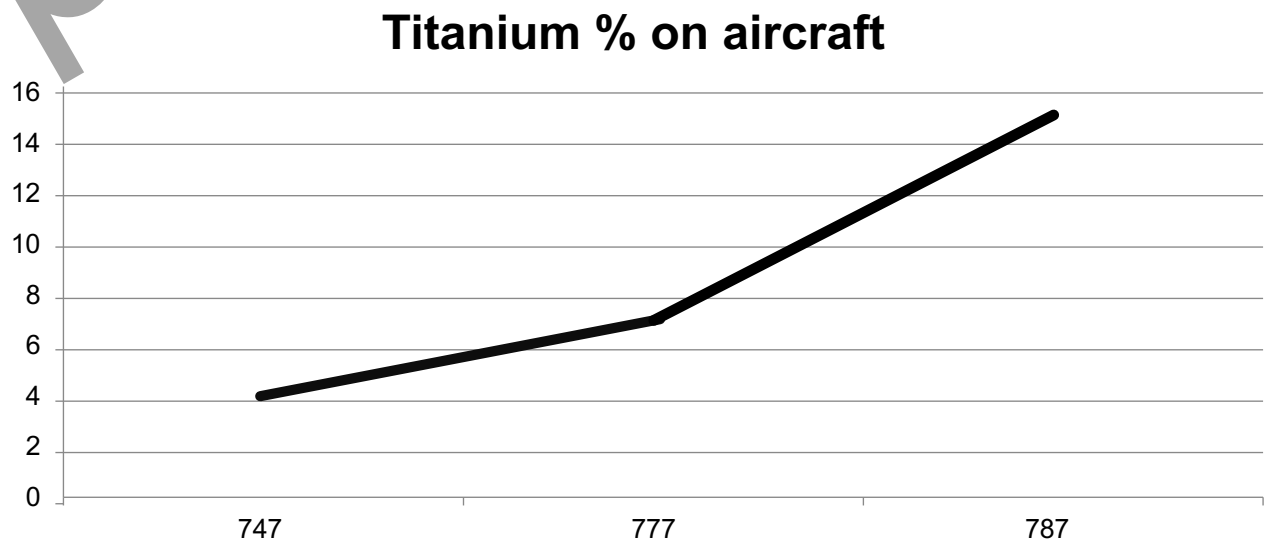
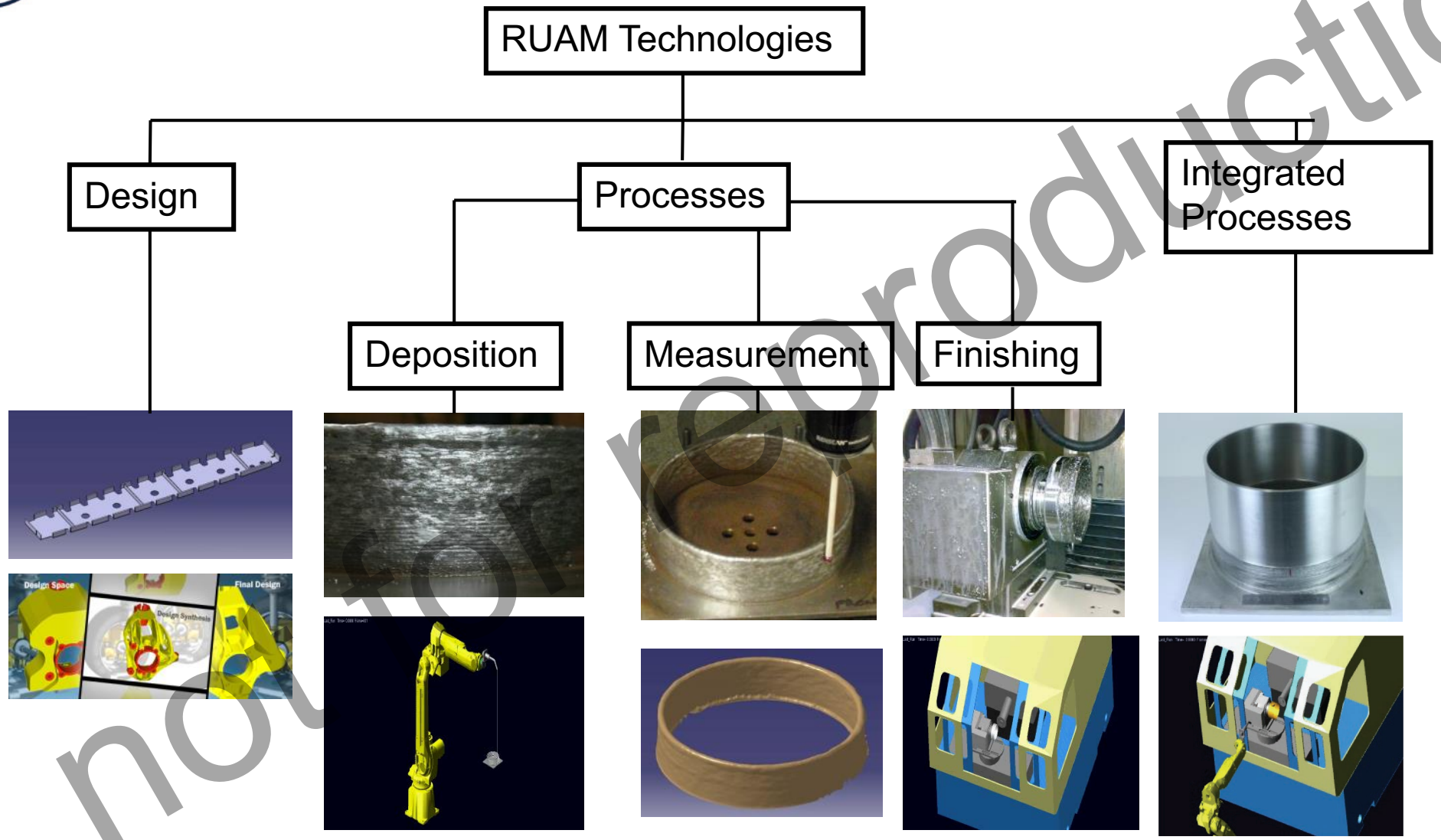
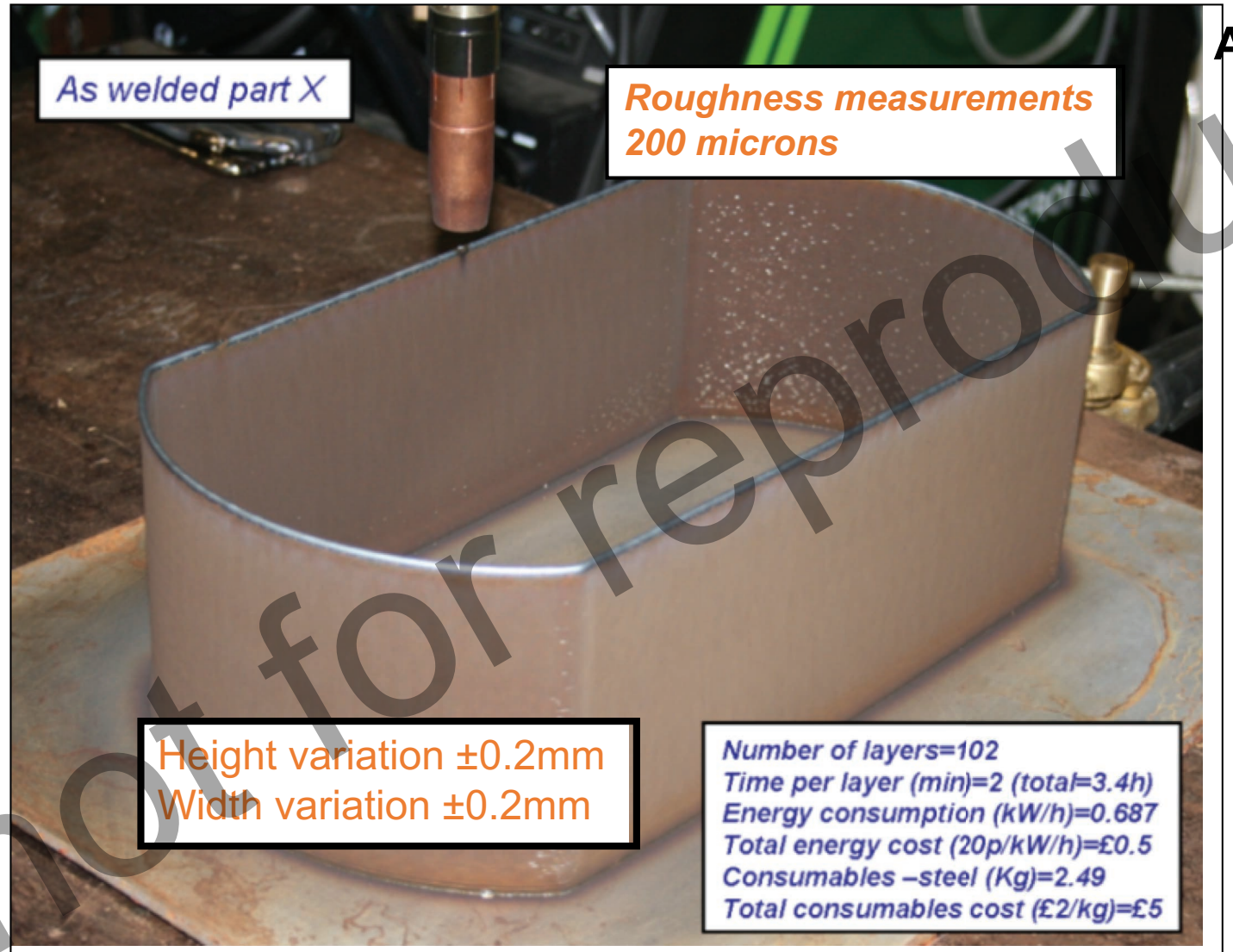


# Ready to Use Additive Manufacture (RUAM) Project 2006 – 2011 – EPSRC IMRC project



# RUAM 2006 – 2011 – 1st 2D Part – CMT – 2.9mm thick walls - mild steel

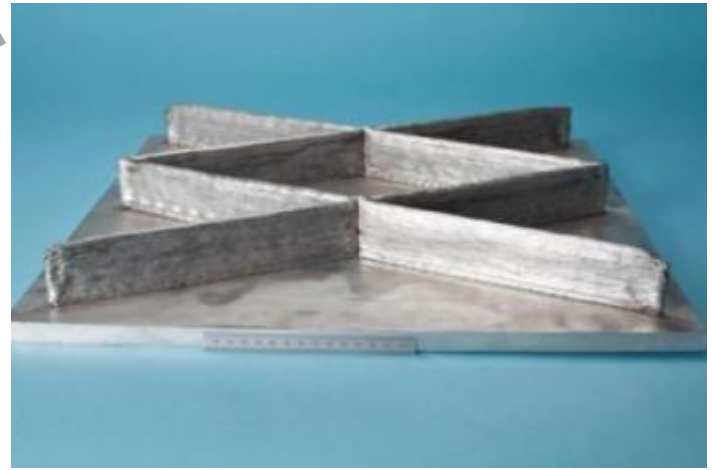



**As deposited – time 3.4 hours**

# 2006 → 2008: the first steps

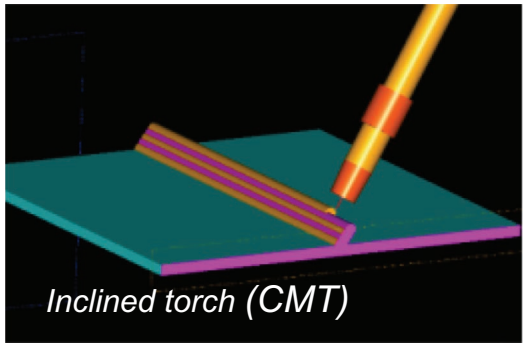
carbon steel (s355)

Aluminium

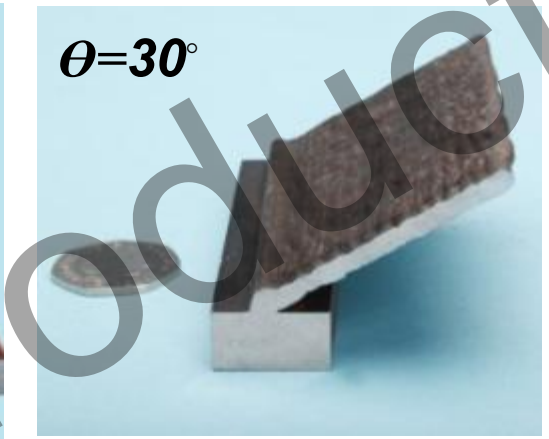


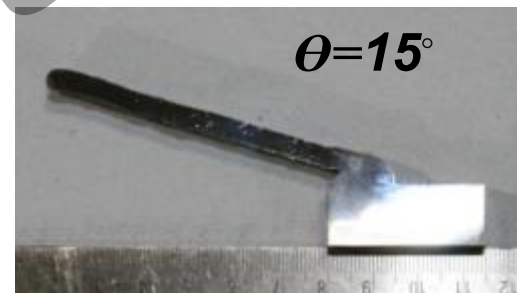
# 2008 → 2009: looking for complexity

**Inclined**

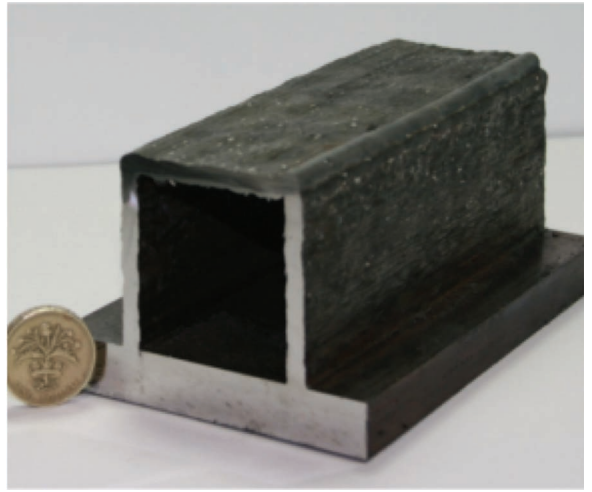






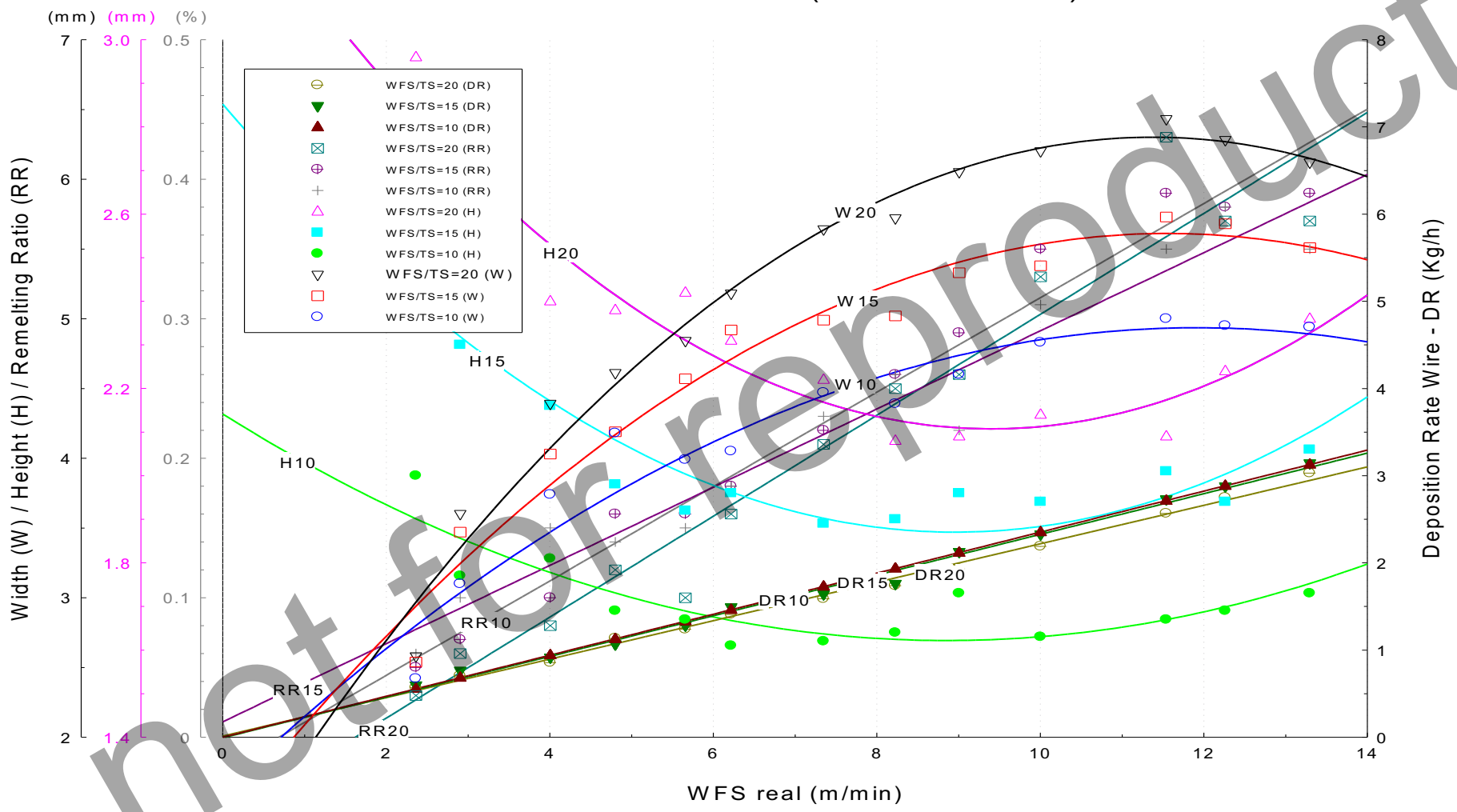



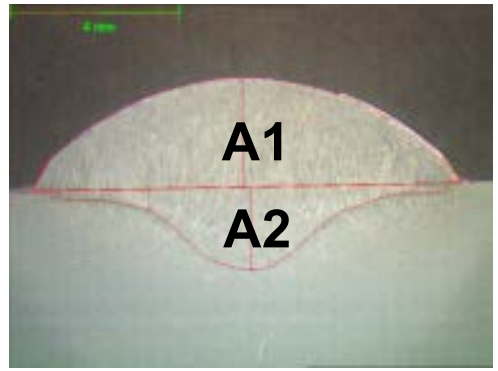

**Horizontal**



**Enclosed section**

# 2009 → 2011: controlling the geometry - CMT

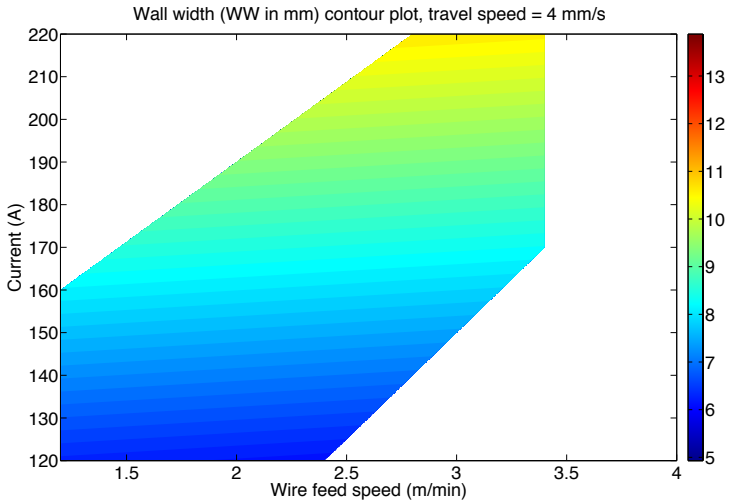


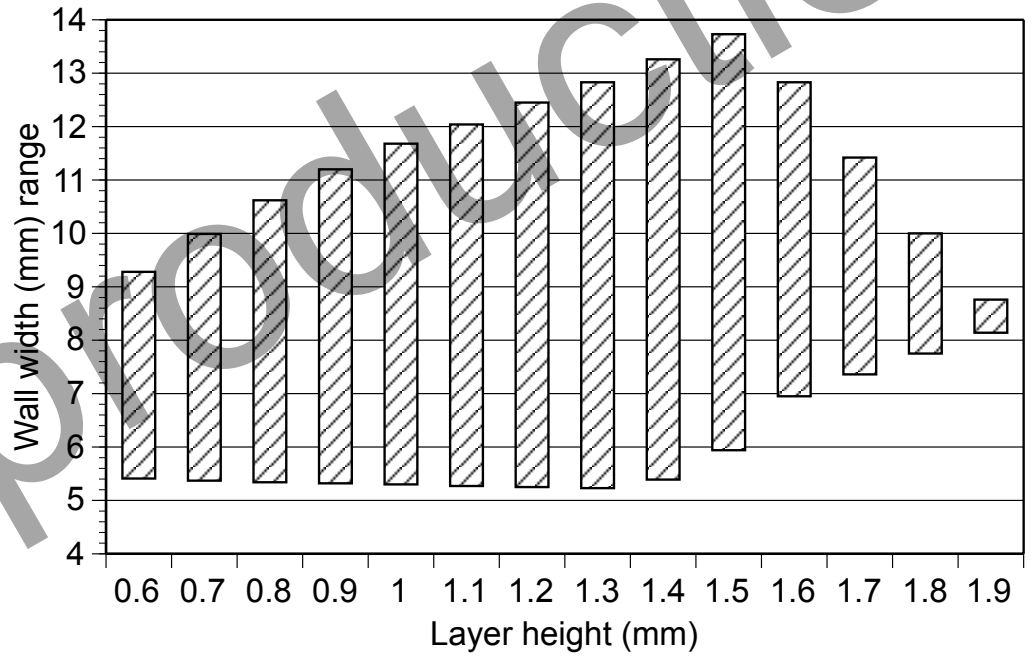




Quality criteria

**2 < WFS < 3=C ; 4 < WFS < 10=A; 11 < WFS < 13=B**

# 2009 → 2011: controlling the geometry - Plasma

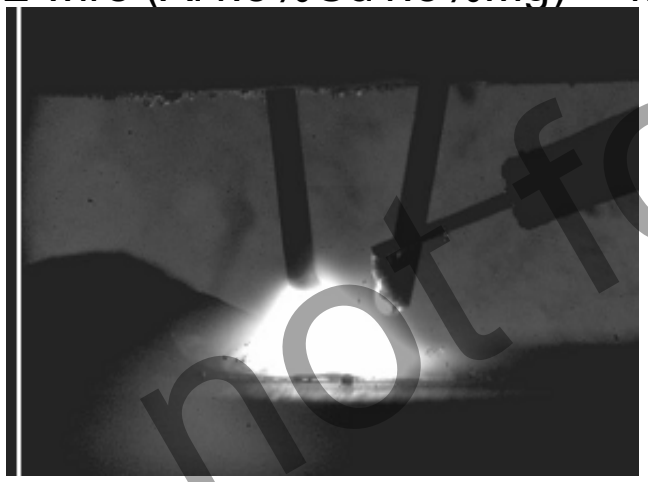


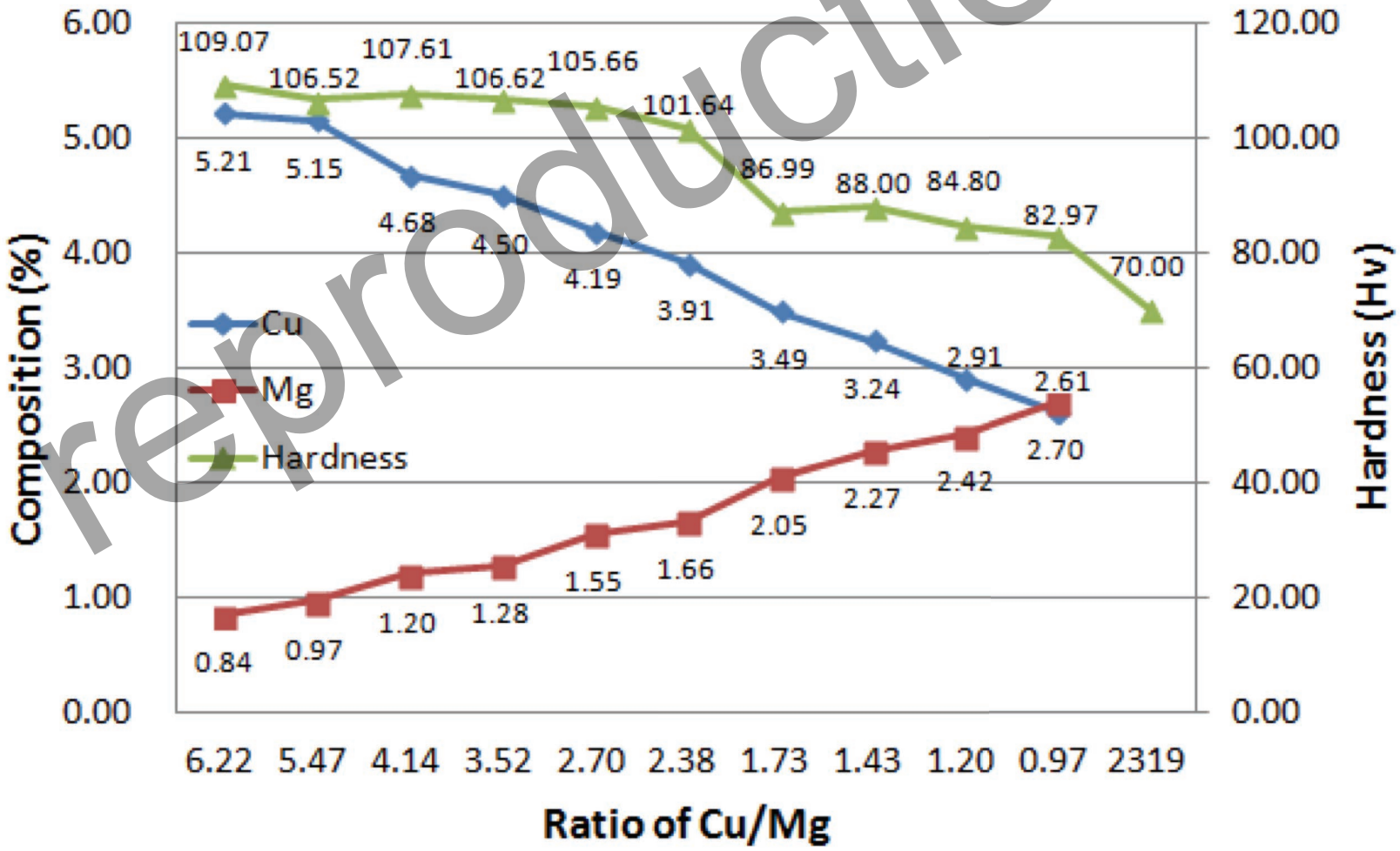

**Wall width and layer height - Contour plots as function of WFS and Current**

# 2009 – 2011 controlling the composition using multiple feeds

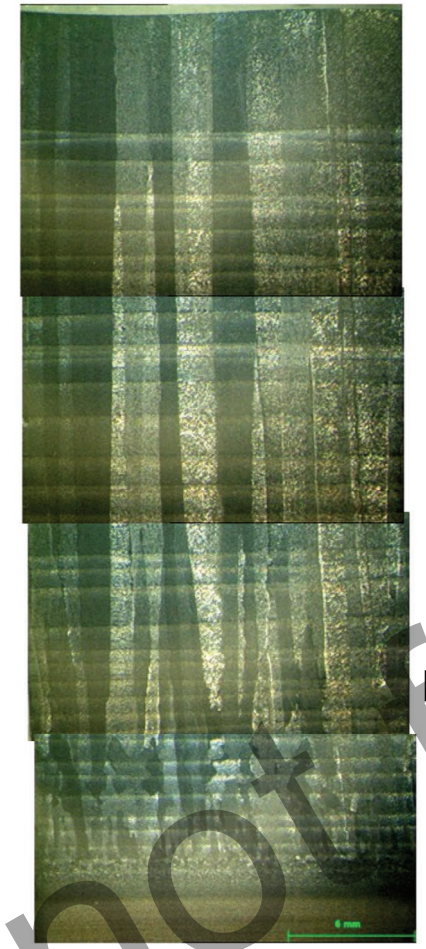

1 wire Al6%Cu– 100HV
2 wire (Al4.5%Cu1.5%Mg) – 120HV

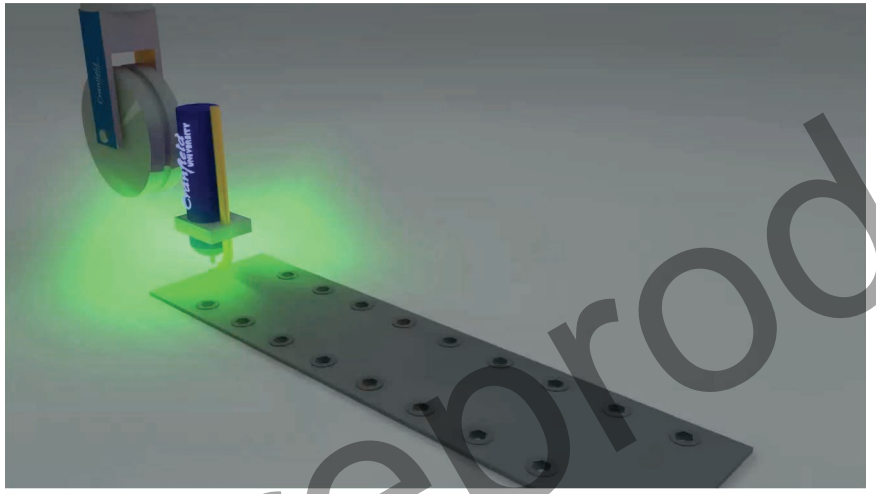


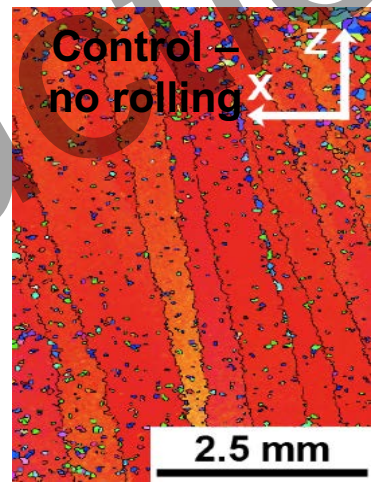
3 wire (Al8%Cu1.5%Mg – 140HV)



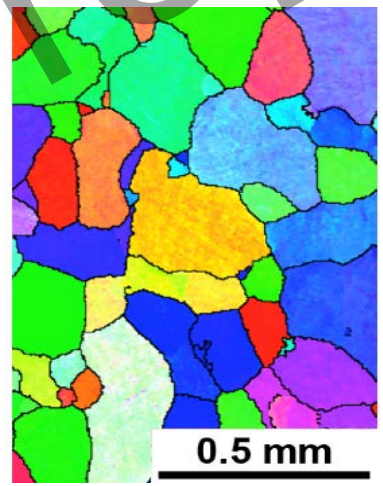
# 2009 – 2010 – Control of properties through cold rolling



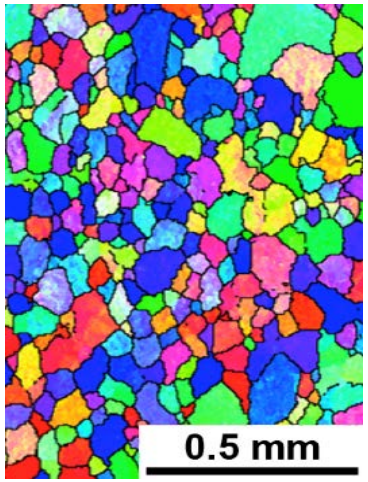





**Rolled @ 50 kN**
**139 µm**

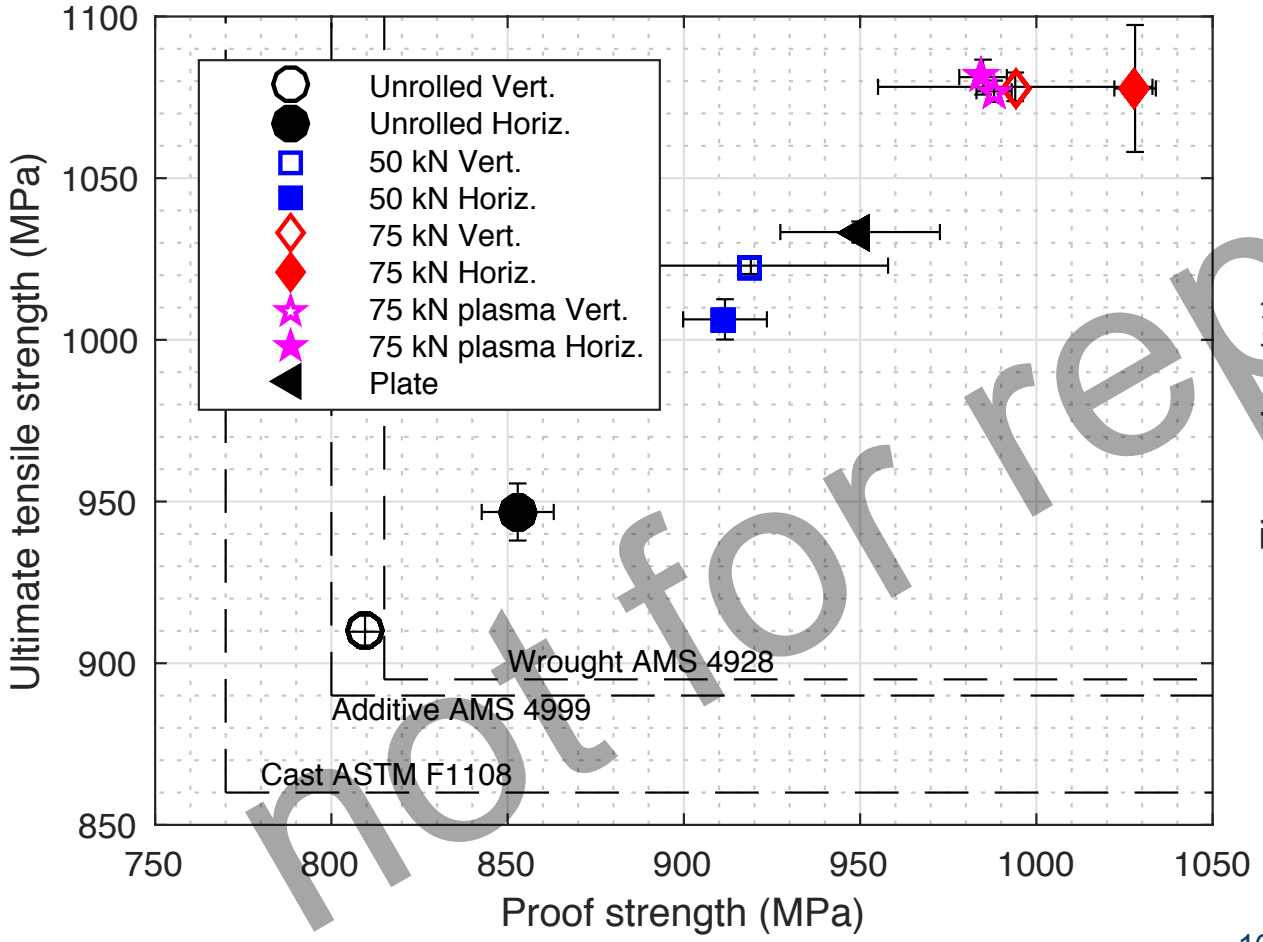


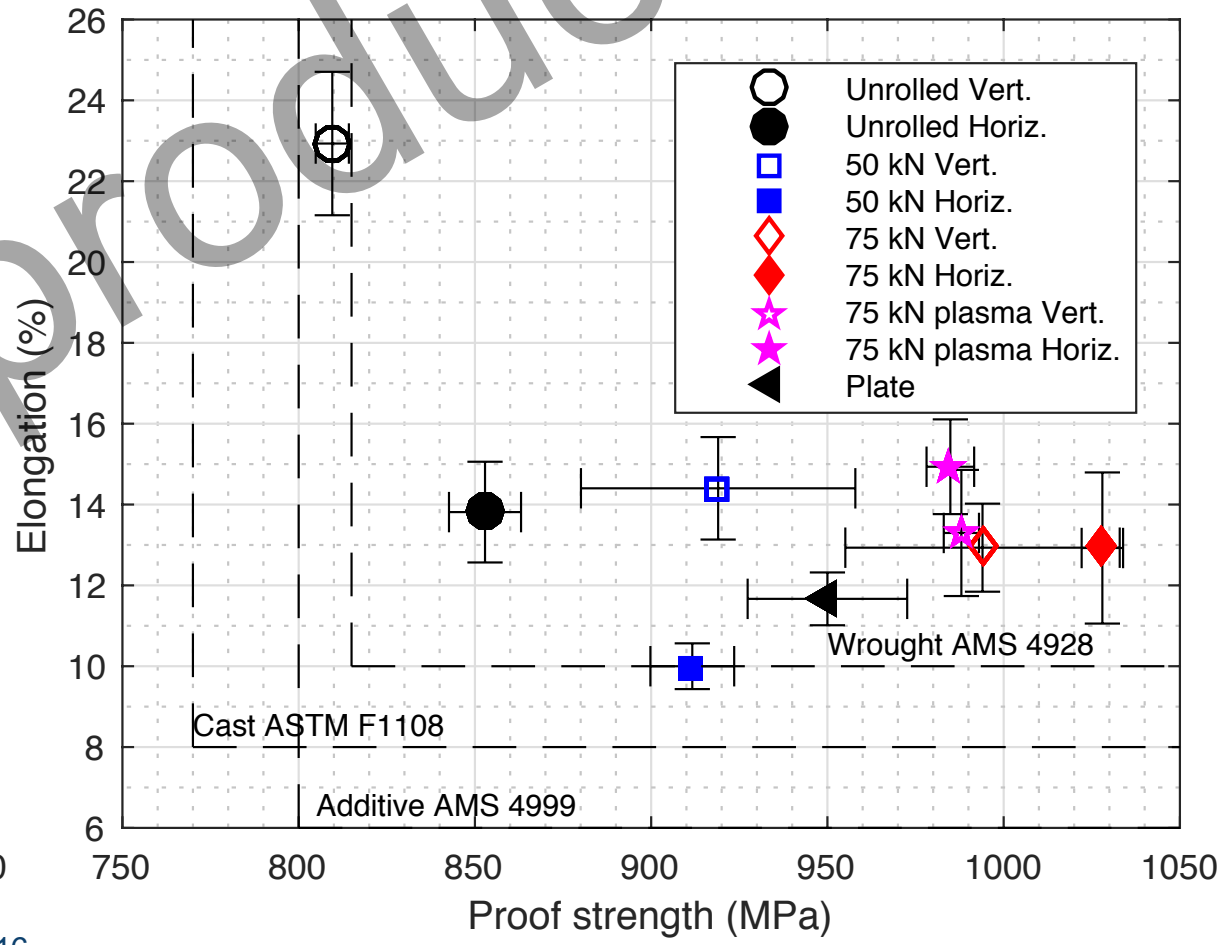

**Rolled @ 75 kN**
**66 µm**



# 2012: the introduction of cold-work

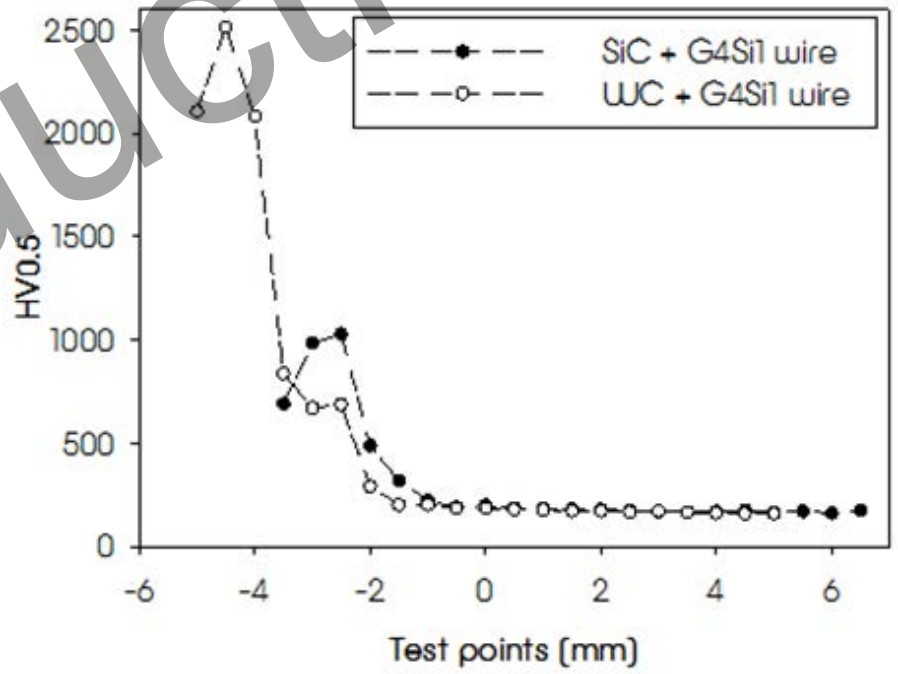
## Directionality



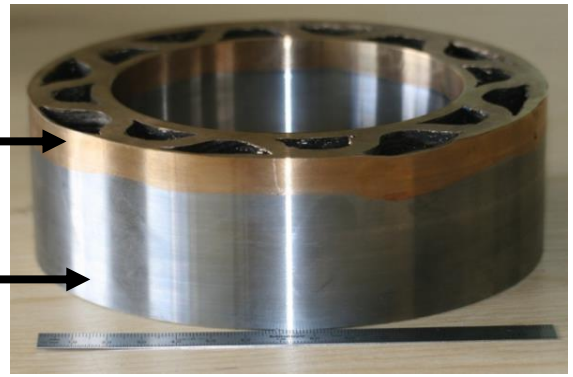
# 2009 – 2011 controlling the composition using powder + wire

## Wire (steel) + Powder (WC)

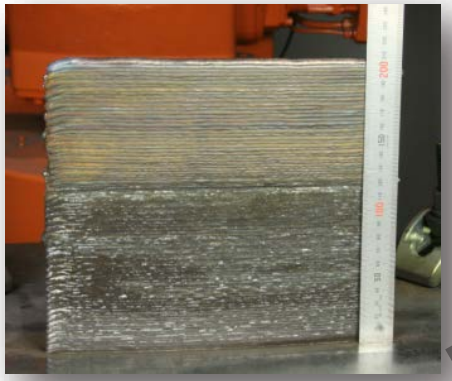
# 2009- 2012 controlling the composition - mixing materials

## Copper steel ring



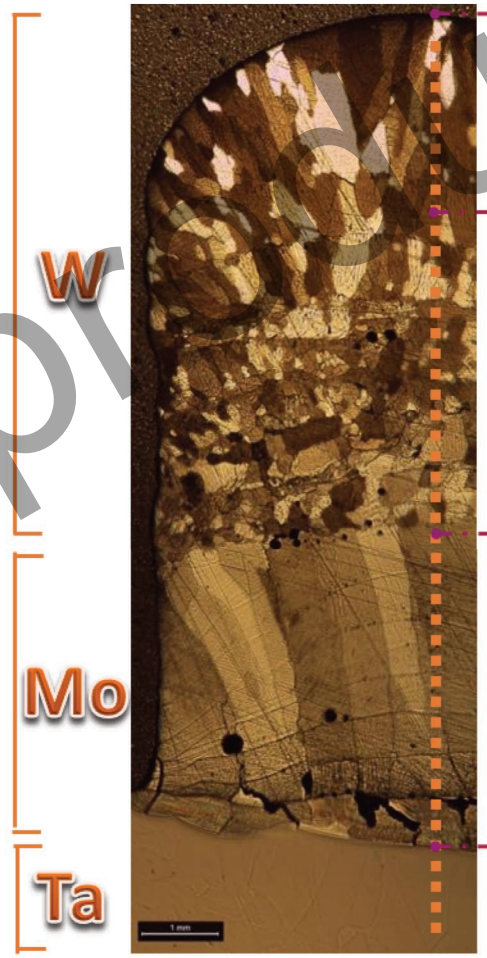


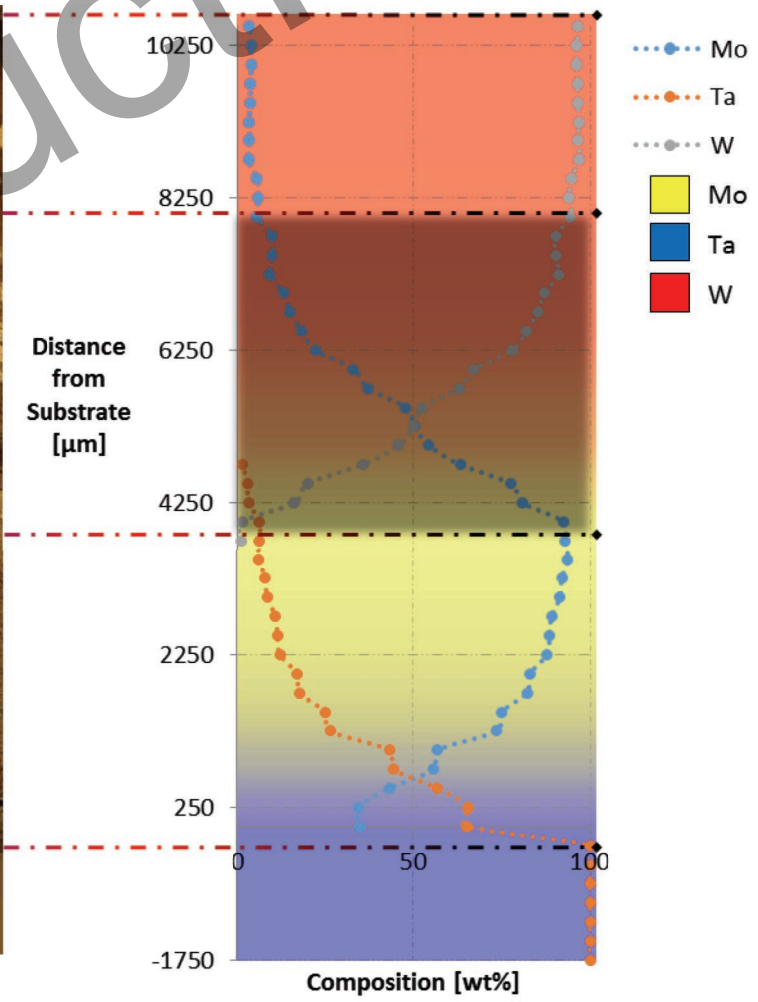
## Invar-steel wall



| | Peak Load (MPa) |
|---|---|
| Invar Steel | 493.8 |
| Invar Longitudinal | 489.4 |
| Invar Transverse | 503.5 |

## Tantalum – Molybdenum – Tungsten graded wall



# 2011: the first real complex large part (steel)

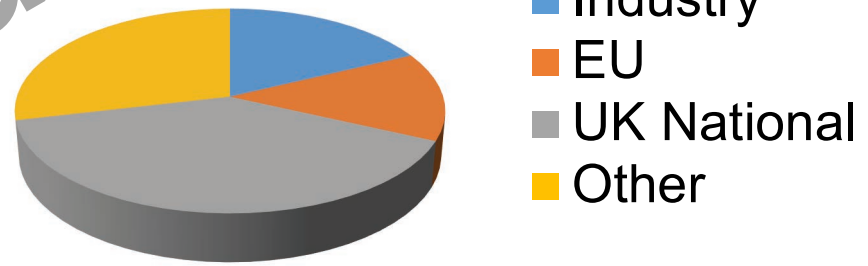
# 2011: the first real complex large part (finally Ti64)

- Undercuts
- Accumulation of errors in layer height
- Cracking of the baseplate

- Four deposition strategies
- No undercuts
- Compensation for changes in thermal fields

# The WAAMMat programme – 2012 - present

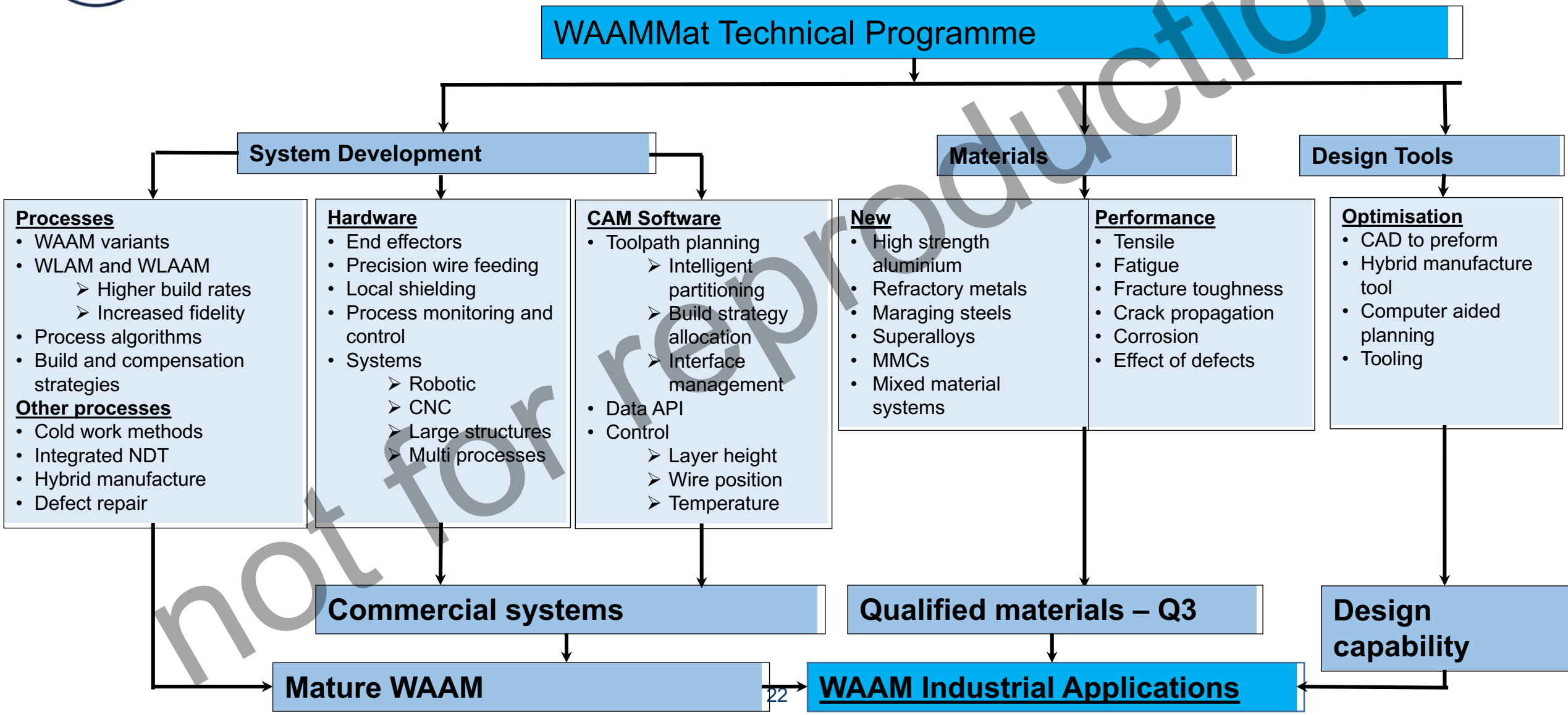
- **WAAMMat** is a rolling technology programme targeting maturation of wire based AM
  - Industry sponsored research
  - Projects funded by outside bodies (e.g. EU, EPSRC, InnovateUK)
  - PhDs and masters projects
- Currently > **50 projects**
- **Total value > £13M** , **Rolling value £9M**
- At Cranfield there is team of **30 people** working on WAAM
  - 7 academics, 12 PhD students, 8 researchers and 3 technicians
- 13 academic partner Universities 11 Academics + 18 researchers/students



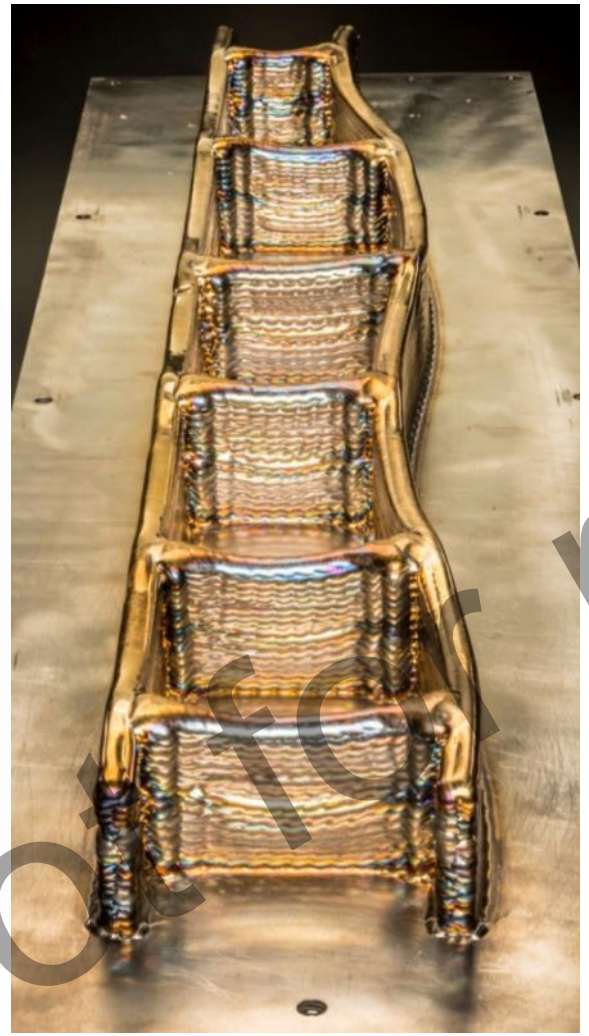

**<u>~ 60 people in total working on WAAMMat programme</u>**

**<u>12 full industrial members and a further 20 affiliated members</u>**

# WAAMMat – Technical Programme Overview

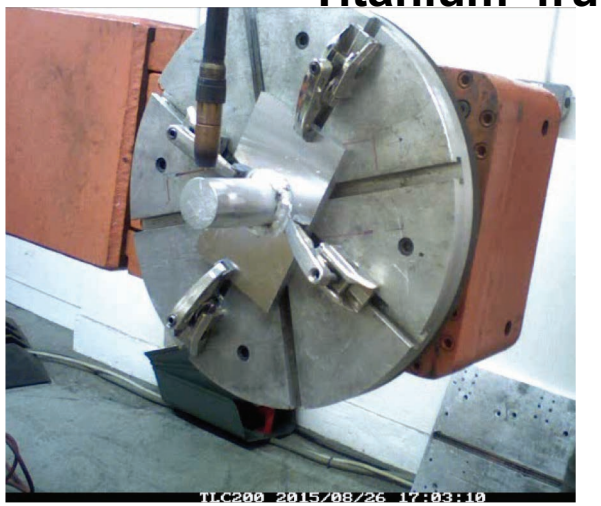


# 2013: more complex parts



# 2014-15 - WAAM part building – coordinate motion and multi hierarchy

**Titanium ‘fruit bowl’ as deposited and after machining**



**Multi – hierarchy aluminum structure**

**Steel elbow structure**

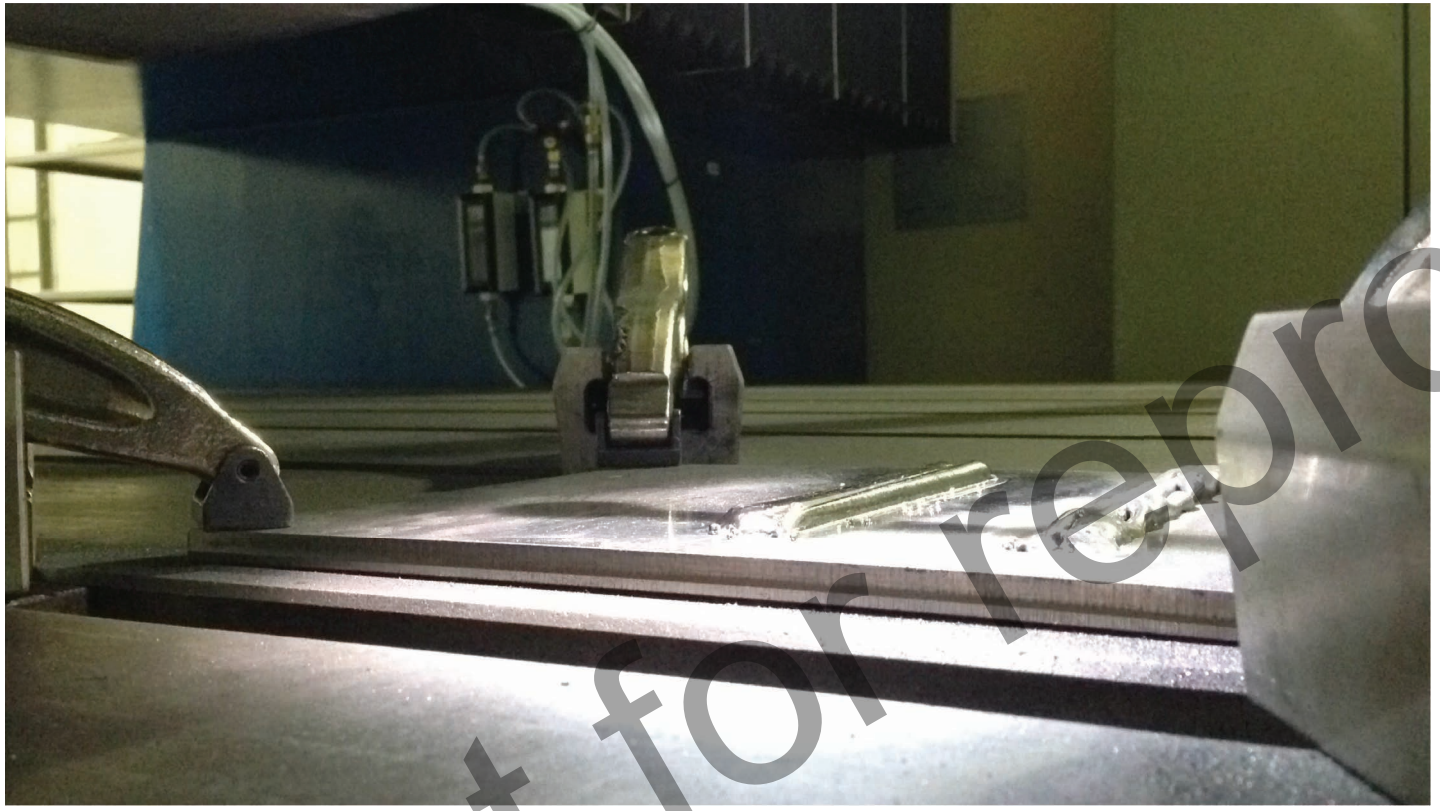
Required layer height ratio inside to out

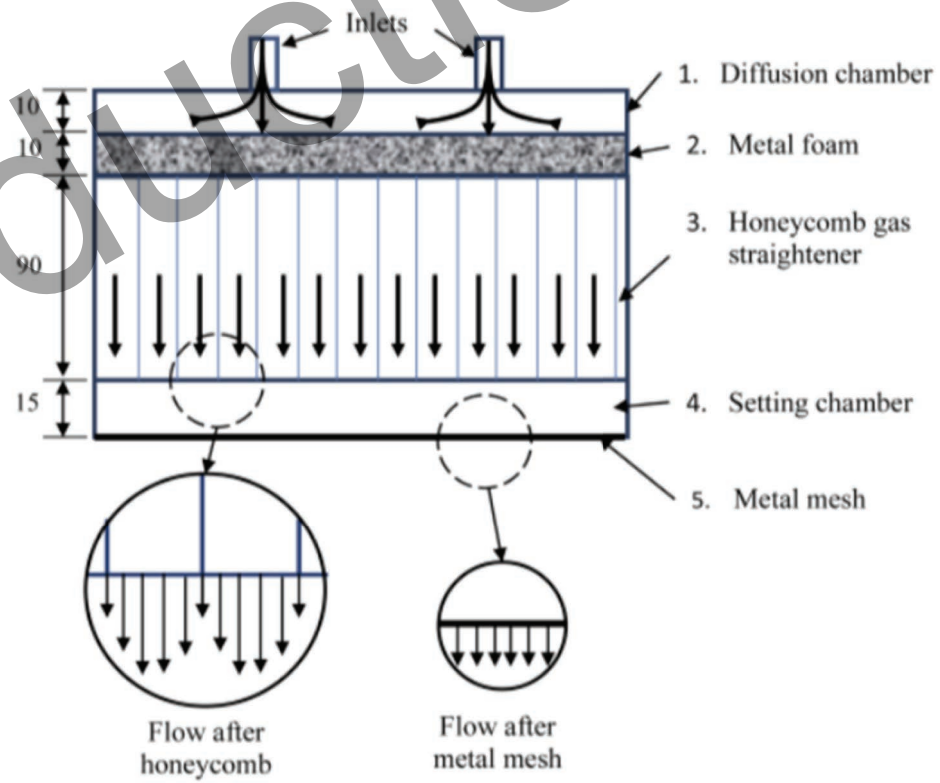
**1:2.7**

# 2017 - Titanium civil aircraft frame structures

Asymmetric half inch build - no distortion

# 2015: WAAM system developments - Local shielding + multi dimensional rolling HiVE v2

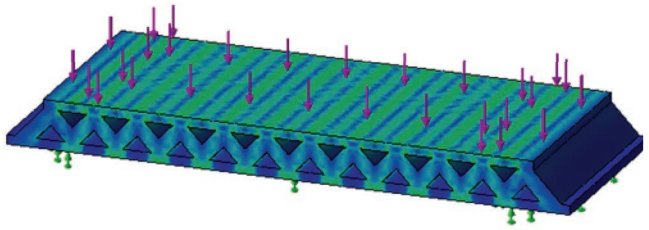


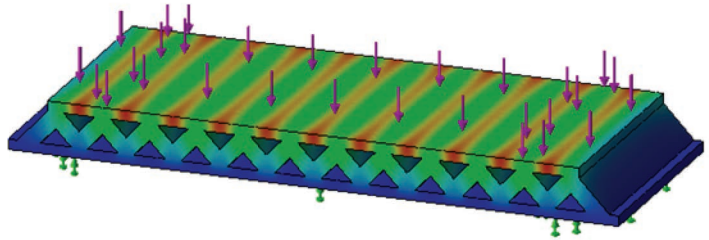


# 2016 - 17: complex parts on the HiVE

- **Singled sided part – no distortion**
- **Complex rolling**
- **Local shielding**

# 2015/18: high aspect ratio holes and conformal channels for tooling



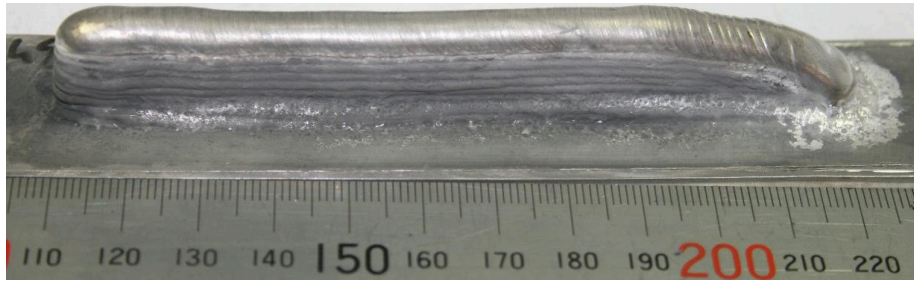


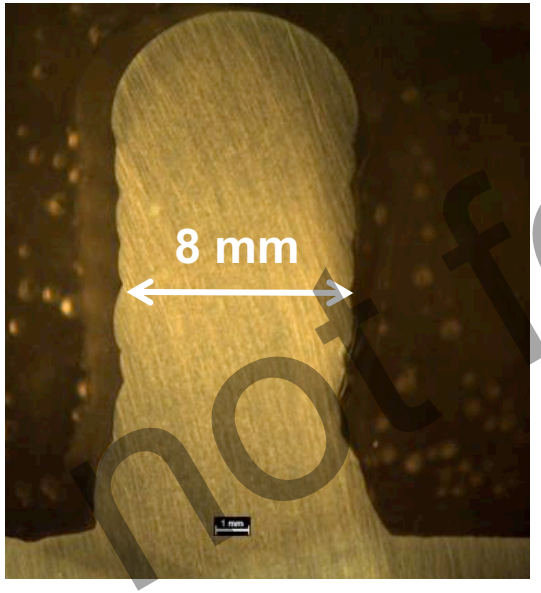
# 2017: what we've deposited so far

- **Titanium**
  - Commercially pure
  - Ti 64
  - Ti 64 low O2
  - Ti 5553
  - Ti 704
- **Aluminium**
  - 2024
  - 2319
  - 4043
  - 5087
  - 205
  - Safra 66
- **Steels**
  - ER60
  - ER80
  - ER90
  - ER120
  - Maraging grade 250
  - Maraging grade 350
  - Stainless (17-4 PH, 316L, 420)
- **Invar**
- **Inconel**
  - 625
  - 718
- **Refractories**
  - Tungsten
  - Molybdenum
  - Tantalum
- **Copper**
  - CuSi3
  - CuAg0.5
- **Mg A92A**
- **Bronze**

# 2017 – New Materials

## Magnesium AZ92A

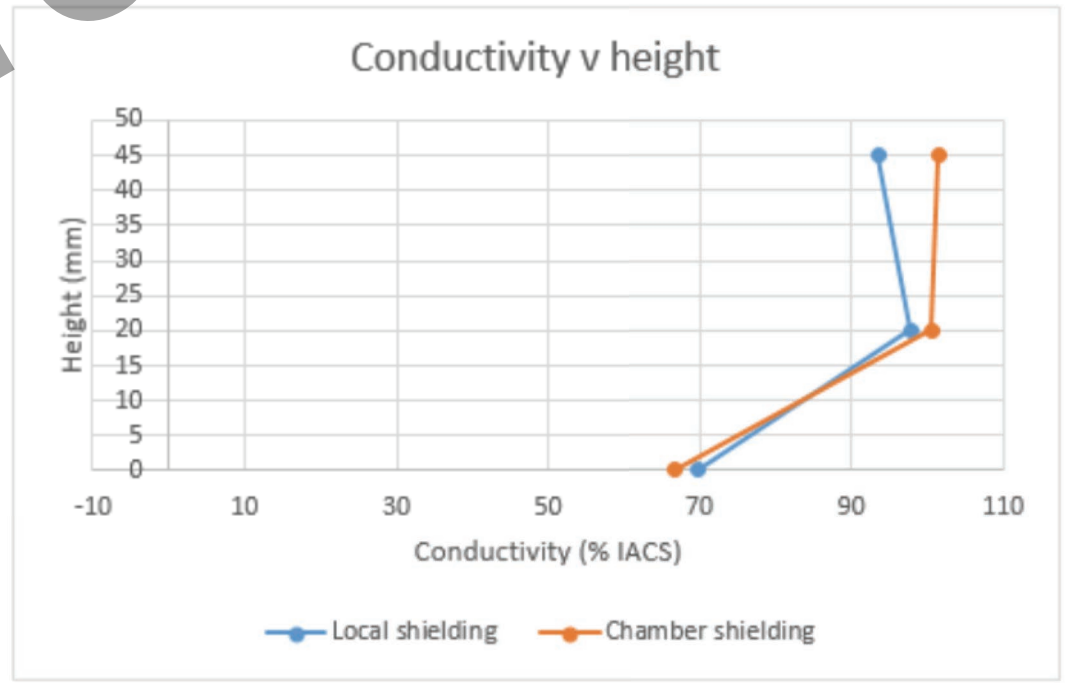


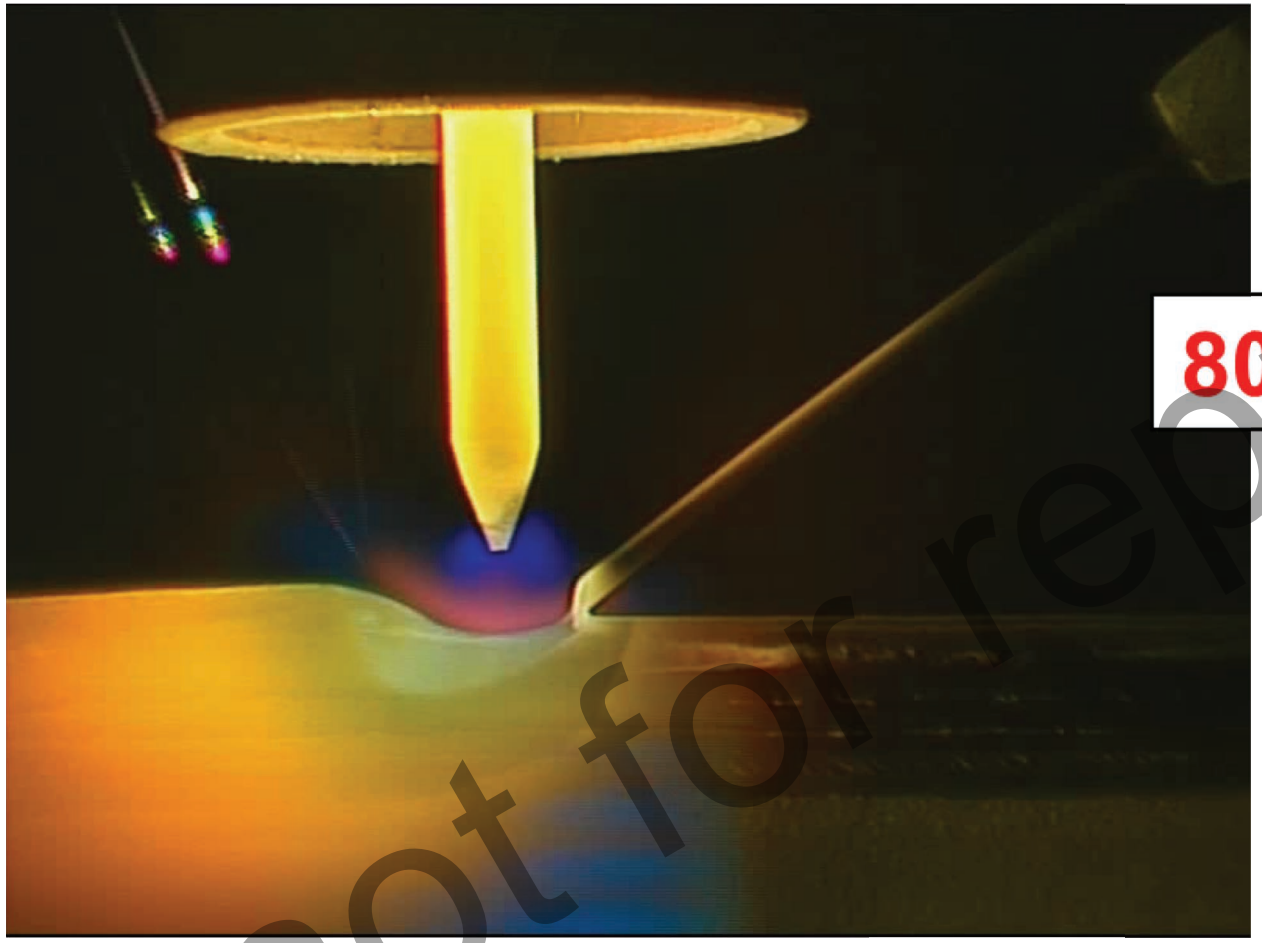


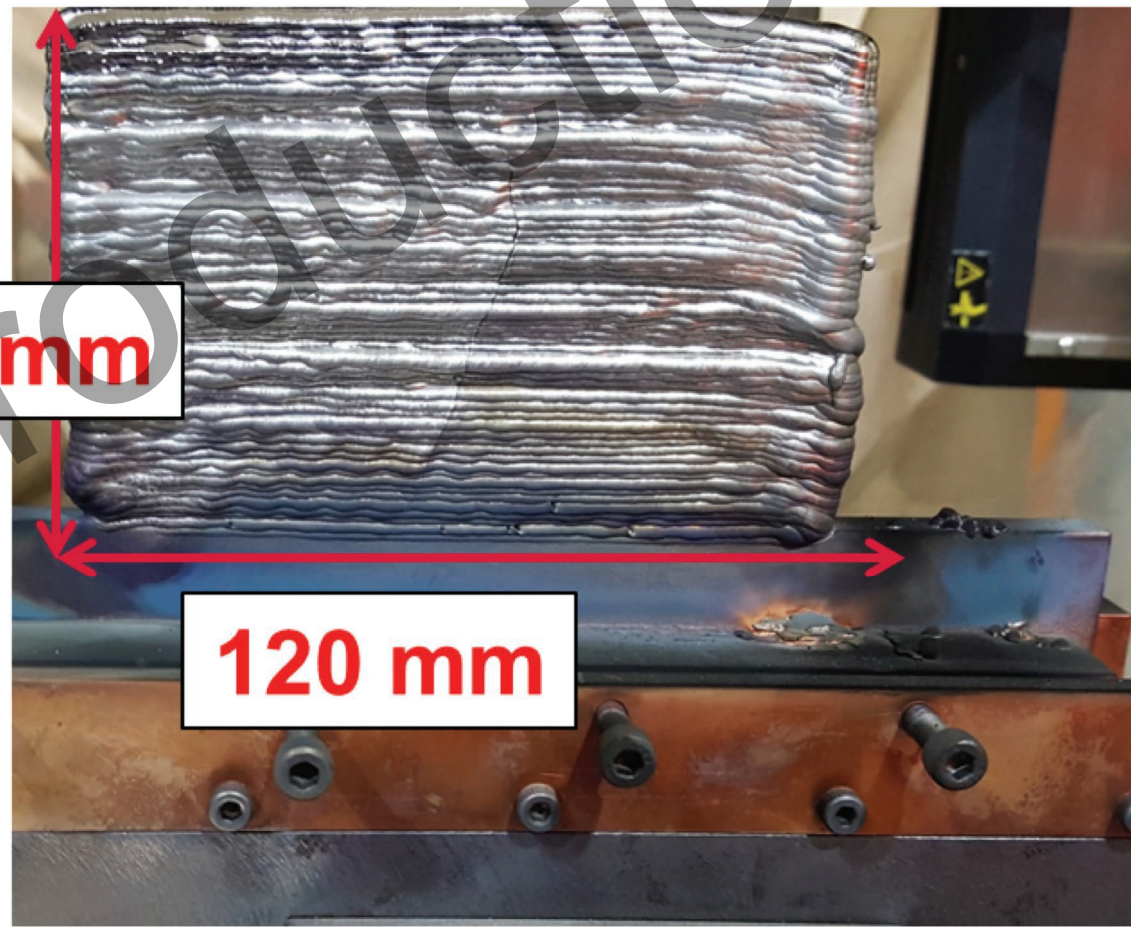
100% dense


102% IACS



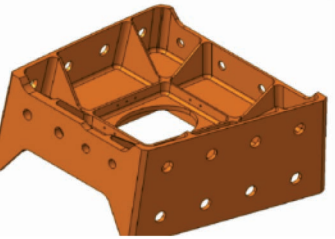
# 2016 – large scale Tungsten deposition





# 2016-18: software development

Import CAD model



## WAAMDesign

Generate net shape and check WAAM compatibility and baseplate position

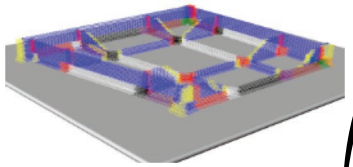
Cost analysis

## WAAM Data (API)

Primary process parameters

Thermal mass calculation around path

Allocation of thermal, geometrical & system compensations



Slice and allocate baseline bead geometrical parameters

Partition (manually/ automatically)

Allocate partition and interface build strategies and sequence

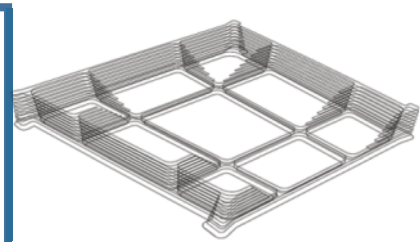
Tool path generation

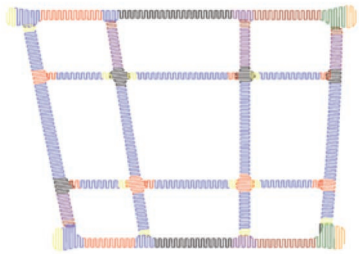
Tooling geometry

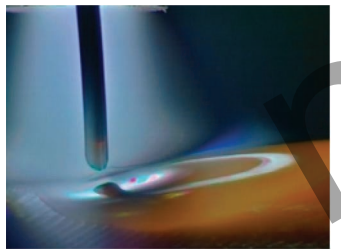
Simulation, collision detection

Programme for CNC machines/ robots

## WAAMSoft







Process monitoring and control, geometry and temperature

System controller

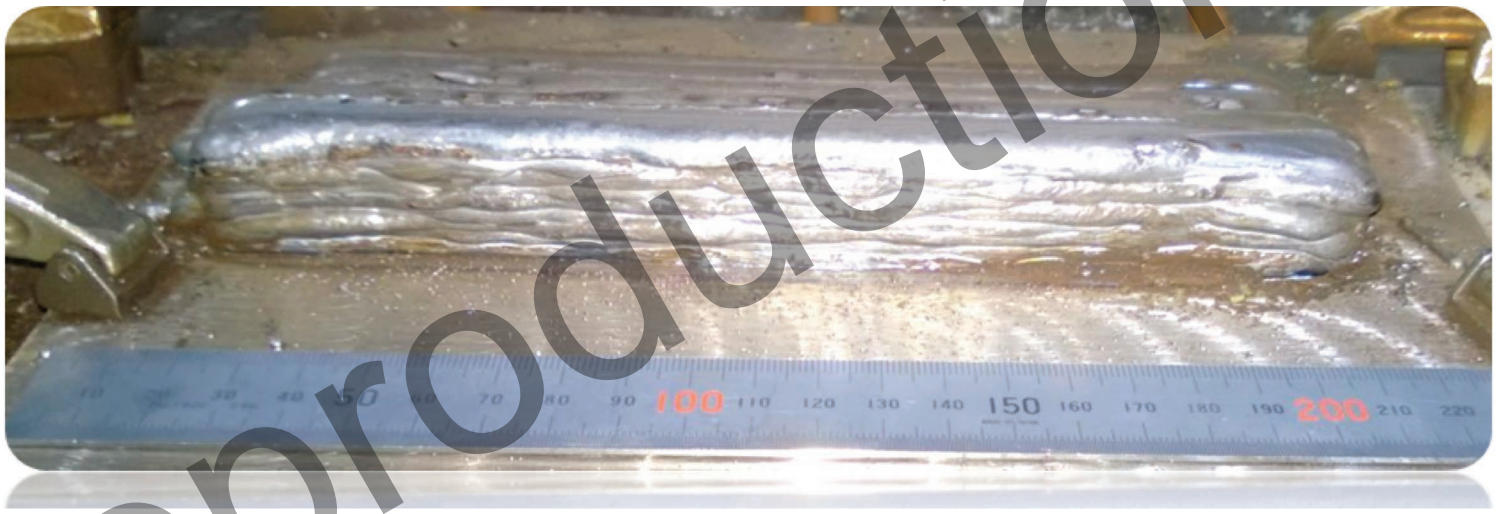
## WAAMCtrl

# Wire based DED AM – challenges going forward

- New processes and materials – not using commercial off the shelf materials and equipment
  - High build rate net shape deposition
  - Tailored materials
- Much greater science knowledge including physics based modelling
- Physics based qualification
- Large area deposition
- Multiprocess systems
- 3D printing in space
- Software completion
- Commercialisation

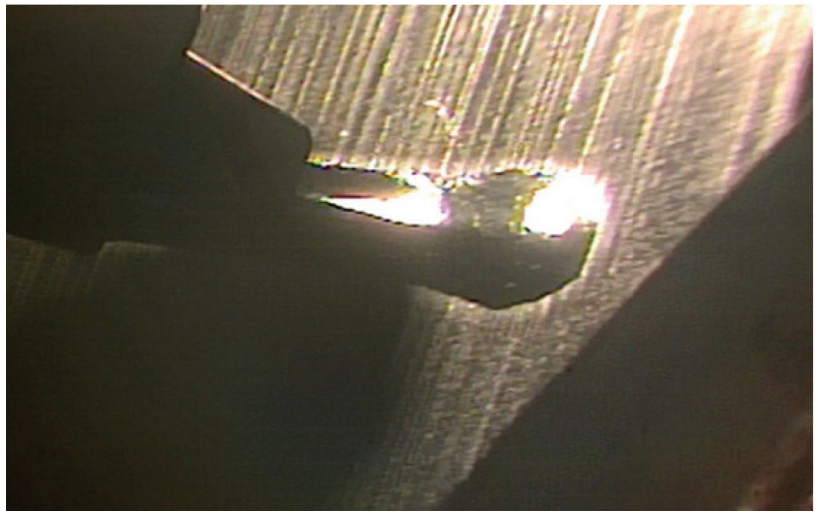
# High deposition rate - tandem MIG

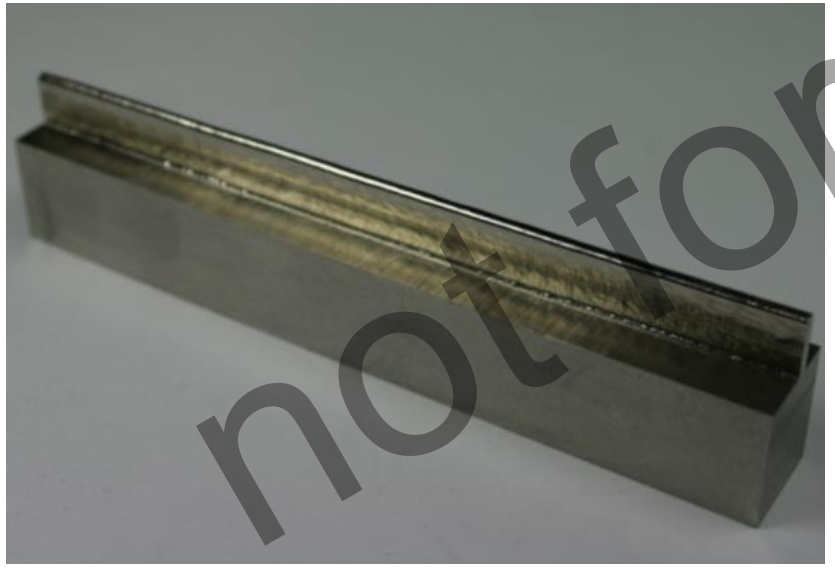
Twin wires

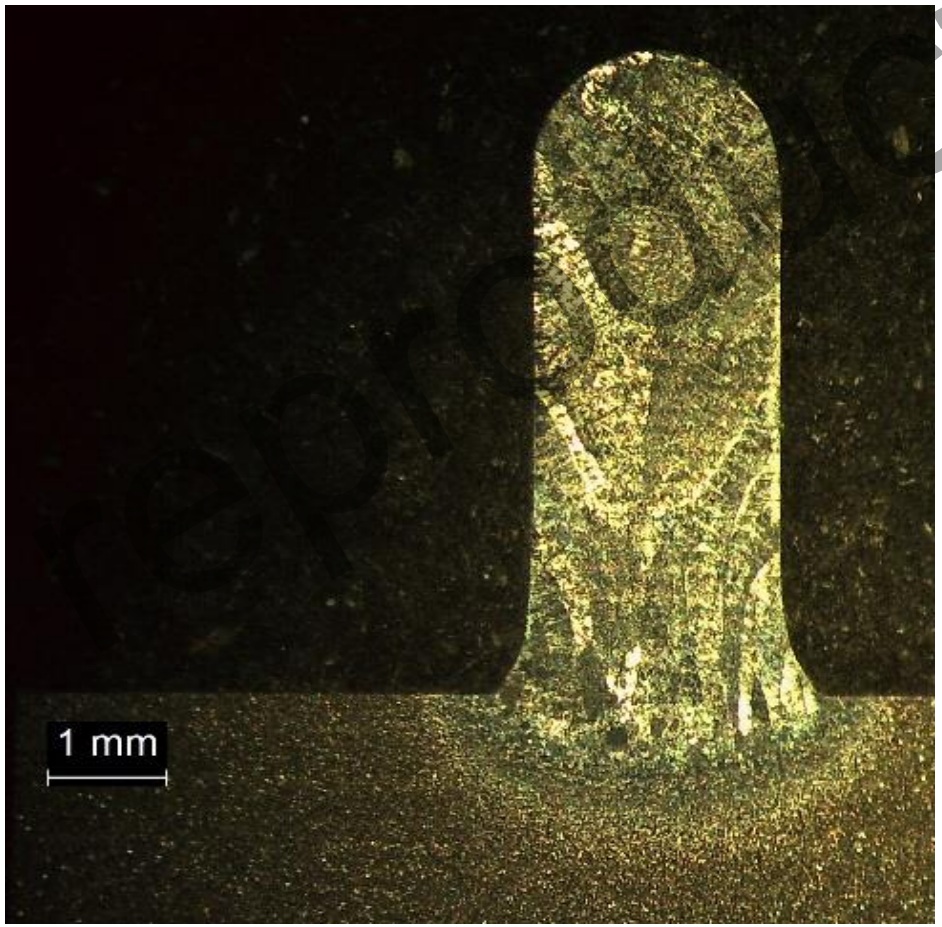



| | |
|---|---|
| Effective Wall Width (mm) | 27.83 |
| Average Layer Height (mm) | 2.71 |
| Wire Configuration | Lead & trail |
| WFS (m/min) | 20 |
| TS (m/min) | 0.8 |
| Deposition Rate (Kg/hr) | 10.63 |
| Number of layer | 10 |
| Number of pass | 3 |

# Net shape deposition - wire + laser AM = WLAM





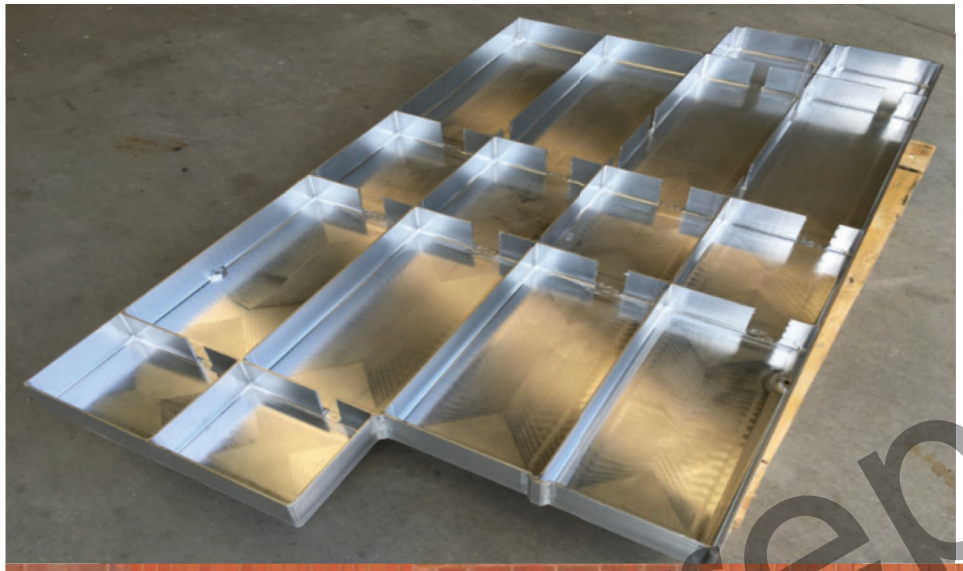



**Net shape precision deposition**

Cold-worked

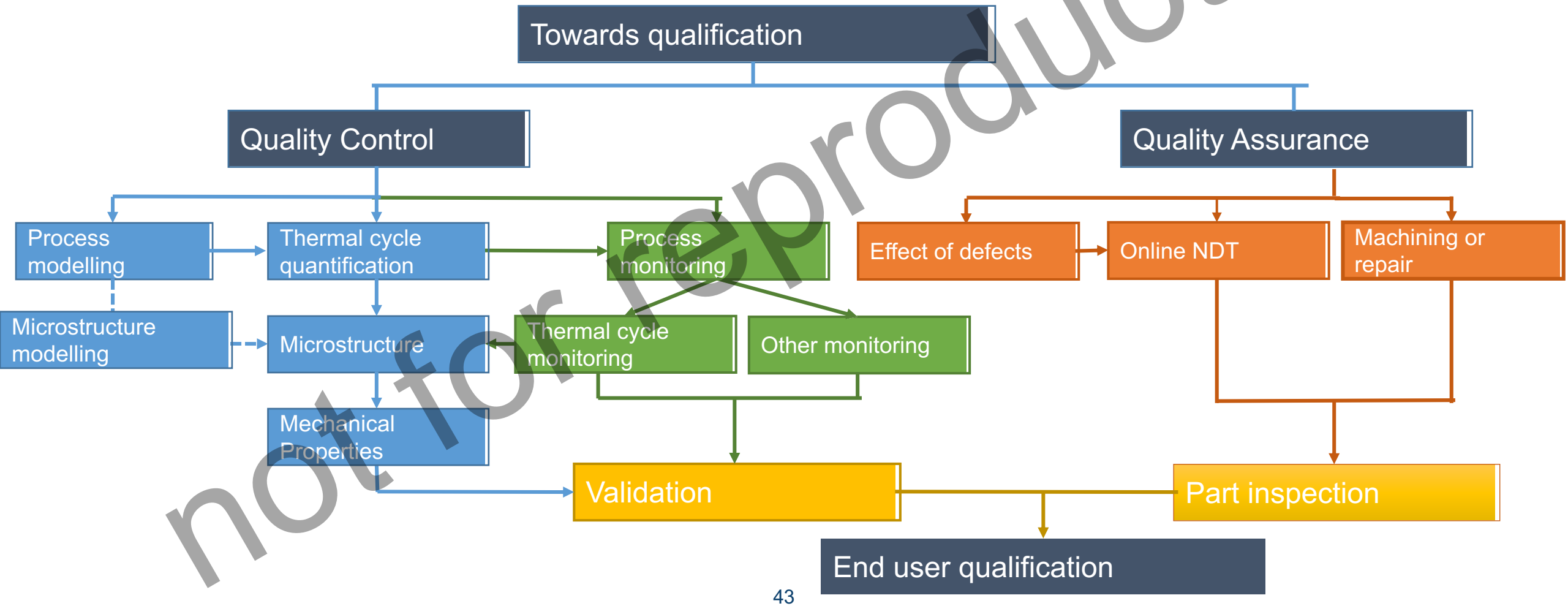
# Large area metal additive - approaches

## Industrial robot



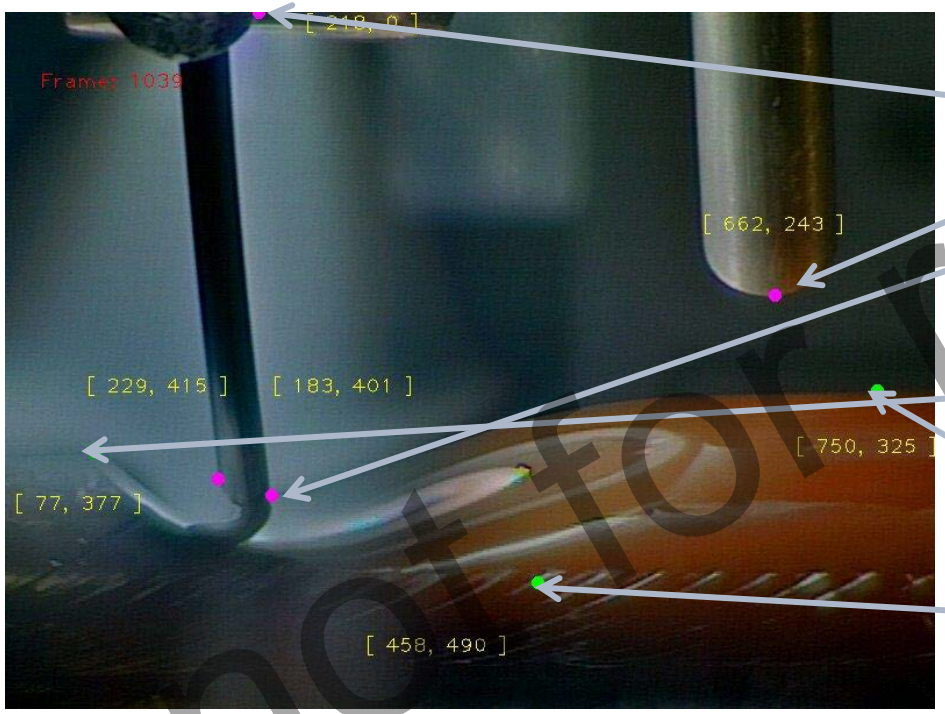
Worlds largest 3D metal printed part

# Q3 project – Quality control and Quality assurance for Qualification



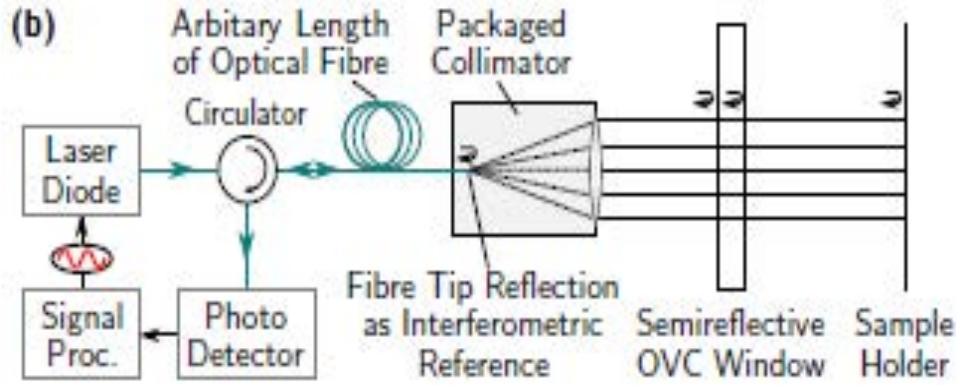
# Process monitoring – process camera

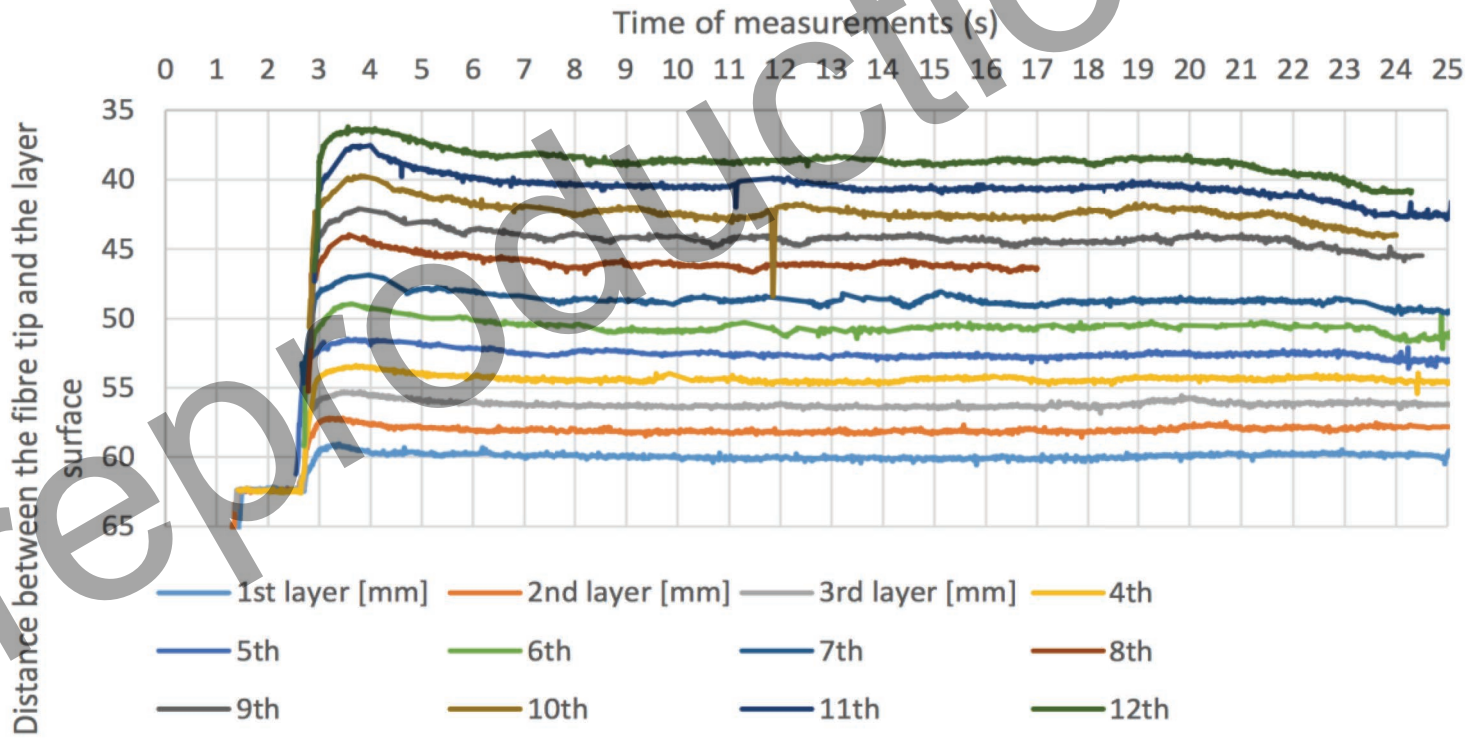
## Image processing

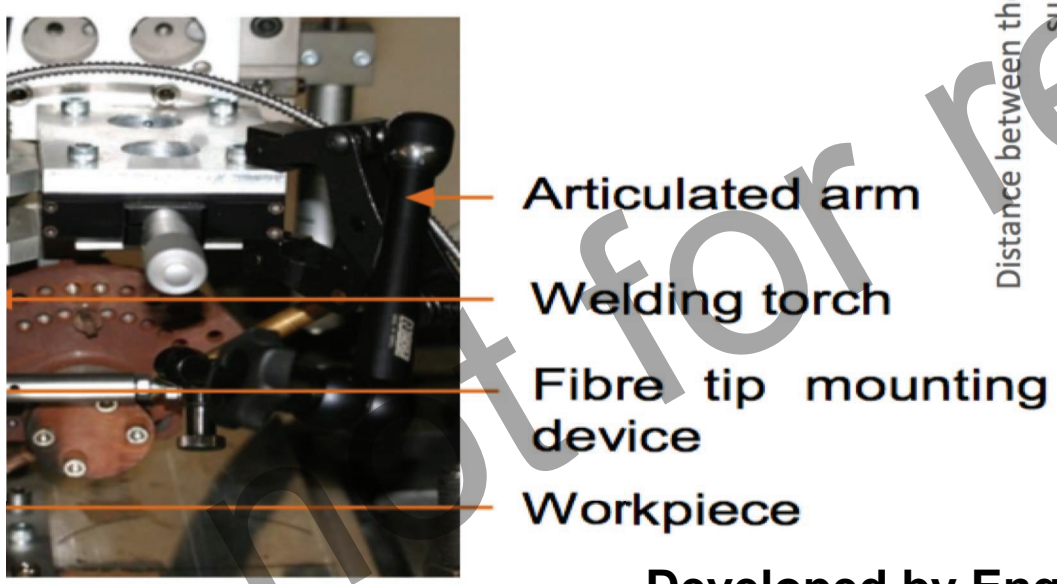


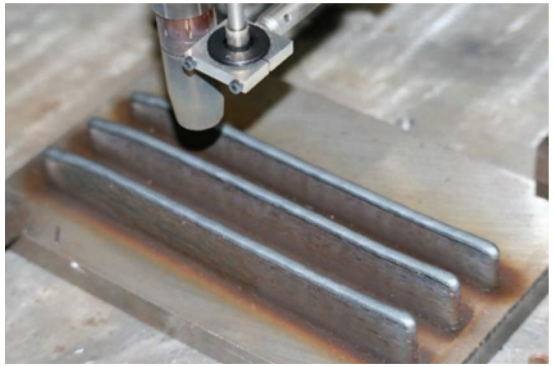

- Solid parts
  - Torch position
  - Reference wire
  - Wire position
- Liquid parts
  - Previous layer height and front of weldpool
  - Deposited layer height and rear of weld pool
  - Weld depth and depression

# Coherent Range Resolved interferometer CORRI - layer height on-line



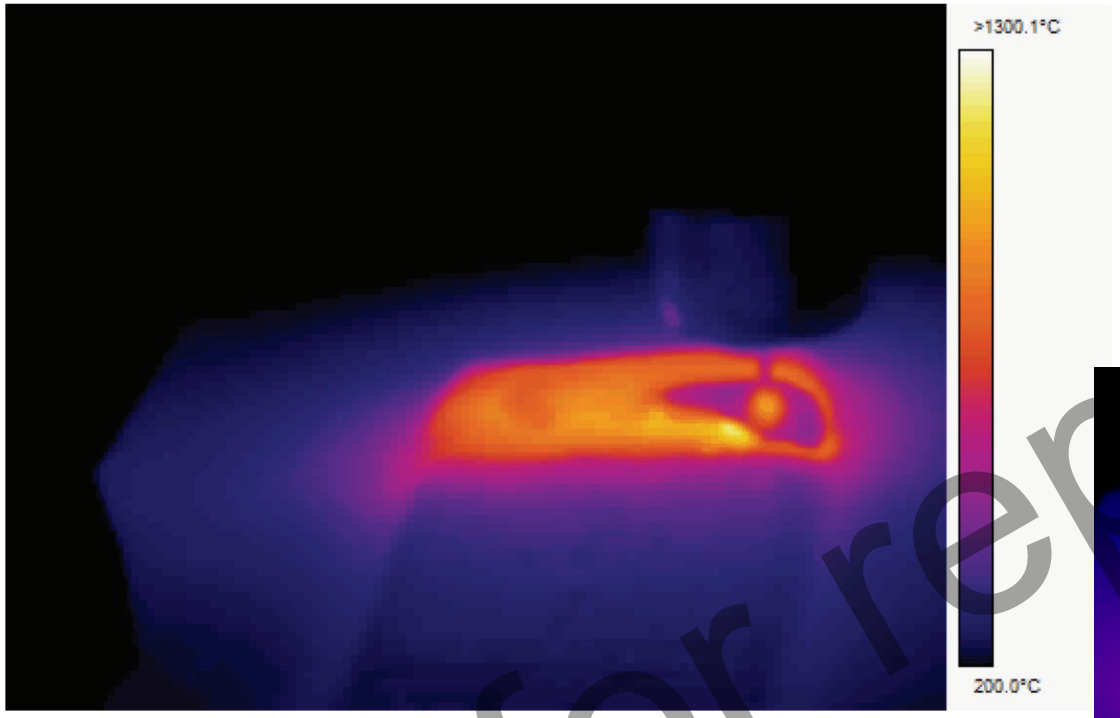



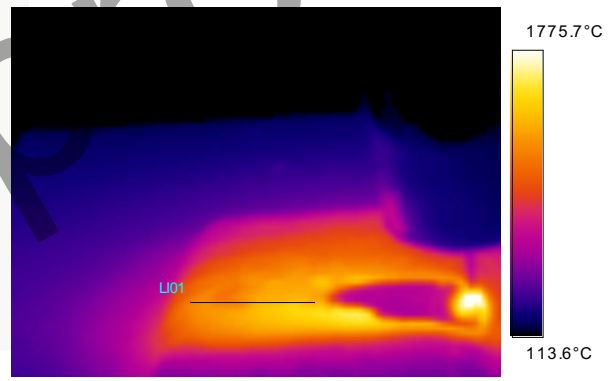



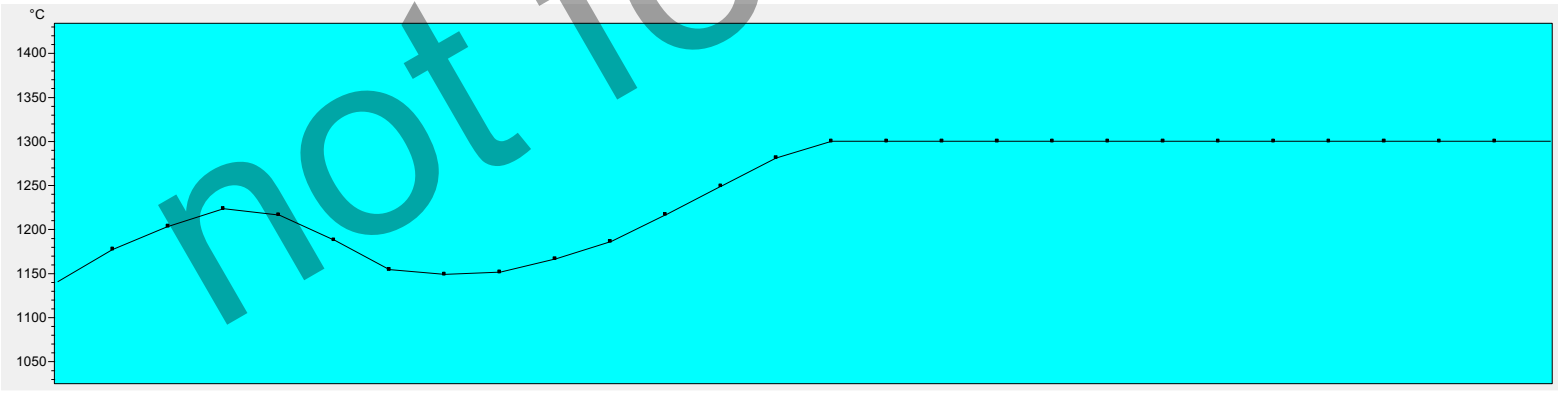



**Developed by Engineering Photonics Group**

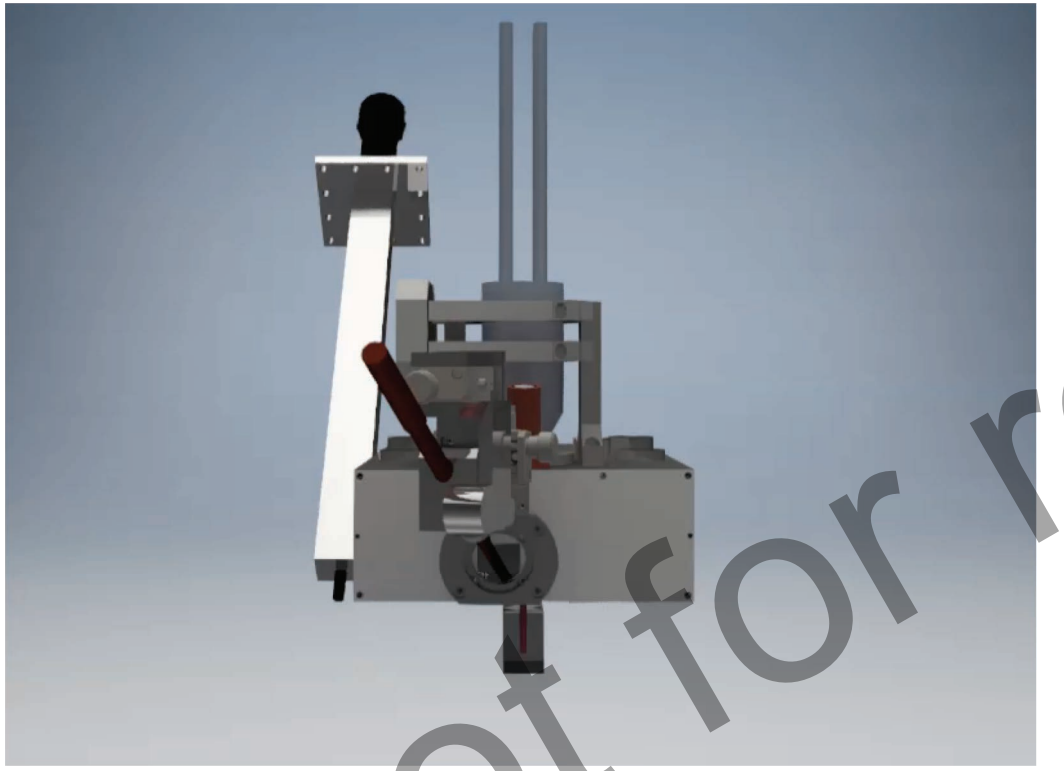
# Process monitoring – IR imaging?

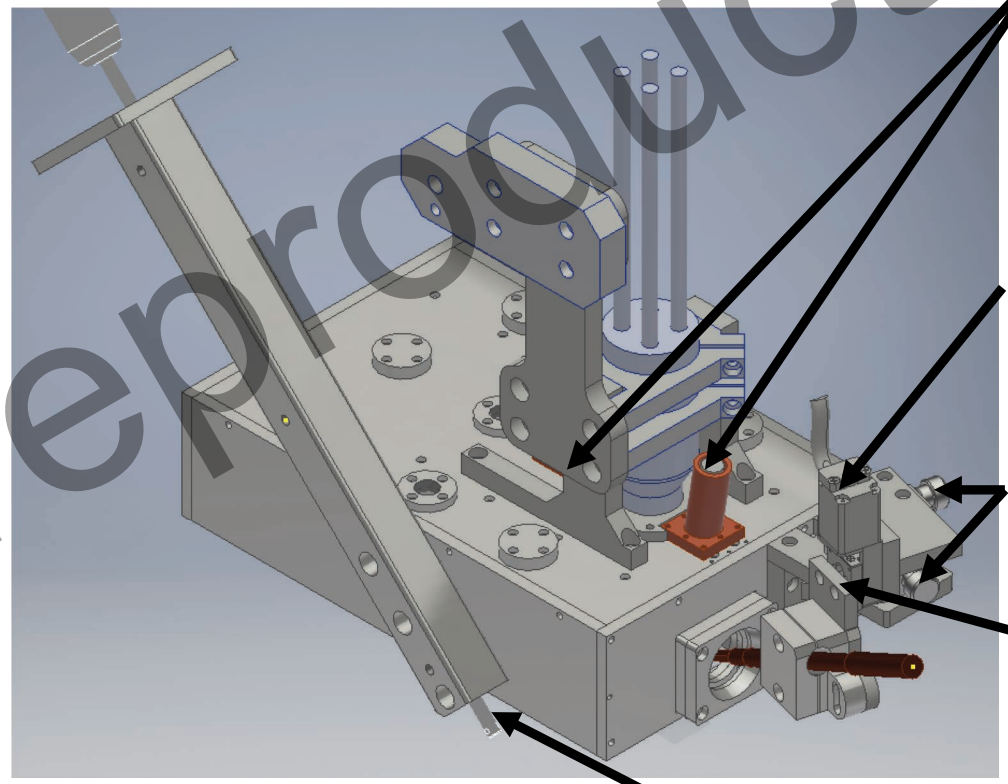


# Local shielding with sensors: WAAMShield





# Challenges: multi process systems


LAMP system

LASIMM system

- **Deposition + deposition**
- **Deposition + cold work**
- **Deposition + metrology**
- **Deposition + NDT**

# NEWAM – Wire based AM programme grant - EPSRC

**Vision:** To transform large area metal additive manufacture by pioneering new high build rate wire based processes with greater precision of shape and microstructure enabling production of net-shape large-scale engineering structures, at low cost.

- EPSRC Programme grant ~£6M + £3M industry support **= £9M**
- Programme duration 5 years
- Programme start date June 25th 2018
- Programme academic partners

| University | Lead Investigator | Programme role |
|---|---|---|
| Cranfield | Williams | Programme lead, process innovation and modelling |
| Manchester | Robson | Materials expertise – characterisation, modelling and design |
| Strathclyde | Pierce | In process NDT |
| Coventry | Zhang | Effects of defects, structural integrity |

# Grand challenges – NEWAM

- The grand challenges for NEWAM are:

  - **New innovative** high build rate metal wire AM processes and systems for net shape deposition at low cost over large volumes with homogeneous microstructure and properties – **target 8kg/hr net shape for Titanium**

  - To build robust **physics-based process and materials' models** that give detailed process understanding, to enable more rapid process development and provide algorithms for **in-process microstructure control**

  - Design of **new materials and alloys**, **tailored** to both existing and new deposition processes, giving performance **better than the equivalent wrought alloys currently used**

  - To ensure guaranteed as-built structural integrity with process-independent **physics-based quality control and assurance** enabling low cost industrial qualification

# 2018: MSc course on Metal AM

## Finally – not forgetting we are supposed to educate as well!

### Academic partners

Cranfield Manufacturing — Wire-based AM processes

University of Birmingham — Powder-based AM processes

Universität Bremen — Modelling and software

Técnico Lisboa — NDT and inspection aspects

### Industry partners

Global Robots Ltd

IREPA LASER

mtc Manufacturing Technology Centre

European Federation for Welding, Joining and Cutting — EWF

### Plans

- Pilot course: Oct 2018
- Full launch: Oct 2019
- Steering council – open to all industry partners – what do you want in this course

Much more information on our website

waammat.com

THANK YOU FOR YOUR ATTENTION ☺

OR CONTACT: Prof Stewart Williams s.williams@cranfield.ac.uk