

AMAZE

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



Courtesy Renishaw & Thales Alenia



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

PHOTONICS PUBLIC PRIVATE PARTNERSHIP

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

Factories of the Future
Public Private Partnership

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

Clean Sky 2

External Wing Integration for Regional Aircraft 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


SEVENTH FRAMEWORK PROGRAMME

Additive Manufacturing Aiming Towards Zero Waste and Efficient 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

Innovate UK

Advanced Laser-additive layer Manufacture for Emissions Reduction
Call: Highly Innovative Technology Enablers for Aerospace 2 (HITEA2)
Capitalise on the rapidly emerging technology of Powder Bed Direct Laser Deposition (PBDD). 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 PBDD. 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 PBDD, 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

Innovate UK

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.




analysis & design software for engineers

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....



UNIVERSITY OF
BIRMINGHAM



TRUMPF



BAE SYSTEMS



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

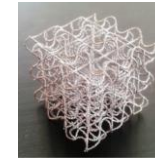


Links between different AMAZE activities

Design, materials & process development



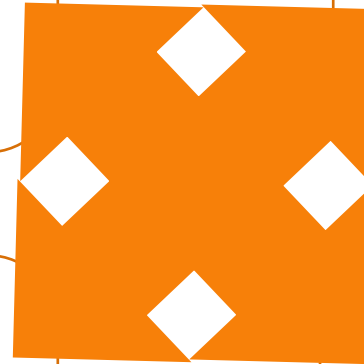
Exploratory Research
(Materials, process, simulation & design)



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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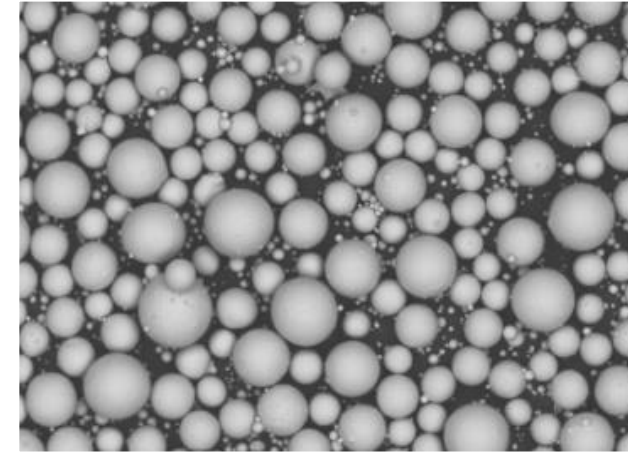


Materials Testing

- 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

Morphology

Surface texture

Particle size
distribution

Specific surface area

CHEMICAL PROPERTIES

Main elemental
composition

Interstitial
composition

BULK PROPERTIES

Packing Density
(apparent, tapped)

Hall flow rate

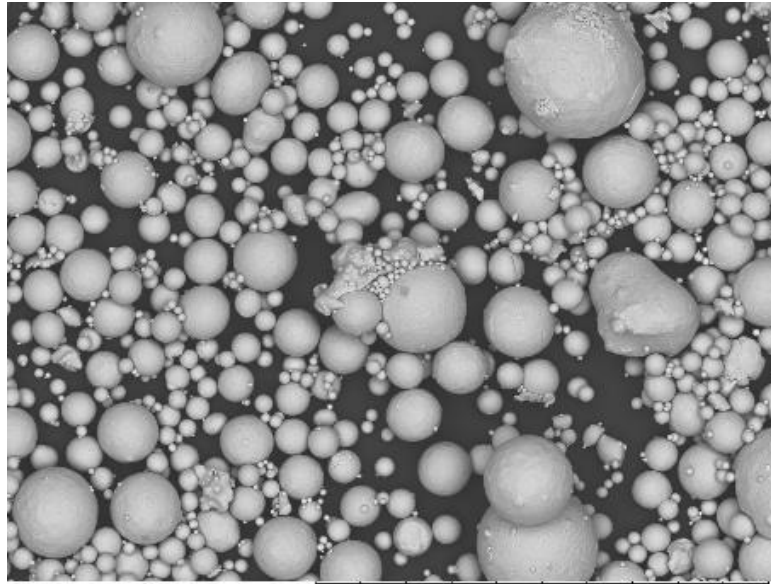
Dynamic flow

Shear properties

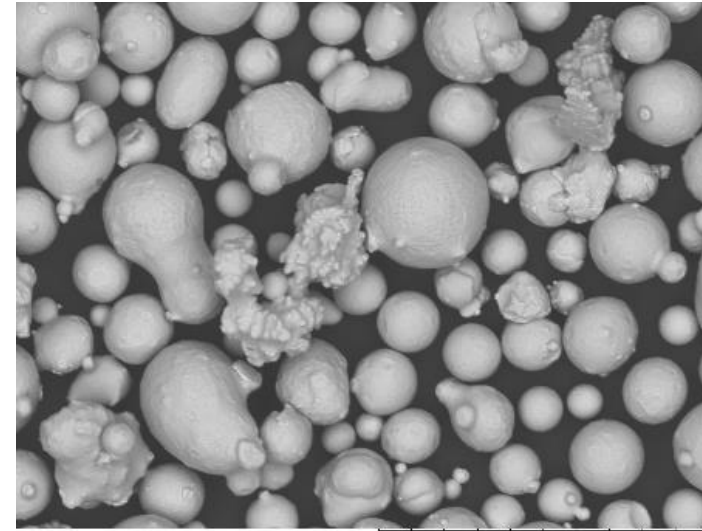
AMAZE



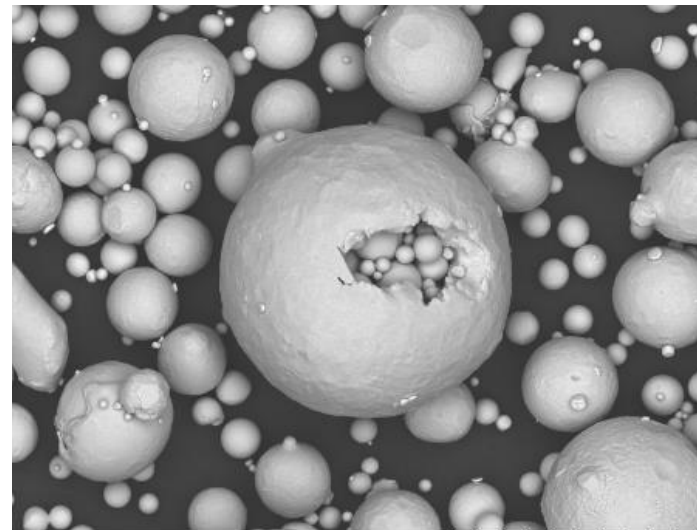
New Powder Quality



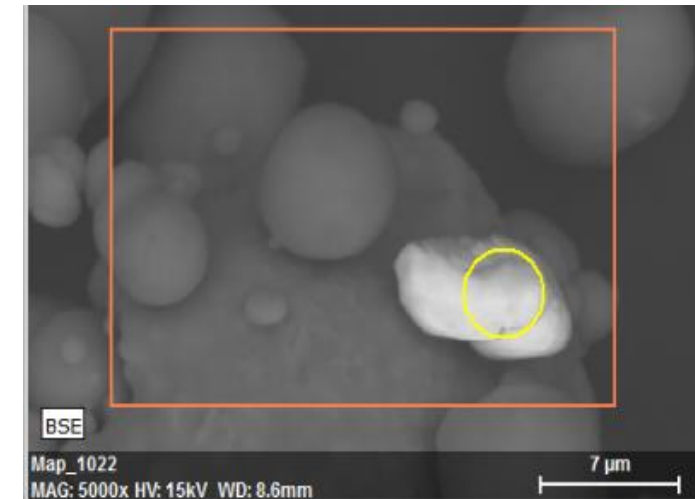
Excessive amount of fines
($<15\mu\text{m}$)



Poor powder
morphology



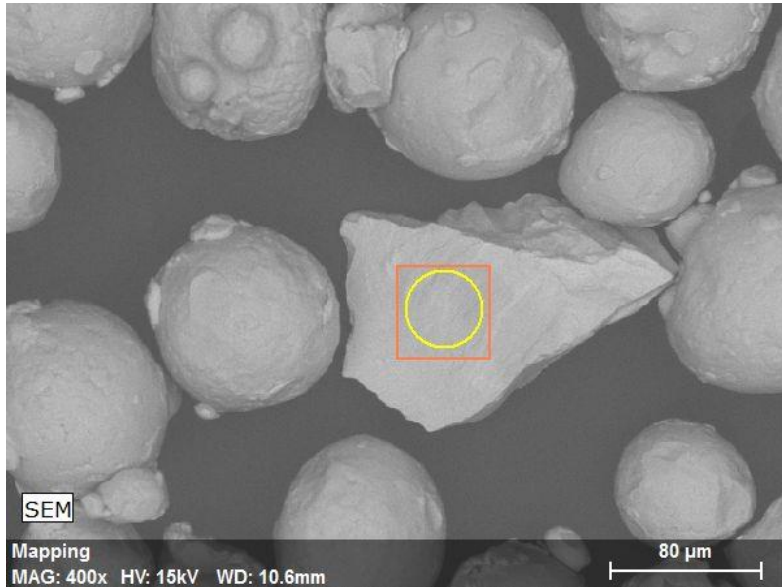
Porous/shell particles



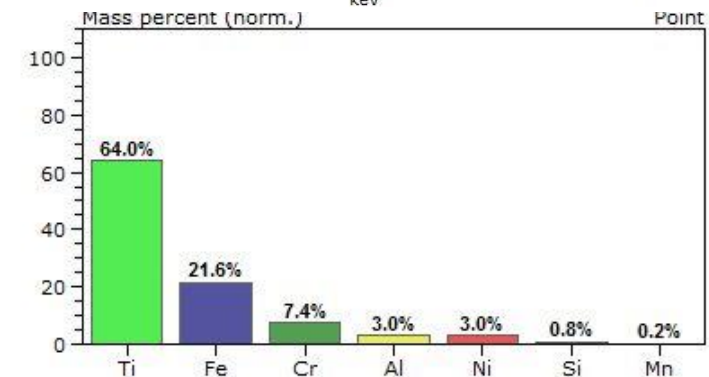
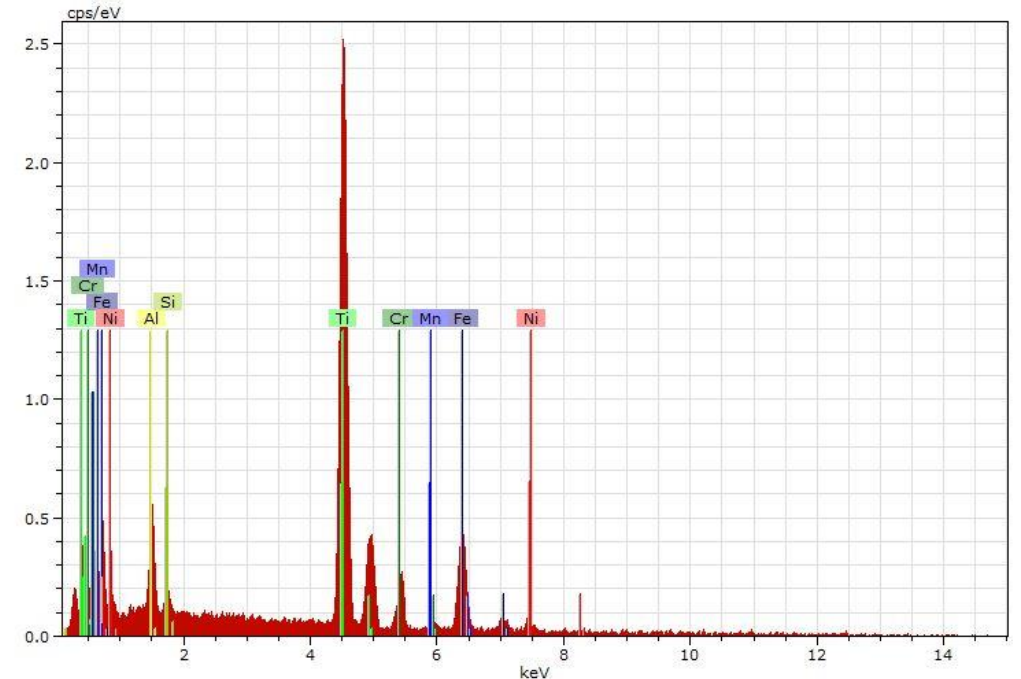
Contamination



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

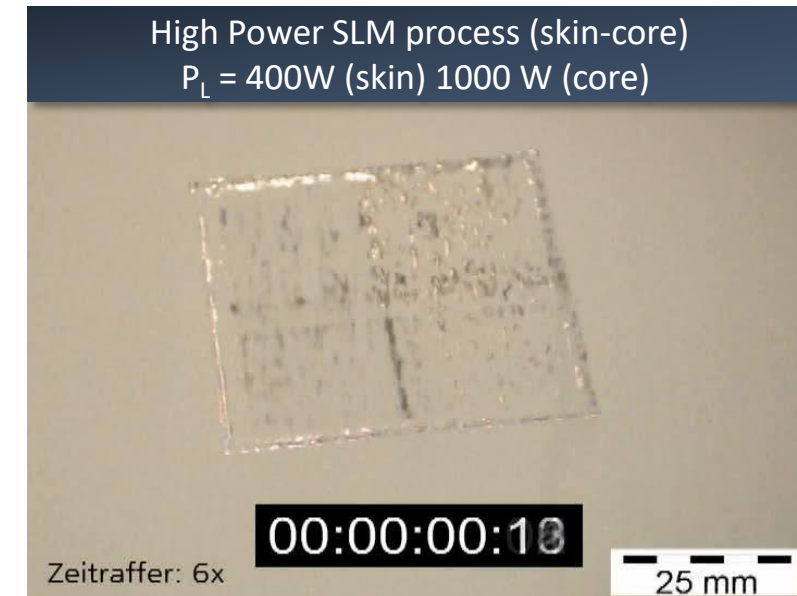
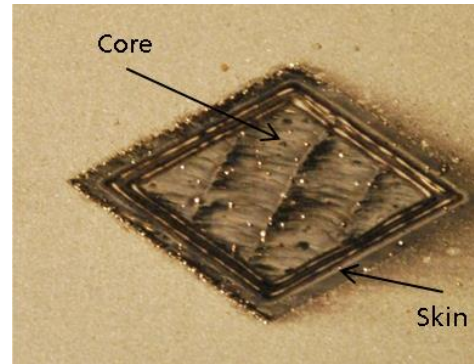
3. Improve part quality / reduce the level of scrap

4. Widening the range of proven materials



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



Process Development

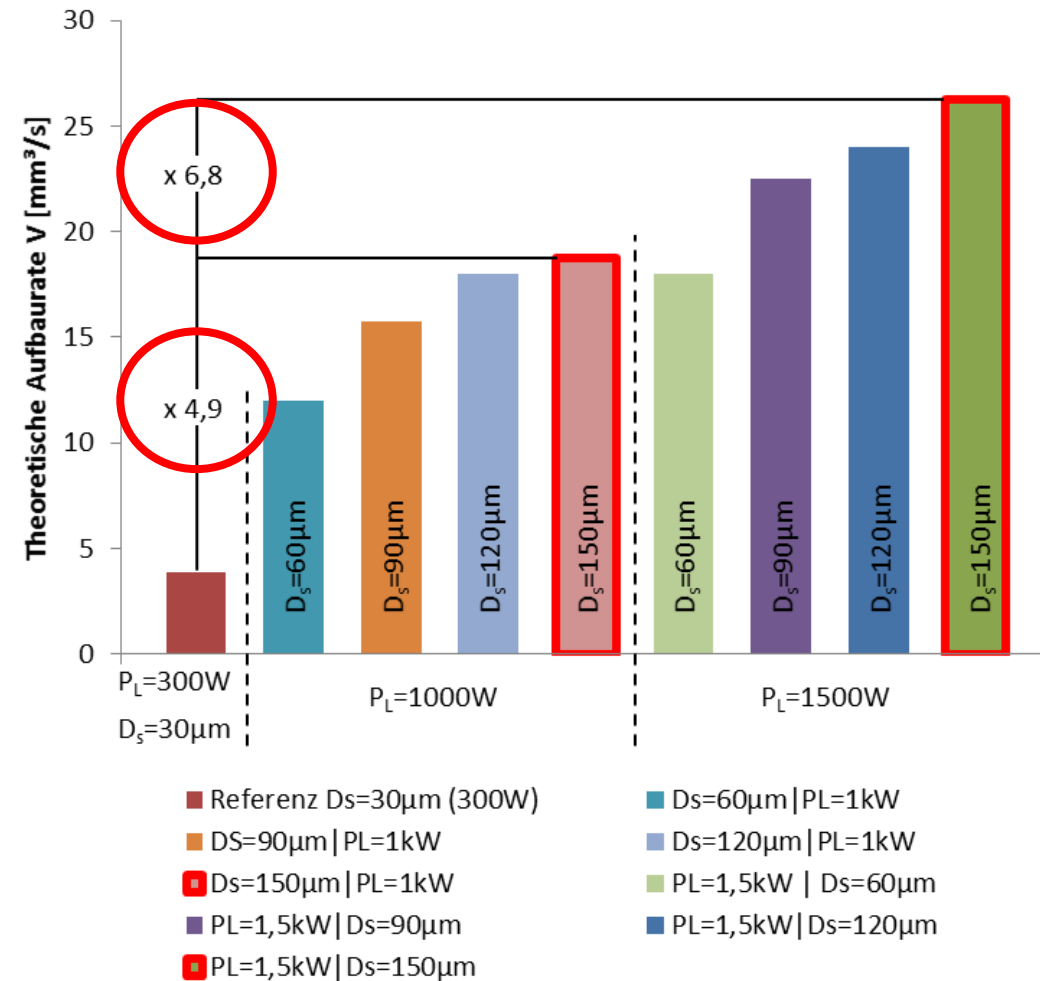
Layer Thickness / Laser Thickness

Process parameter:

- Laser power: $P_L=1-1,5\text{kW}$
- Hatch distance: $\Delta y_s=500\mu\text{m}$
- Layer thickness: $D_s=60-150\mu\text{m}$

Results:

- $P_L=300\text{W}$: $V_{th}= 3,84\text{mm}^3/\text{s}$
- $P_L=1\text{kW}$: $V_{th}= 18,75\text{mm}^3/\text{s}$
- $P_L=1,5\text{kW}$: $V_{th}= 26,25\text{mm}^3/\text{s}$



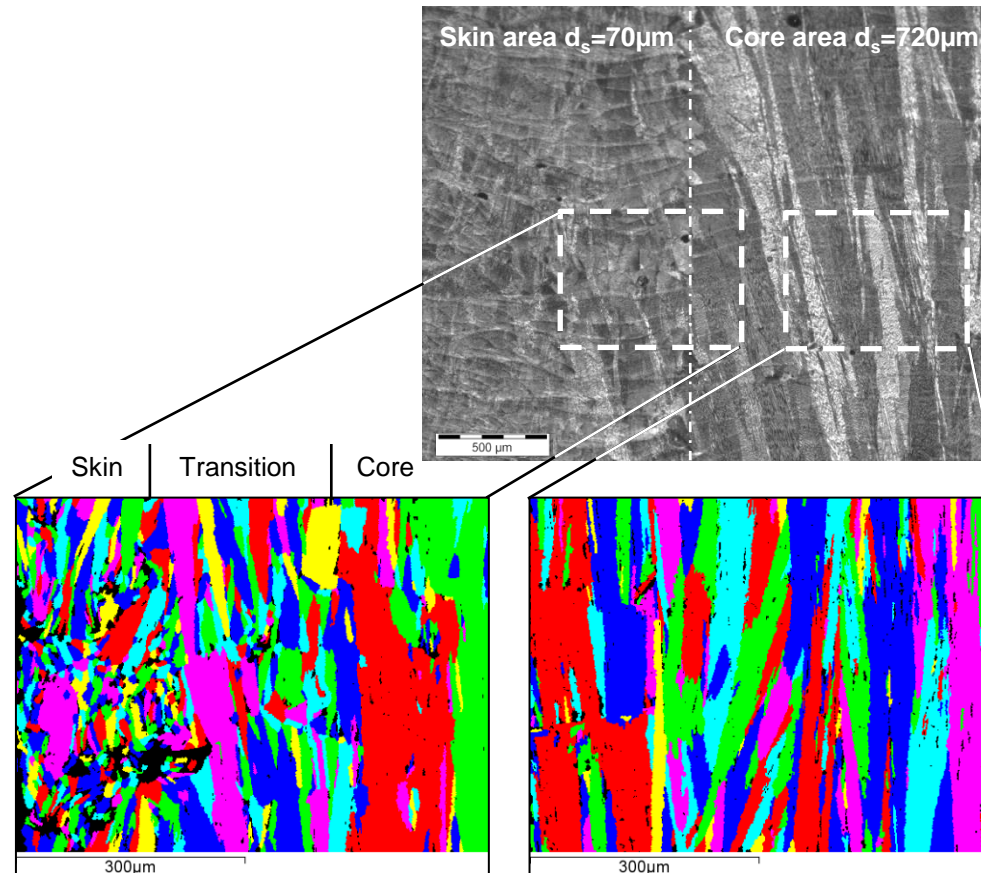
Microstructure

Process parameter:

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

EBSD analysis:

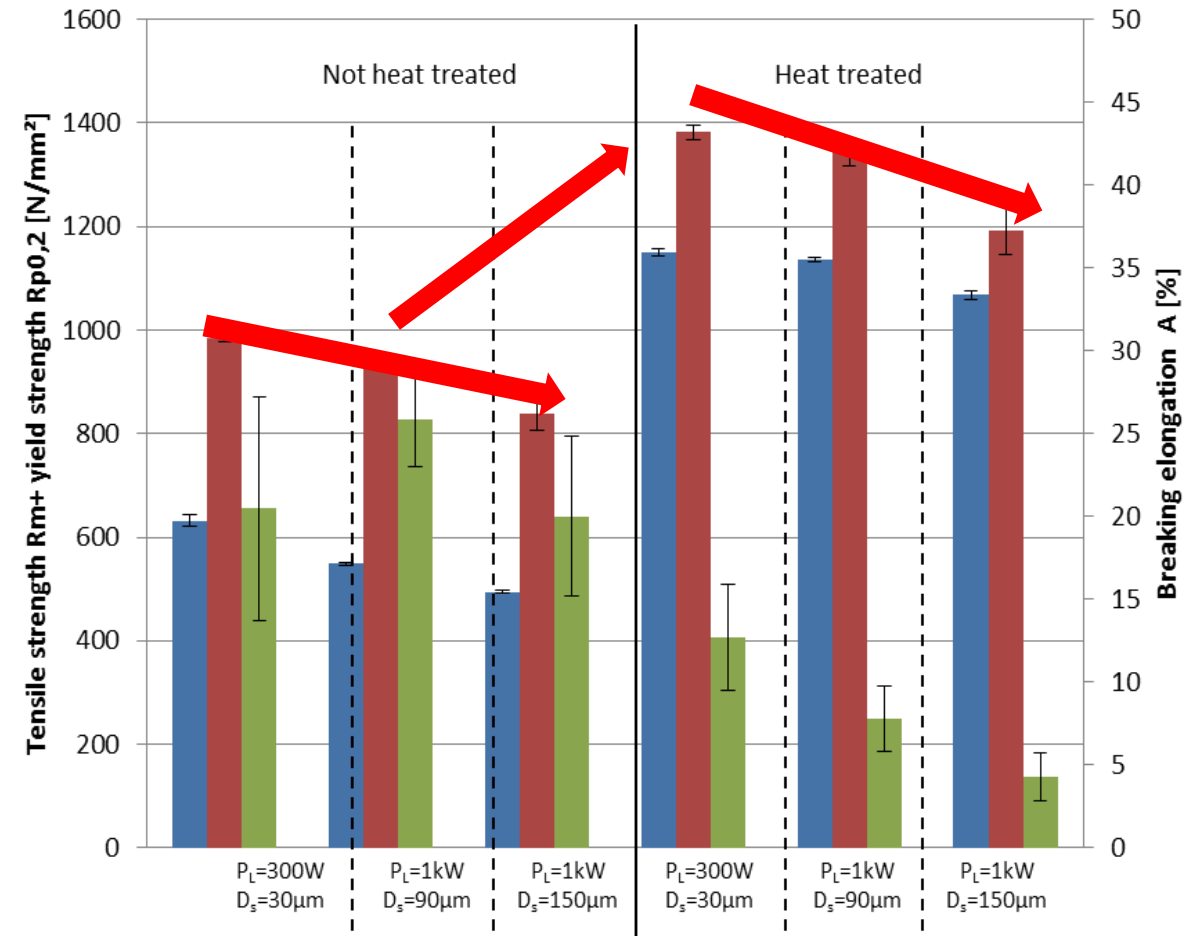
- Skin area:
 - Fine grains do not have a preferred orientation
- Core area:
 - Very long grains strongly oriented in build-up direction



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

Mechanical properties (tensile test static load)

- Specimens manufactured with $P_L=1\text{kW}$ at $D_s=90\mu\text{m}$
- Heat treatment:
 - AMS 5662 + Hipping
 - 1. Hipping: $T=965^\circ\text{C}$ | $t=1\text{h}$ | $p=2000\text{bar}$
 - 2. Solution annealing: $T=980^\circ\text{C}$ | $t=1\text{h}$
 - 3. Aging: $T=720^\circ\text{C}$ | $t=8\text{h}$
 - 4. Aging: $T=620^\circ\text{C}$ | $t=8\text{h}$
- 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 : $\approx 12\text{m}^3$

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
 - 100-150cm³/h



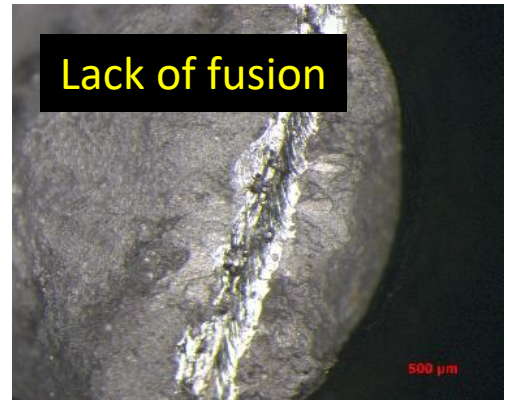
MacroCLAD nozzle 24Vx

Improved part quality

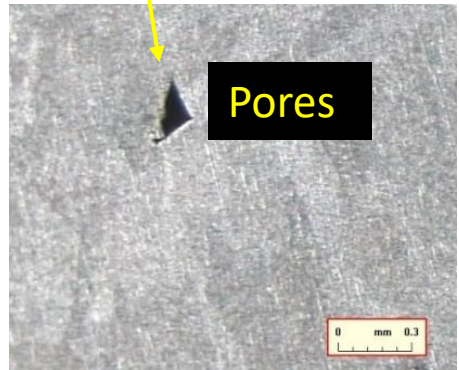
Tearing



Lack of fusion



Pores



Optimised Parameters

Parameters

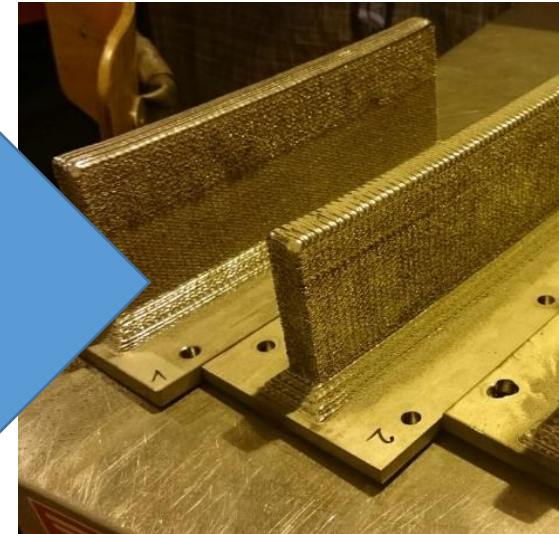
Laser power	1800 W
velocity	2m/min
Contour velocity	No contour
Powder flowrate	12.4g/min
Track height	0,75mm
Track width	2,5mm
Overlap	30%

Powder catchment efficiency

Effective PCE	72 %
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Building rate

Effective building rate	136 cm ³ /h
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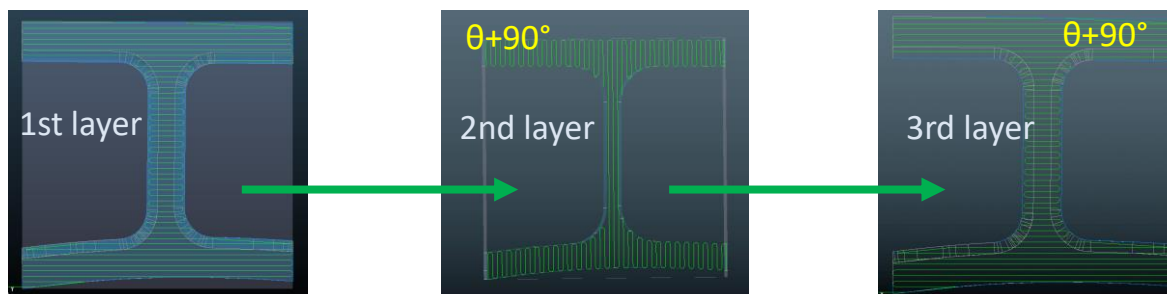


Deposition strategy optimization

Multiple deposition strategies tested:

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

Selected deposition strategy : Raster rotation/layer : 90°



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

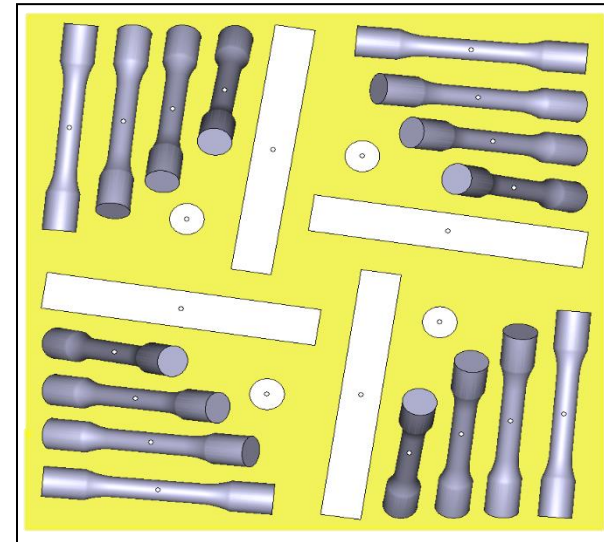
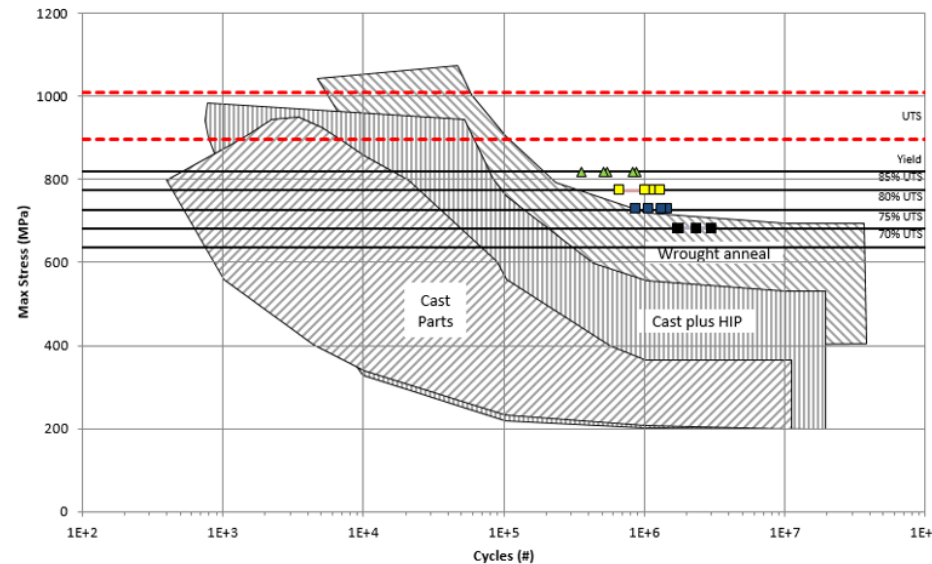
Deposition strategy	Raster rotation/layer: 90°
Time (min)	104
Deposited volume (cm ³)	171,6
Build up rate (cm ³ /h)	99,0
Powder catch. efficiency (%)	58,9



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

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

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ADDITIVE MANUFACTURING

As 3D printing) was first introduced for the production of rapid prototypes processes such as machining, where material is removed from a block to where material is shaped in a mould, in additive manufacture parts are built up layer by layer.

over conventional manufacturing methods:

relative ease, including high performance parts incorporating the lattice

required to producing complex parts using conventional manufacturing can waste more than 80% of the material

out the need for tooling, giving unrivalled flexibility and allowing cost including one-off customised parts

can be used which would be difficult, if not impossible, to process using

AM, all based on the fundamental principle of layer manufacturing, have

metallic, polymers and even ceramic material to be processed.

design and manufacturing of complex parts.

use of additive manufacturing for the production of end-use parts is still

There are a number of critical barriers which are hampering the adoption of additive manufacturing technology. These include:

- Limited range of proven materials and the associated mechanical property data
- Lack of understanding of the opportunities and requirements of design for AM
- Limited knowledge of the fundamental principles which underpin the AM process
- Lack of industrial case studies which demonstrate the benefits and limitations of the process.

5

as addressed these and many other barriers to enable series production metallic parts to be undertaken.

OBJECTIVES OF THE AMAZE PROJECT

A AMAZE project are to:

to define these additively manufactured metallic components up to two metres in size, zero waste

Phase in process productivity

reduction for finished parts, compared to traditional processing

accuracy to 20%

less than 5%

an end-to-end approach has been used, which covers the entire process chain for AM

parts.

of additive manufacturing, parts need to be designed for the process. Often conventional

or difficulty of machining them, or the limitations of tooling to form the shape. The

AM processes have been developed including

machines where a high power laser or electron beam is used to selectively fuse a fine

from the part.

Directed energy deposition where powder or wire is fed into a melt pool formed using heat from a laser or

electric arc to build each layer of the part using a direct melt-chamber method.

powder bed processes are ideally suited to the production of small complex parts whereas direct energy deposition is

also offer the capability of producing larger parts and also undertake repair of high value components.

accepting of key process variables, which are used to control the process, and which control end feedback to prevent process and thereby control.

DESIGN AND INSPECTION

For most applications, AM is a complex multi-stage process which can, if not

been cause a significant failure of parts in service.

Algorithms and rules current have been developed to detect the type of

of the process, and development a change in form of the new design engine

AM which often requires conventional NDT methods.

Using techniques including non-contact laser ultrasonic methods. This

which is possible in the future as the process, allowing the AM process to

parts with the surface finish required by industry. Moreover, that

and using conventional methods are difficult. To overcome this process,

using methods, including the use of laser printing, has been developed

parts.

It is a important to apply automation methods to reduce the cost and

and operations. In addition, within the AMAZE project, the manufacturing

the time. The time experienced production provides often significantly

to become the base of four new AM factories established in the project.

STREAMLINING PRODUCTION

and a important to apply automation methods to reduce the cost and

and operations. In addition, within the AMAZE project, the manufacturing

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to become the base of four new AM factories established in the project.

to overcome the risk of industrial use doubts and also highlight the developments made in the AMAZE project, a

portfolio of demonstrator parts produced as well as covering all of the actions represented by the end users in the

project have been made available and made available.



AM research is a marathon not a sprint ..

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



Questions ?

