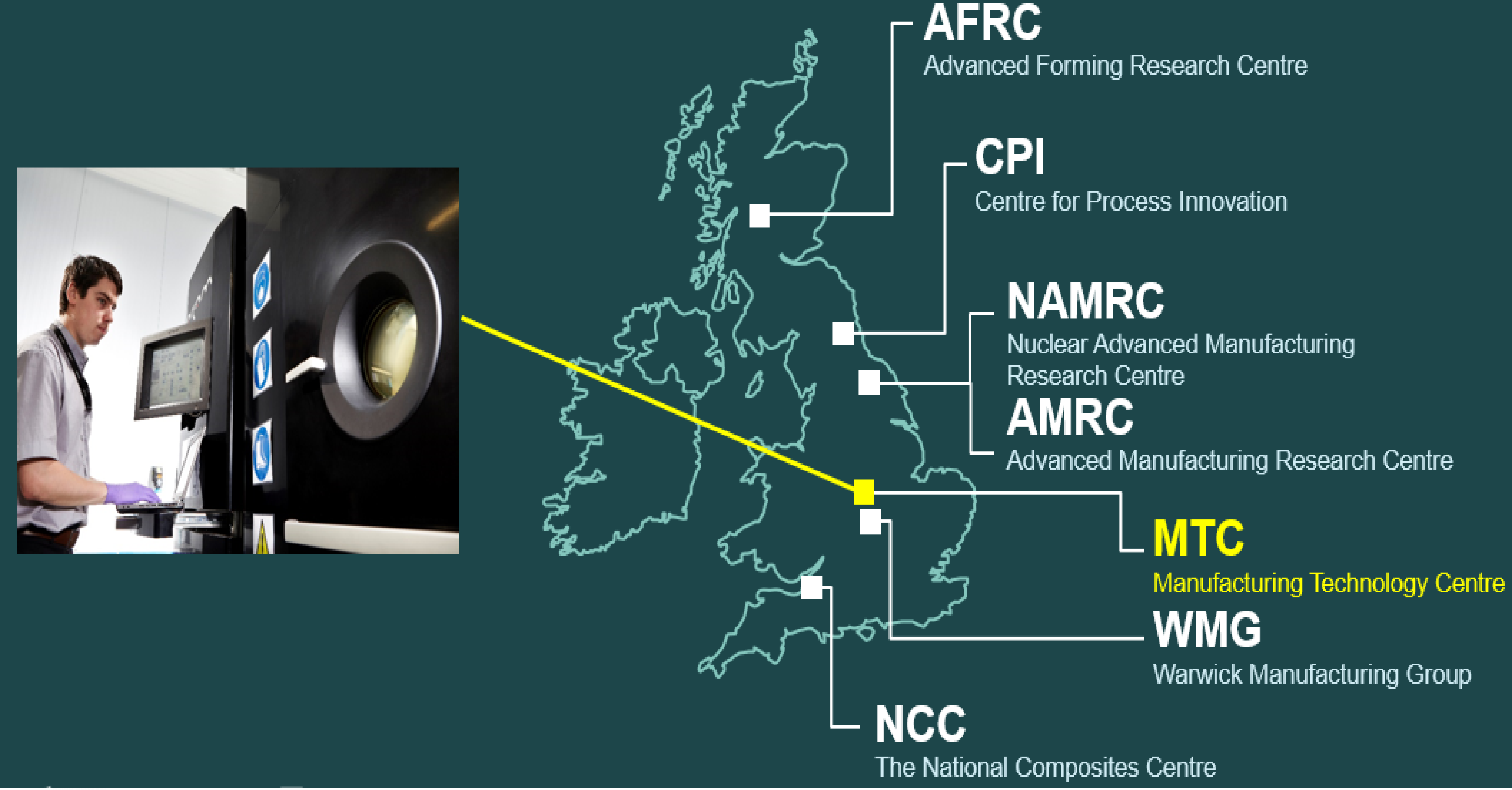
AMAZE

(Additive Manufacturing Aiming Towards Zero Waste and Efficient Production of High –Tech Metal Parts)

Courtesy Renishaw & Thales Alenia


AFRC
Advanced Forming Research Centre
CPI
Centre for Process Innovation
NAMRC
Nuclear Advanced Manufacturing Research Centre
AMRC
Advanced Manufacturing Research Centre
MTC
Manufacturing Technology Centre
WMG
Warwick Manufacturing Group
NCC
The National Composites Centre

Core public funding

For investment in the capabilities, know-how, expertise and skills and long term capital assets of the centre

Business funded R&D contracts

(i.e contract research) won competitively

Collaborative (applied) R&D projects

Funded jointly by the public and private sector, won competitively

ENCOMPASS

Duration: 3 years
Value: €4m

Call: H2020 FoF13 – 2016
Photonics Laser-based production

Principally aims to create a fully digital integrated design decision support (IDDS) system to cover the whole manufacturing chain for a laser powder bed fusion (L-PBF) process encompassing all individual processes within in. The ENCOMPASS concept takes a comprehensive view of the L-PBF process chain through synergising and optimising the key stages. The integration at digital level enables numerous synergies between the steps in the process chain and in addition, the steps themselves are being optimised to improve the capability and efficiency of the overall manufacturing chain.

OPENHYBRID

Duration: 3 years
Value: €6.5m

Call: H2020 FoF1 – 2016
Novel hybrid approaches for additive and subtractive manufacturing machines

Overcome the technical and commercial barriers of current hybrid manufacturing systems to deliver a single manufacturing system capable of undertaking a wider range of processes in a seamless automated operation. The new system will offer unrivalled flexibility in terms of materials, including the ability to switch between powder and wire feed-stock within a single part. Moreover the process can be fitted to a diverse range of platform to produce parts from 2cm to 20m in length. The capability of the OPENHYBRID approach will be validated through the production of industrial demonstrators from the power generation, automotive and mining equipment sectors.

EWIRA

Duration: 6 years
Value: €11m

External **W**ing **I**ntegration for **R**egional **A**ircraft Demonstrator

Call: H2020-CS2-CPW02-2015-01 – Wing Integration Regional Demonstrator Flying Test Bed #2

Investigate and develop innovative and market acceptable solutions for an advanced electric wing with the aim to achieve TRL6 and obtain experience for long-term operational demonstration in a real aircraft environment.

Core Partners of Clean Sky 2

AMAZE

Duration: 4.5 years
Value: €18m

Additive **M**anufacturing **A**iming Towards **Z**ero Waste and **E**fficient Production of High–Tech Metal Parts

Call: FP7 (FoF-NMP.2012-4 high performance manufacturing technologies in terms of efficiency)

Develop and demonstrate metal AM process chains for industrial production (focusing on PBF and DED)
- Robust AM process chain for small to large parts
- Industrial scale parts which have been tested
- Demonstration AM production factories

ALMER

Duration: 3 years
Value: £1.2m

Advanced **L**aser-additive layer **M**anufacture for **E**missions **R**eduction

Call: Highly Innovative Technology Enablers for Aerospace 2 (HITEA2)

Capitalise on the rapidly emerging technology of Powder Bed Direct Laser Deposition (PBDLD). This technology will enable conceptual design freedoms not available to conventional methods used for the manufacture of aerospace Combustion components. Advanced cooling technologies and lighter components will be manufactured using PBDLD. To achieve this, a consortium of companies of varying sizes, research organisations and academic Institutions will deliver material data for categorisation in known high temperature alloys, which will enable components to be designed and validated for use. Software is also being developed as part of this program, to exploit this manufacturing technology for the design of components with minimum weight, whilst retaining the desired strength and functionality. This work will ensure that the UK remains at the leading edge of PBDLD, and is able to exploit the benefits in terms of reduced emissions. This will enable compliance with ever increasingly stringent aerospace legislation.

ANVIL

Duration: 3 years
Value: £0.9m

Forging the standards which will shape the UK's AM sector

Call: Inspiring new design freedoms in additive manufacturing / 3D printing

A major challenge for industry is to understand the true capability of the new techniques - especially making comparisons between machine platforms. The ANVIL project will overcome this issue, by bringing together key end-user sectors and AM experts to develop a standard way of assessing the capability of metal powder bed fusion processes. This approach will be used to compare the latest machines and the information generated will form the basis of an interactive design for AM guide. Application demonstrators will be designed using this guide and manufactured to provide case studies for promoting the effective use of AM technology.

AMAZE Overview

- Largest and most ambitious metal AM research project in Europe
- €18m from EUFP 7 and industry
- 4.5 year long project concludes June 2017
- 26 organisations across Europe
  - Research organisations at the forefront of AM technology
  - World leading end-users from aerospace, space, automotive and nuclear sectors

The Partnership….

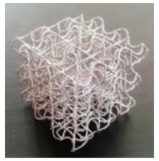
AMAZE Objectives

- Produce large AM metallic components
- Increase in process productivity
- Reduce defects/scrap levels
- Reduce the cost of finishing parts
- Improve in-process and ex-situ inspection methods

Links between different AMAZE activities

Design, materials & process development

Exploratory Research
(Materials, process, simulation & design)



Demonstration Part production & Testing

AM Factories

Project Scope

Project structured to address all of the critical aspects required to develop a robust end-to-end AM process chain;

- Part design for AM
- Materials development and testing
- High productivity AM process development
- Process modelling
- Process monitoring and control
- Part finishing
- In-situ and ex-situ Inspection methods
- Developing integrated and streamlined AM factory solutions
- Demonstration part production

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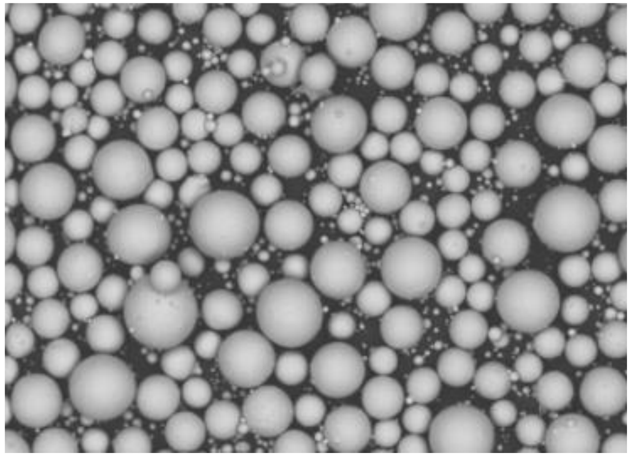
Materials Testing

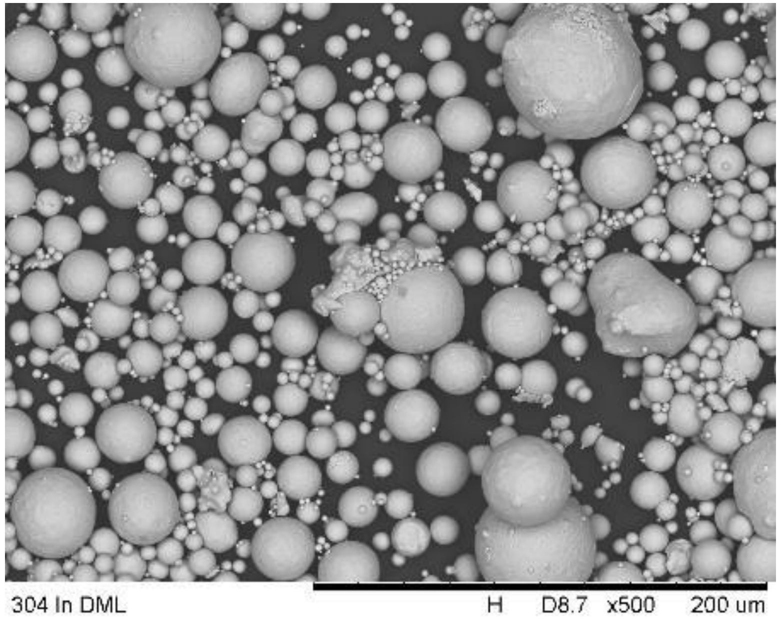
- Development of AM material specifications for powder & wire
- Assessment and selection of feed-stock suppliers
- Testing of all material used in the project

Powder Testing

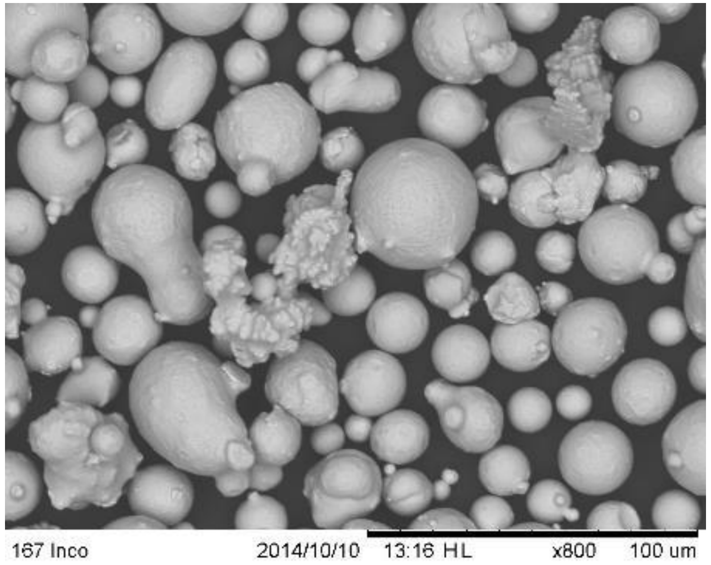


Particulate Properties	**Chemical Properties**	**Bulk Properties**
Morphology	Main elemental composition	Packing Density (apparent, tapped)
Surface texture	Interstitial composition	Hall flow rate
Particle size distribution		Dynamic flow
Specific surface area		Shear properties

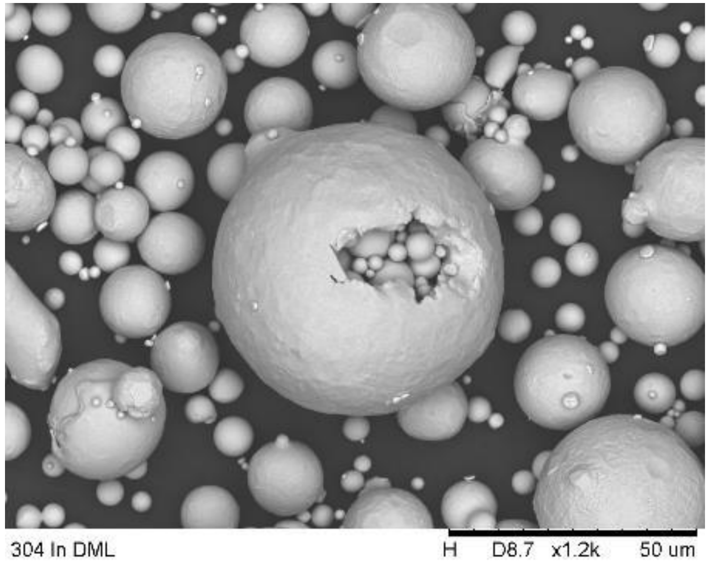
New Powder Quality



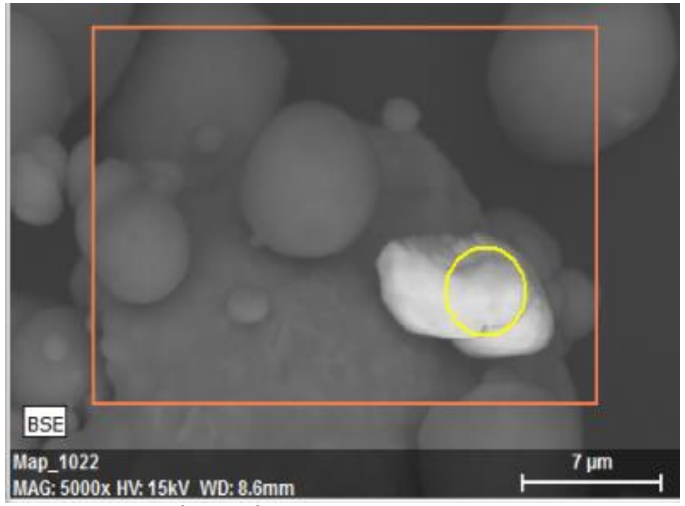
Excessive amount of fines (<15microns)



Poor powder morphology

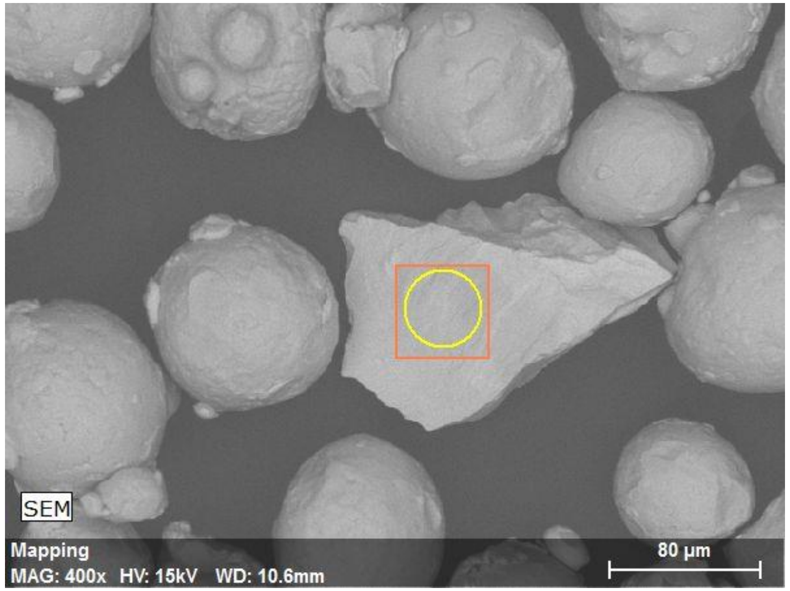


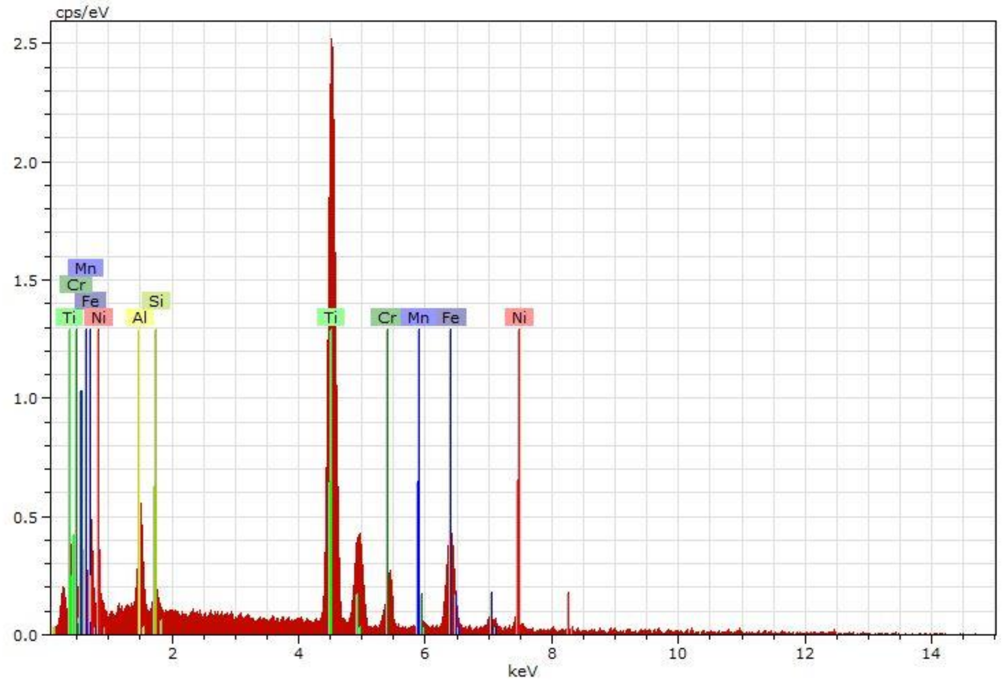
Porous/shell particles

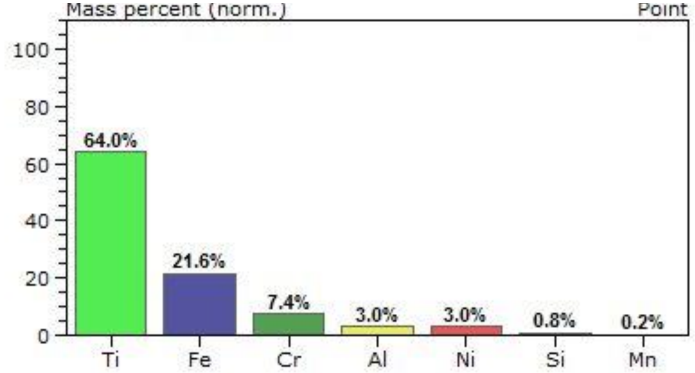


Contamination

Contamination when powder is reused







EDS shows this irregular particle is Fe-based powder, containing Ti, Cr, Ni, Al, Si, and Mn
(stainless steel?)

Increasing the capability of AM processes

Contributors: Airbus Group, Renishaw, Concept Laser, FhG-ILT, Trumpf, Irepa Laser, Norsk Titanium, Tecnalia, Manchester University, Birmingham University, The Manufacturing Technology Centre.

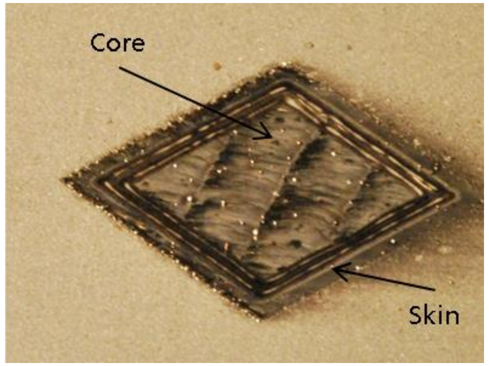
4 Primary Objectives

1. Increase the build rate of the AM process
2. Extend the part size and complexity
3. Improve part quality / reduce the level of scrap
4. Widening the range of proven materials

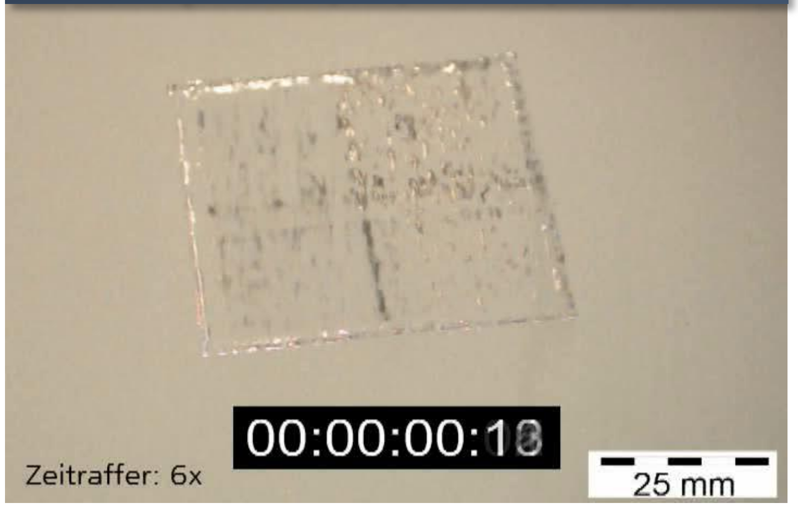
AMAZE

Fraunhofer-ILT

- Focus on **hull and core** build strategy
  - High power laser to fuse core
  - Low power laser to fuse edges
- Study effect of this approach on
  - Mechanical properties
  - Microstructure/density
  - Accuracy/surface finish
  - Build rate improvement
- Trials undertaken using In718

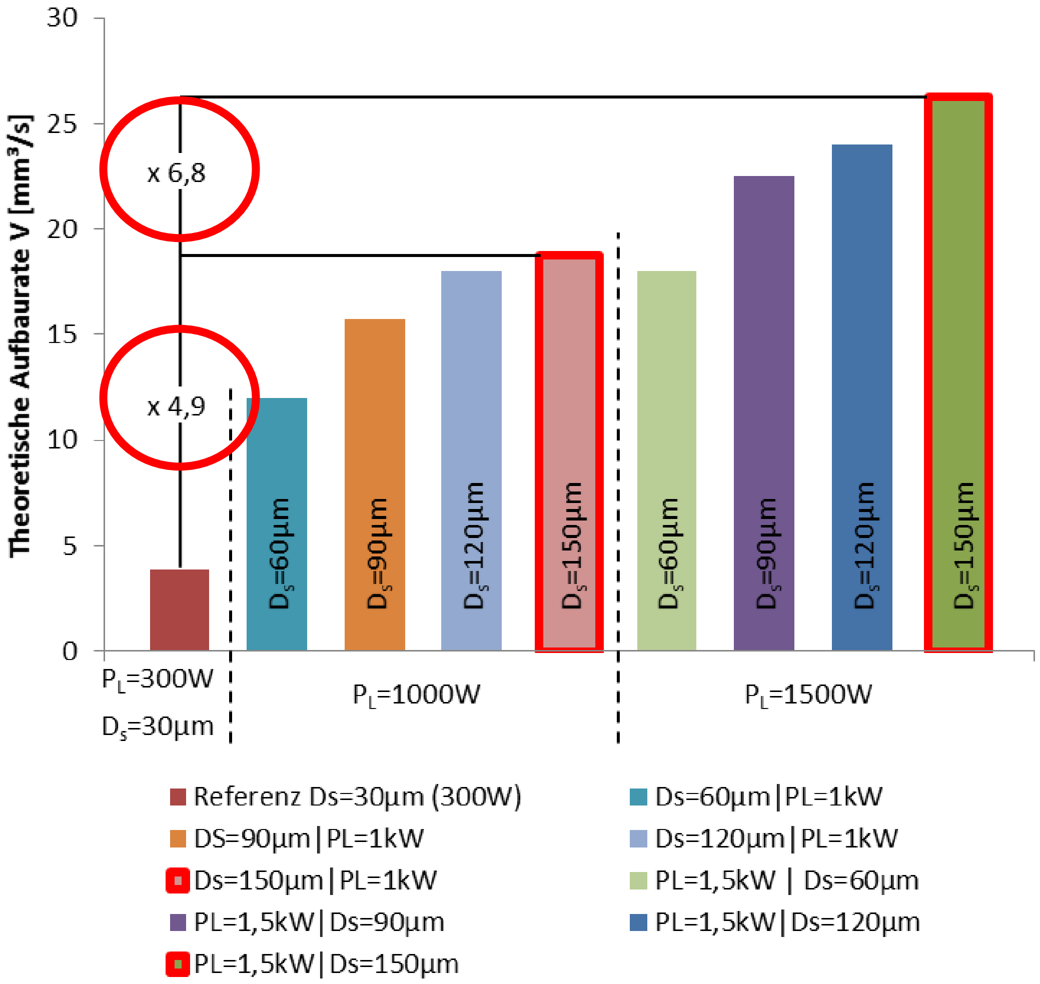


High Power SLM process (skin-core)
P_L = 400W (skin) 1000 W (core)



Process Development
Layer Thickness / Laser Thickness

- **Process parameter:**
  - Laser power: P_L=1-1,5kW
  - Hatch distance: Δy_s=500µm
  - Layer thickness: D_s=60-150µm
- **Results:**
  - P_L=300W: V_{th}= 3,84mm³/s
  - P_L=1kW: V_{th}= 18,75mm³/s
  - P_L=1,5kW: V_{th}= 26,25mm³/s



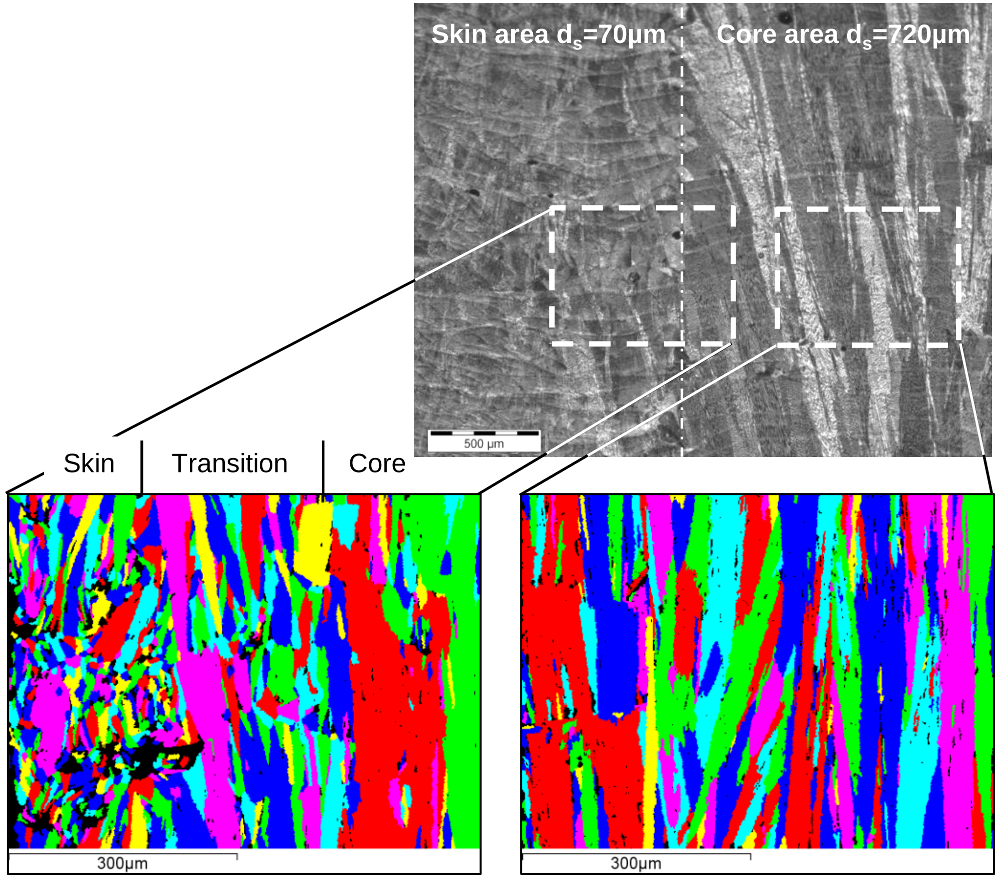
Microstructure

Process parameter:

- SLM 280HL: d_{s1}≈70µm (Gaussian)
  d_{s2}≈720µm (Top-hat)
- Laser power: P_{L1}=300W | P_{L2}=1000W
- Layer thickness: D_{s1}=30µm|D_{s2}=90µm

EBSD analysis:

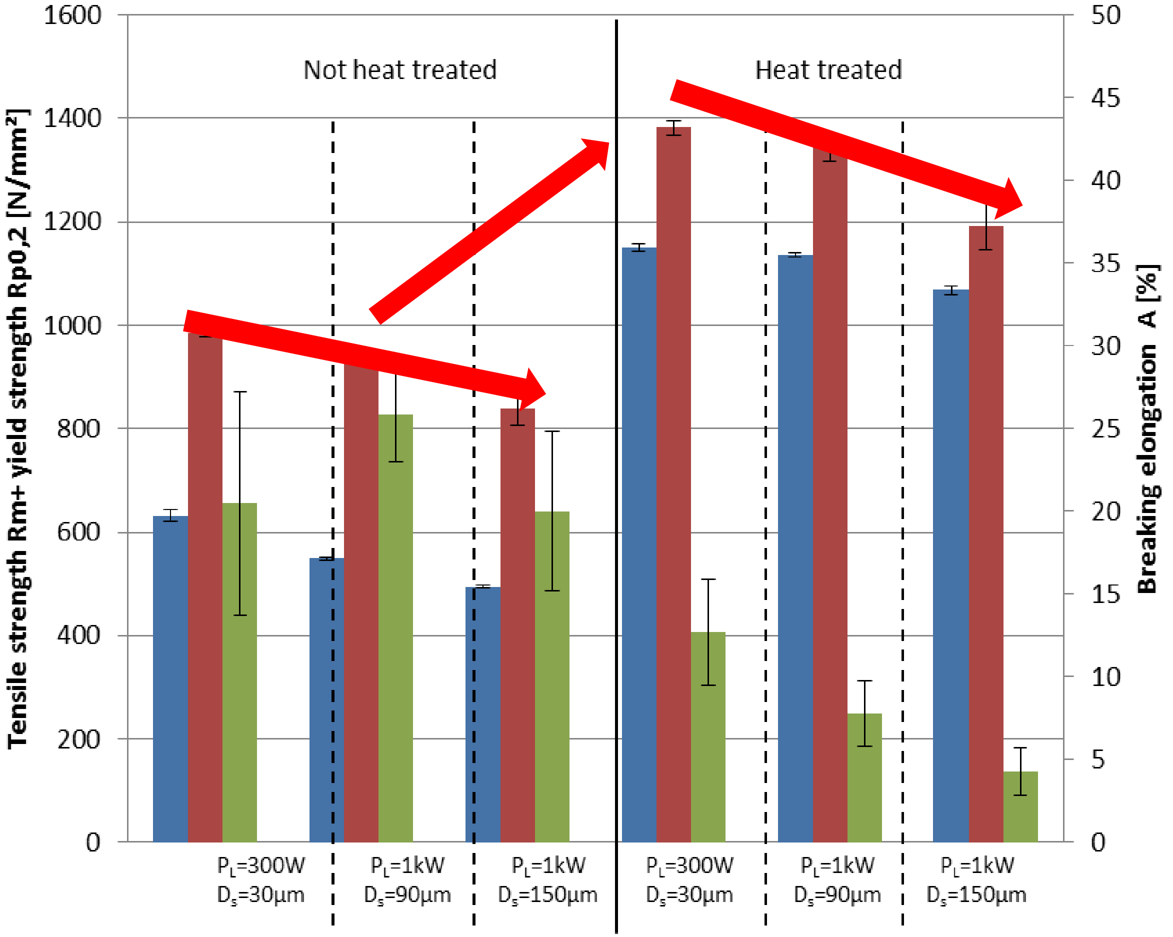
- Skin area:
  - Fine grains do not have a preferred orientation
- Core area:
  - Very long grains strongly oriented in build-up direction



No evidence of defects between skin and core but change in microstructure

Mechanical properties (tensile test static load)

- **Specimens manufactured with P_L=1kW at D_s=90µm**
- **Heat treatment:**
  - AMS 5662 + Hipping
  1. Hipping: T=965°C | t=1h | p=2000bar
  2. Solution annealing: T=980°C | t=1h
  3. Aging: T=720°C | t=8h
  4. Aging: T=620°C | t=8h
- **Results:**
  - Conventionally Manufactured reference matched by R_m and $R_{p0,2}$
  - Breaking elongation is reached for parameter set 1 (standard SLM) and parameter set



Machine improvement and optimization

- New lasers installed (500W fiber and 2kW diode)
- Accuracy
- 5 axis control
- Inert gas running with extra low O2 level
- Integration of sensors on the CLAD® head

- 5 axis : *XYZ + BC (continuous 5 axis)*
- 3D working space : *1500x840x800 mm3*
- *Max load : 300kg*
- Gas enclosure :

  Volume : ≈ $12m^3$

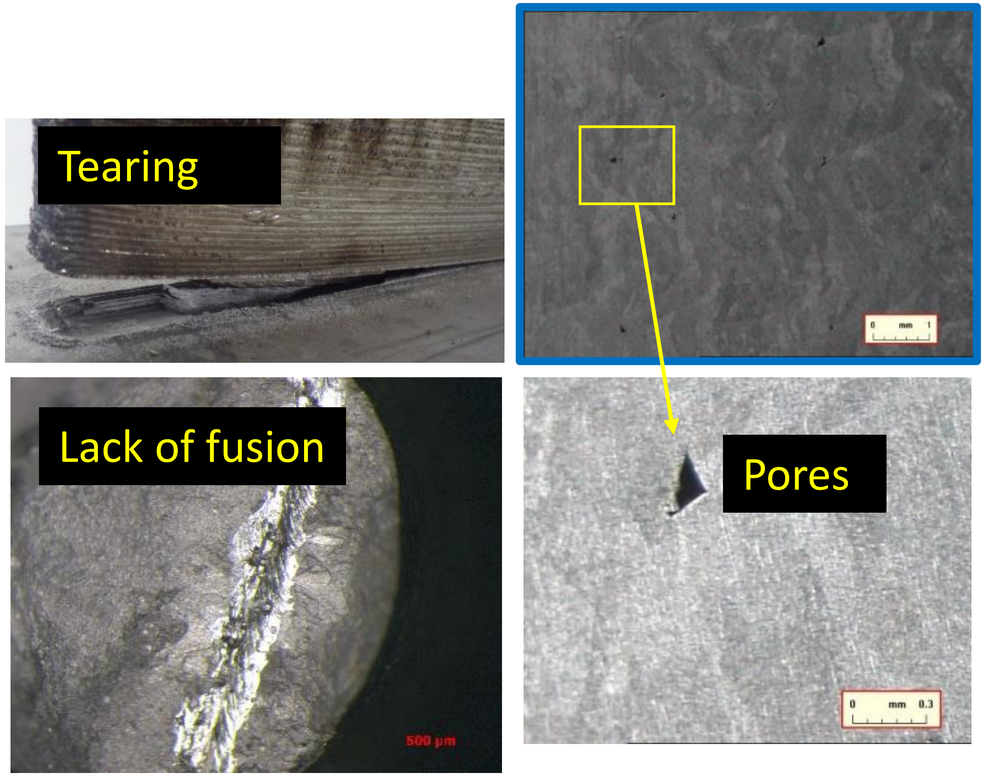
  O2<20ppm, H2O<30ppm automatic gas purification

Deposition head improvements

- Improvements
  - Process robustness (enable longer deposition times)
  - Increased deposition rate and efficiency
- New design for the nozzle
  - Thermal resistance enhancement
  - Better cooling
- Performance
  - 2kw laser power
  - Wall width 2.3mm
  - 100-150cm^3/h

MacroCLAD nozzle 24Vx

Improved part quality

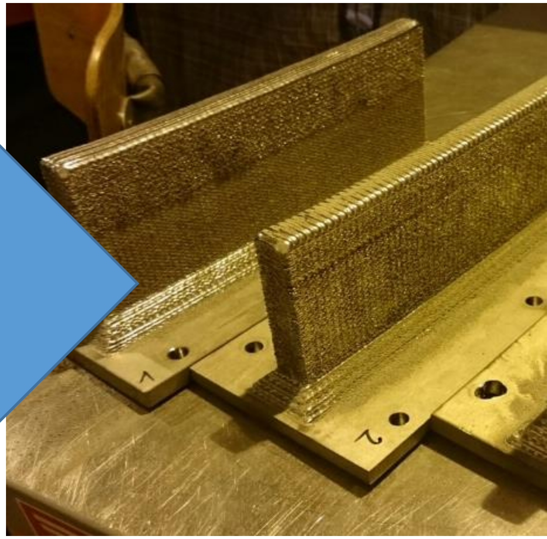


Optimised Parameters

Parameters	
Laser power	1800 W
velocity	2m/min
Contour velocity	No contour
Powder flowrate	12.4g/min
Track height	0,75mm
Track width	2,5mm
Overlap	30%

Powder catchment efficiency	
Effective PCE	72 %

Building rate	
Effective building rate	136 cm3/h

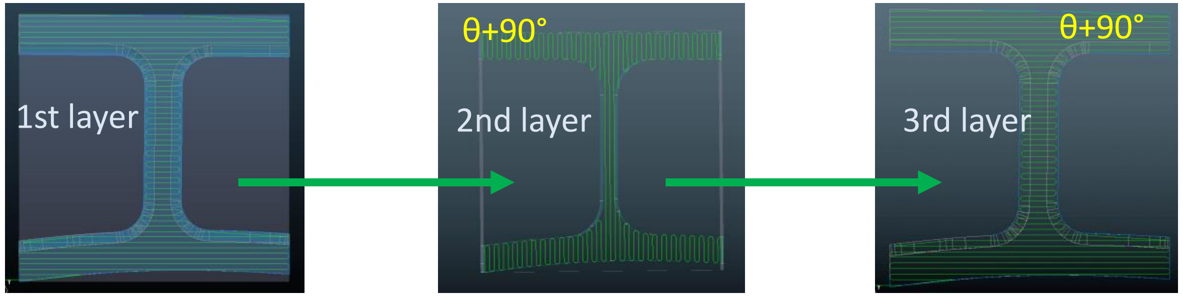


Deposition strategy optimization

Multiple deposition strategies tested:

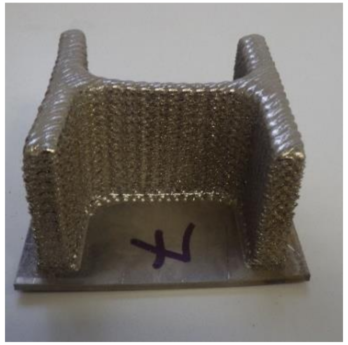
- Raster rotation/layer :
  → 180°, 90°, 45° and 113°
- With and without contour

Selected deposition strategy : <u>Raster rotation/layer : 90°</u>



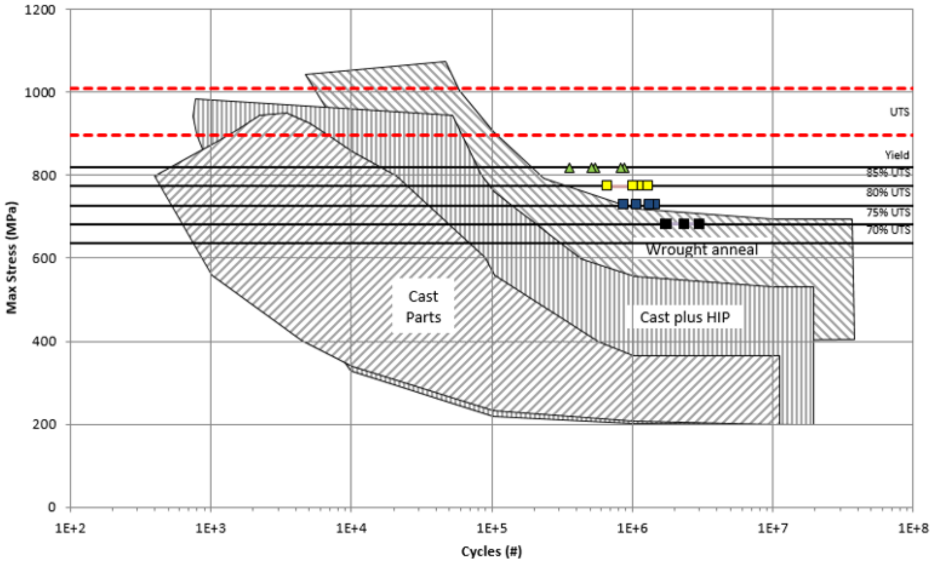
- **Pros :**
  - Lower risk of lack of fusion
  - Lower distortion
- **Cons :**
  - Roughness → thicker material allowance >1mm

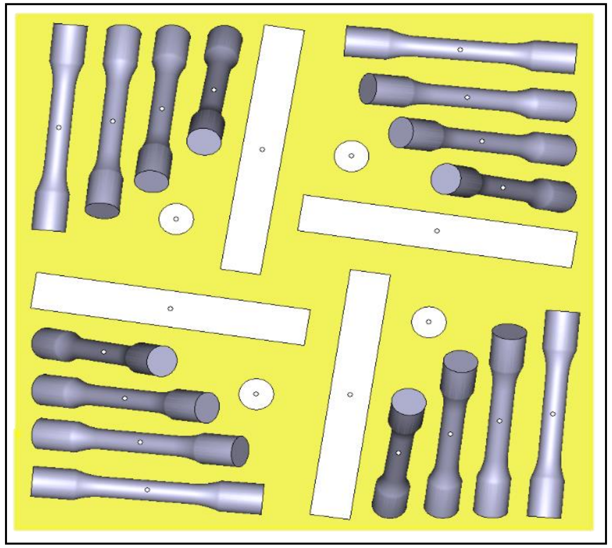
Deposition strategy	Raster rotation/layer: 90°
Time (min)	104
Deposited volume (cm^3)	171,6
Build up rate (cm^3/h)	99,0
Powder catch. efficiency (%)	58,9



Material Property Testing

- Comprehensive mechanical property test campaign
  - Static tensile
  - Fatigue (LCF, FCGR)
- Wide range of processes and materials
- Different build orientations, heat treatments etc.
- Full traceability





Coordinated by Bombardier

Results uploaded to AMAZE database

AMAZE Database

- AMAZE Database was designed by Granta
- Data from the entire AMAZE project has been uploaded included;
  - Material testing methods and results
  - Specimen production parameters
  - Mechanical properties
  - Inspection (metrology and integrity)
  - Process performance data
  - Part design data
  - Demonstration part design and manufacture….
- We hope to maintain and build upon this database for the future

Sorry but this is only a very brief taste of the AMAZE project

Enough data generated to present for a week!

AMAZE Project Technology Forum 2017

Building Confidence in Additive Manufacturing

http://amazeproject.eu/

INDUSTRIAL FORUM

Design principles
Feed stock characterisation and control
Increasing the capability of AM processes
Adaptronics, in-situ sensors, NDT and metrology
Automated post-processing
Pilot scale factories

RESEARCH FORUM
Session 1:

Microstructural control of Ti and Al alloys and large-scale deposition of refractories
Laser powder bed fusion of aluminium based materials
In operando study of laser-powder interaction by synchrotron X-ray imaging
Selective laser melting of refractory metals
Selective laser melting of low CTE alloys
Selective electron beam melting of auxetic lattice structures and pure copper

DEMONSTRATOR COMPONENTS

Sun sensor and antenna support
Manufacture and evaluation of an engine nacelle hinge
Industrial ventilator blade
Additive manufacturing and laser polishing of an IN718 pylon
Modelling of AM processes

RESEARCH FORUM
Session 2:

Modelling of powder bed laser fusion with measured material properties
Additive manufacture for fusion power plant components
Microstructure and mechanical properties of additively manufactured metallic structures
Selective laser melting of Invar

Wednesday 7th June 2017

MTC Advanced Manufacturing Training Centre

All of this is summarised in the AMAZE Booklet

AM research is a marathon not a sprint ..

To keep Europe leading the world in metal AM we have to keep running

Questions ?