High Quality Metal by Additive Manufacturing

B. van der Vorst **(ECN)**
J.J. Saurwalt **(ECN)**

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High Quality Metal by Additive Manufacturing

Precision Fair 2015
Bart van de Vorst
Jaco Saurwalt

Veldhoven
19 nov. 2015

Current and Future application fields of Additive Manufacturing

ECN

Rapid Prototyping 3d-printing	Additive Manufacturing	Mass Customization Bespoke products	Better Solutions by Freeform Features	Function Integration
Test & Prototype	Alternative to Injection Molding Machining, etc.	Client Specific Features or Sizes	Forms we could not (afford to) make up till now. Design requires AM	Devices / sensors Hybrid Materials
Not always functional	Functional	Functional	Functional	Future Goal

High Material Quality Needed


© Stratasys


© EOS


© Phonak


© GE


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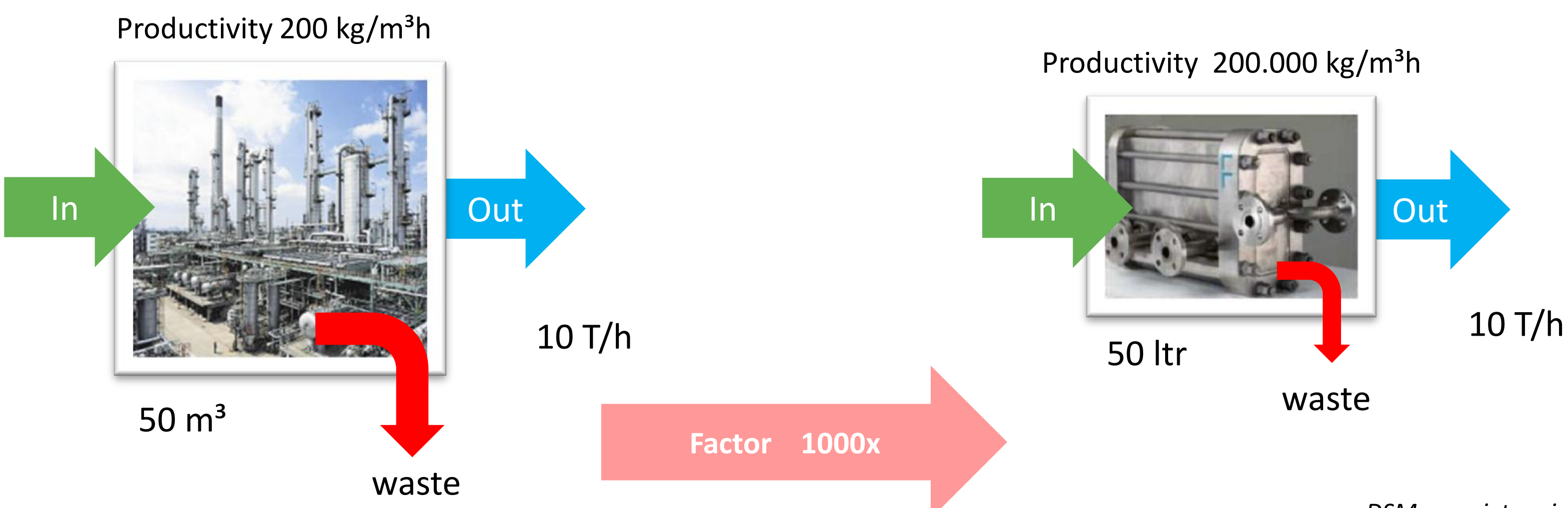
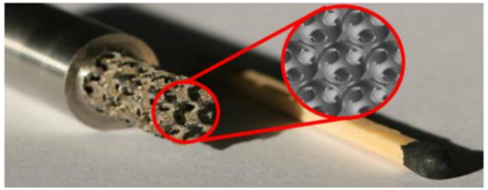
For example: Process Intensification

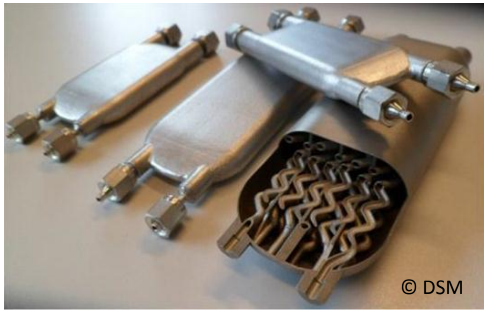
- Trends in the chemical and pharmaceutical industry:
  - Switch from batch to continuous operation mode.
  - miniaturization of units,
  - higher selectivity and yield with lower energy input
  - **Increase in Efficiency.**



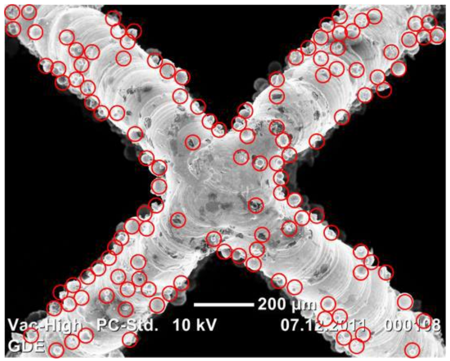
Additive Manufacturing for PI

- Additive Manufacturing candidates
  - Micro Reactors
  - Static Mixers
  - Catalyst bed
  - Heat exchangers
- Benefits of AM
  - Competitive cost level
  - Design freedom
  - Option for parallelization and optimized channel design
- But there is a problem!



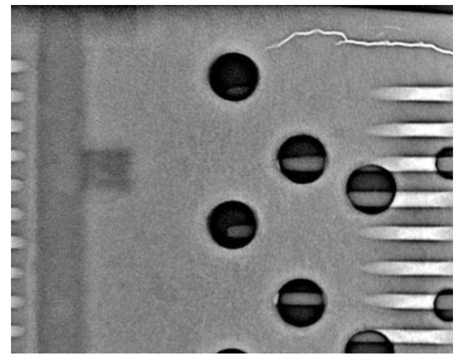


Hidden Additive Manufacturing issues

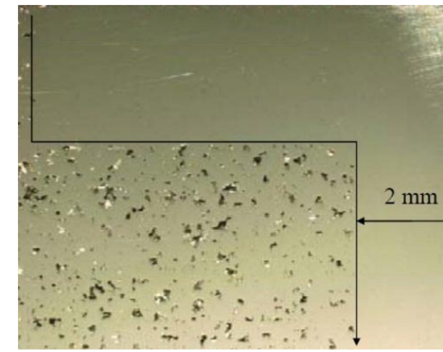


© A. Bergmann – Fraunhofer IPK

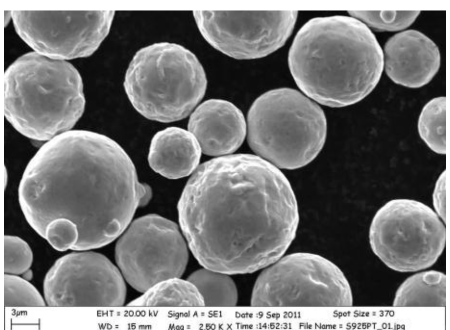
Adhered powder particles



Internal cracks & Stress

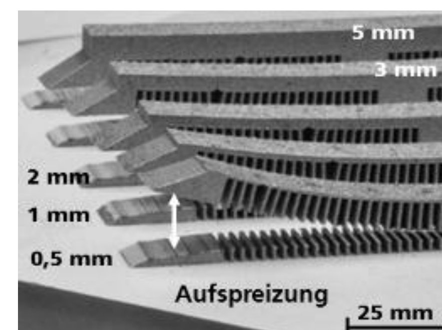


Process dependent porosity



Material Source & History

Non Uniform Microstructure



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Stress build-up

What’s the reason of these failures?

- The current AM process / materials combinations and their limitations are not fully understood,
- Current AM machines are made for prototyping and not production,
- Process conditions are not constant,
- Primarily caused by design, incorrect process parameters and human factors.
  - “Material properties are created on the spot”

The industry demands better Materials!

- The material properties of current Additive Manufactured parts are not sufficient for high-risk and high demanding applications.

- Current processes for metals are limited in feature size.

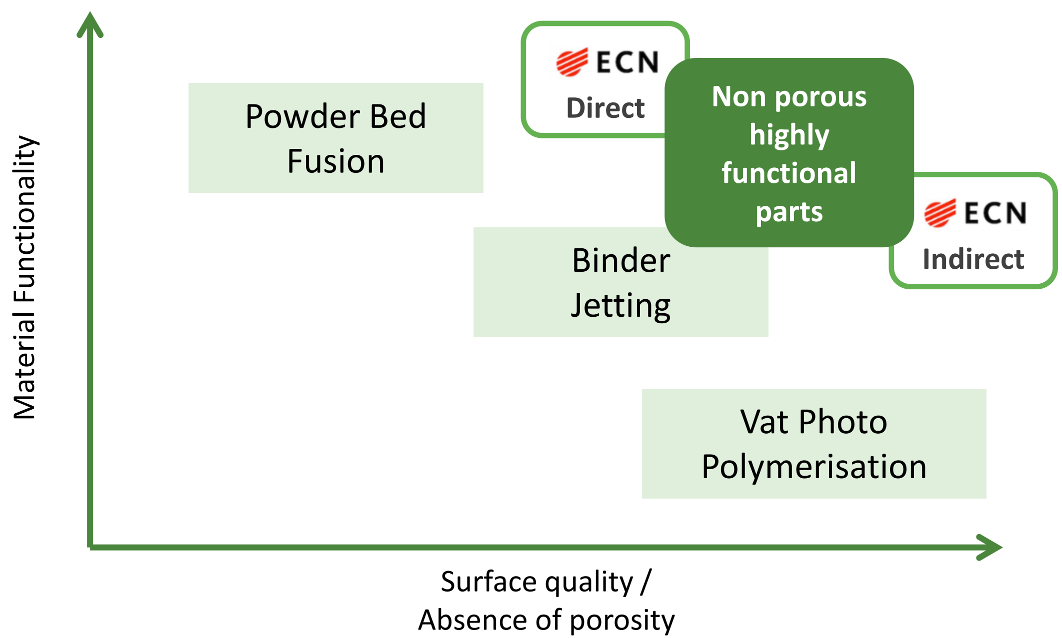
- ECN believes the AM Material properties and resolution can be improved by:

  - Better Understanding of Process & Material
  - Processes Improvement
  - Enhanced Material Systems

  - “Take the whole volume or minimize thermal differences”

The industry demands better Materials!

- Therefore we started the development of a new Direct & Indirect Additive Manufacturing method, based upon our extensive material competences.



Indirect & Direct Manufacturing

- Indirect

Highly filled Resin

Additive
Manufactured
Green Part

Debinded
Brown Part

Sintered
Near Net shape
Part

- Direct

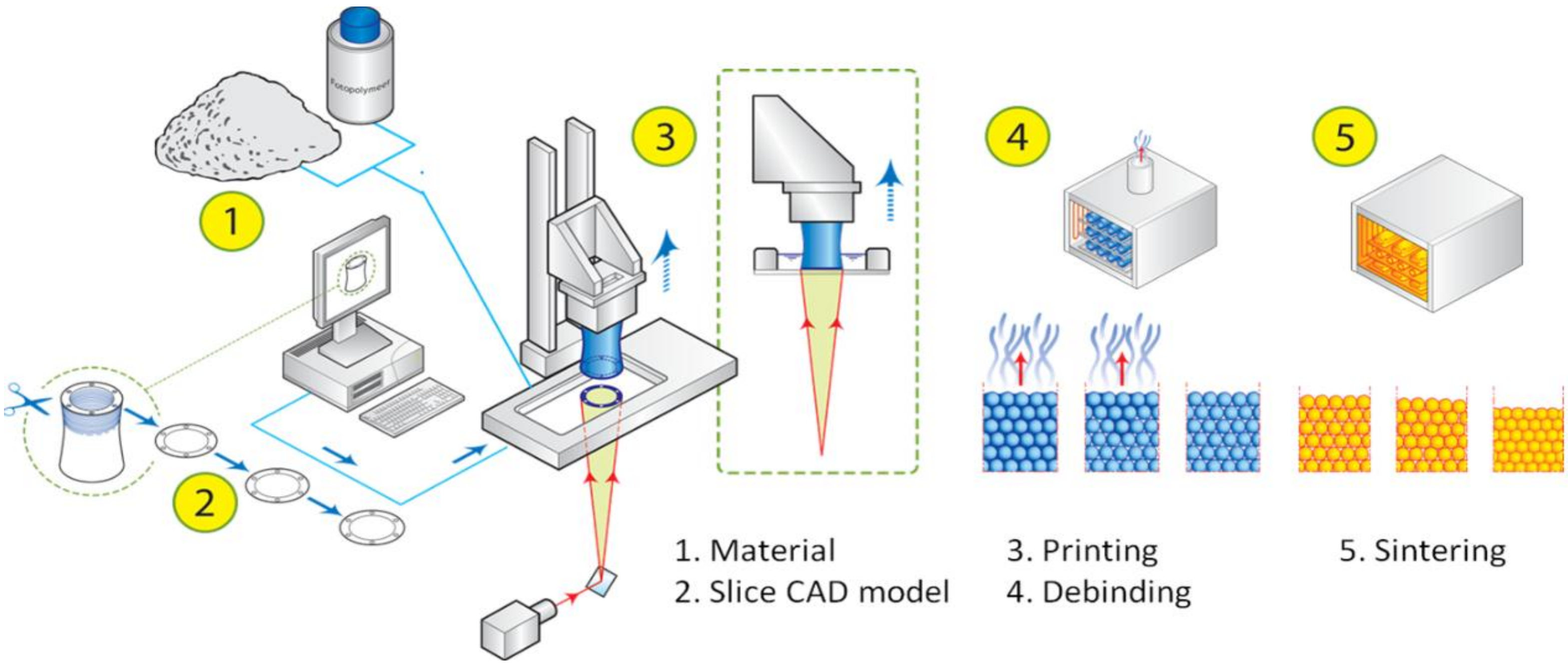
Powder
based
material

Additive
Manufactured
Part

Stress relieved
Near Net shape
part

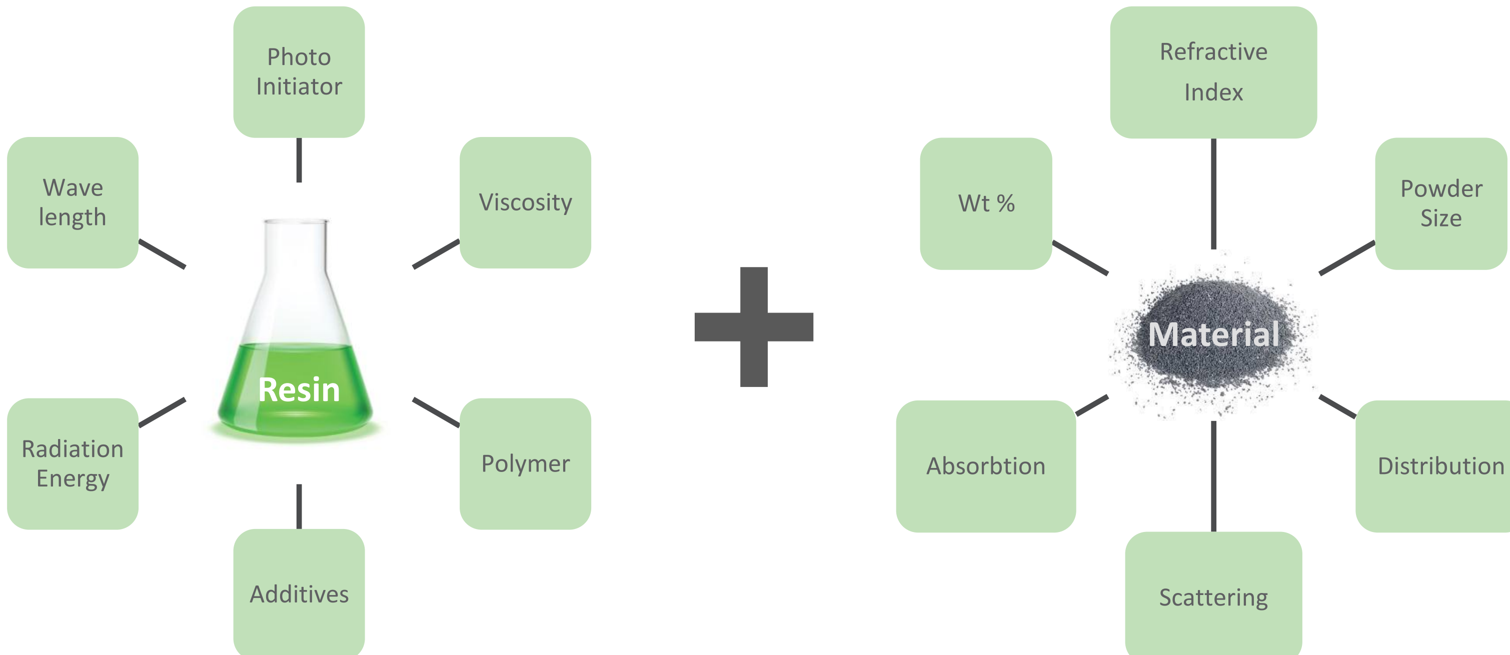
Vat Photo Polymerisation of Metals

- Indirect, Slurry based process



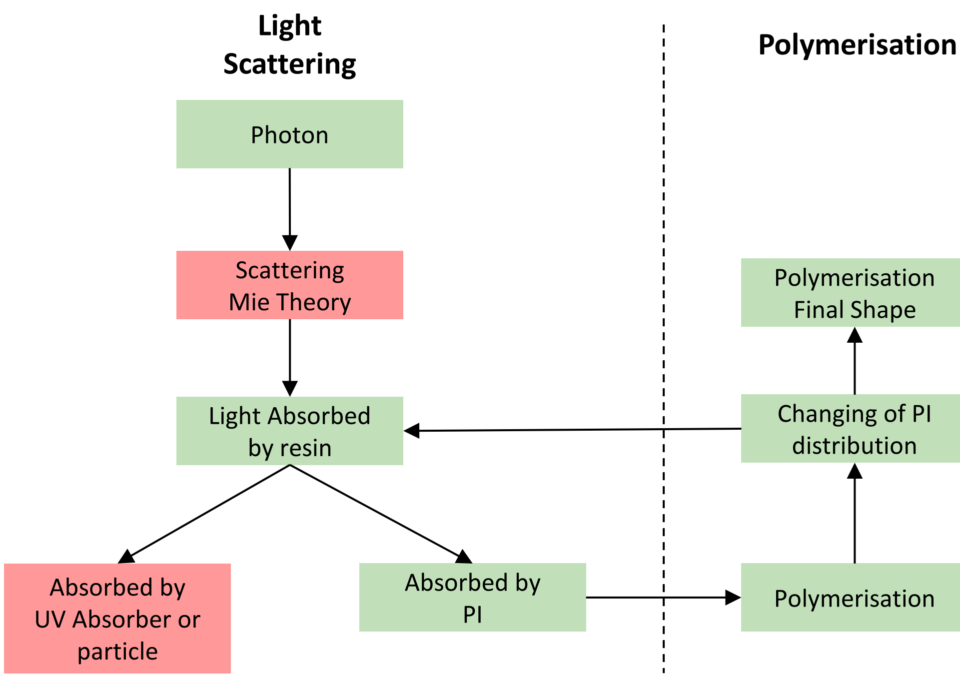
To be succesfull…

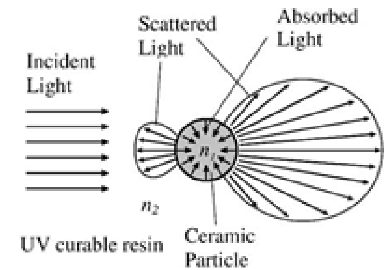
- Preparing a "good" slurry to match your process is key.

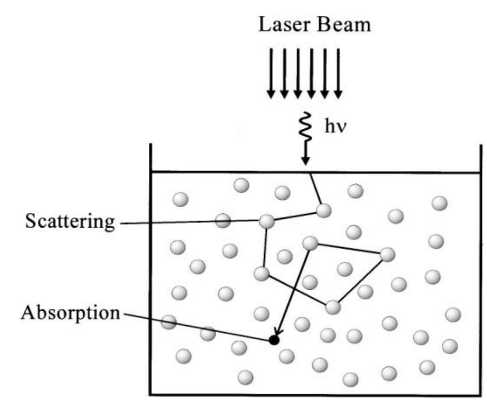


Limitating material properties

- Absorbtion & Light Scattering

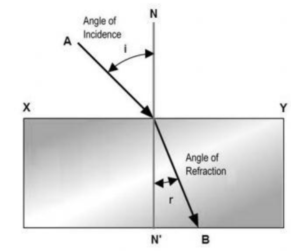






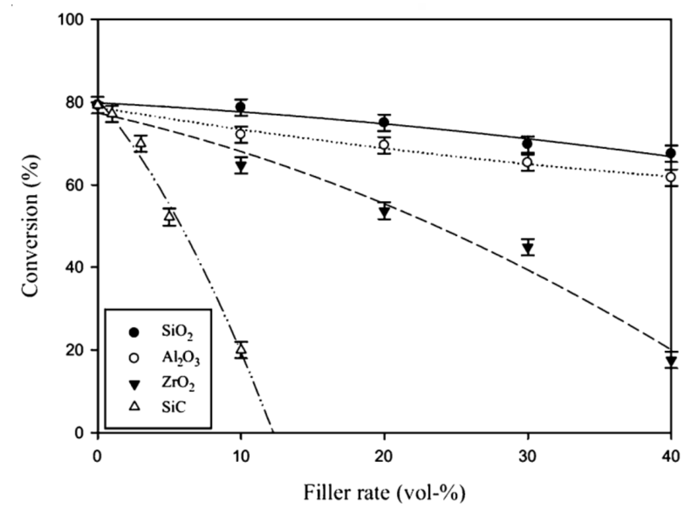
Mismatch in refractive Index

- Higher refractive index difference between particle and resin, the stronger the light scattering.
  (Less cure depth)



More dificult to cure

Material	Refractive Index n @ 437 nm
Resin	1,46
SiO_2	1,47
Al_2O_3	1,70
ZrO_2	2,25
Steel	2,48
SiC	2,69



Influence of the refractive index and solid loading of ceramic filler on the polymerisation conversion of a acrylate filled resin

** Additive Manufacturing of Ceramics: A Review – J. Deckers*

Important characteristics

- Penetration Depth will determine the layer thickness*

UV Curable resin	Powder Nature	Refractive Index n @ 437 nm	Particle Size (µm)	Penetration Depth Dp (µm)
Acrylate	-	1.46	-	242
Acrylate	SiO_2	1.47	3.5	140
Acrylate	Al_2O_3	1.70	10	75
Acrylate	Zirconia	2.25	4.2	50
Acrylate	316L	2.48		
Acrylate	SiC	2.69		

** P.J. Bartolo (ed.), Stereolithography: Materials, Processes and Applications, Materials for Stereolithography: S. Corbel et al.*

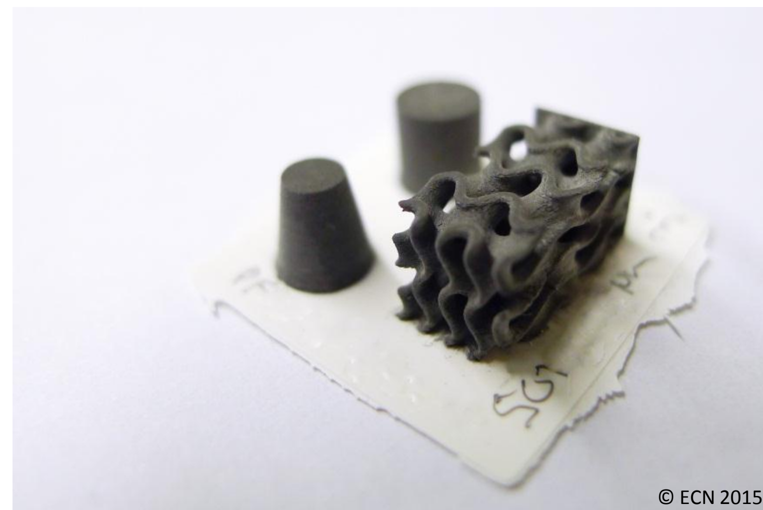
Proven Technology

- "Simple" Ceramic Materials
  - Al_2O_3 & ZrO_2
- 3D Printed ceramic parts are produced by Admatec
  - Shareholders: Formatec & ECN
- Role ECN
  - Slurry & Process development
  - Material Characterisation

Research – Metals

- Vat Photo Polymerisation of green parts
  - Stainless steel 316L

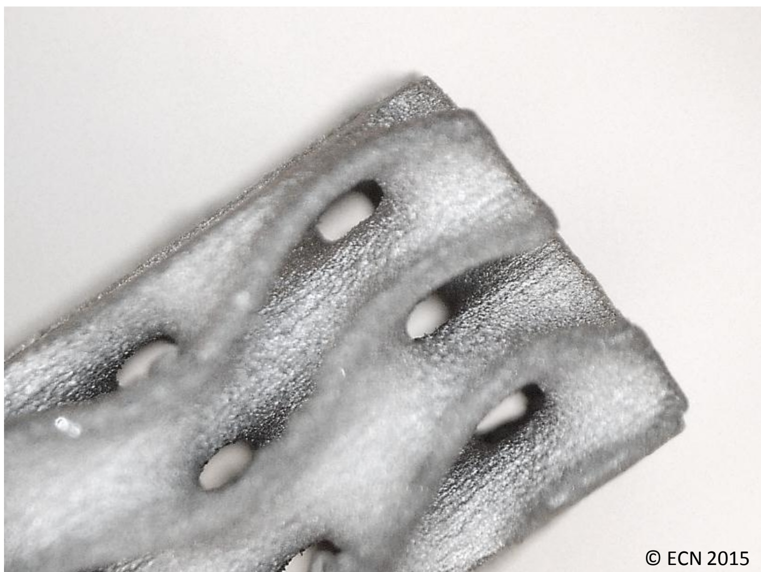
Detail of 3D printed geometry - green



Build platform with 3D printed parts

Research – Metals

- Sintered 316L part
  - Size: 5x5x10 mm

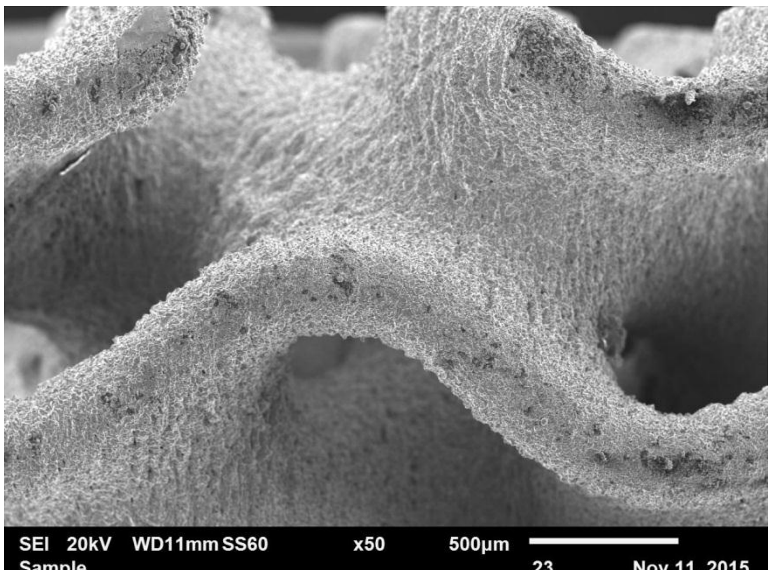


Detail of 3D printed geometry - sintered

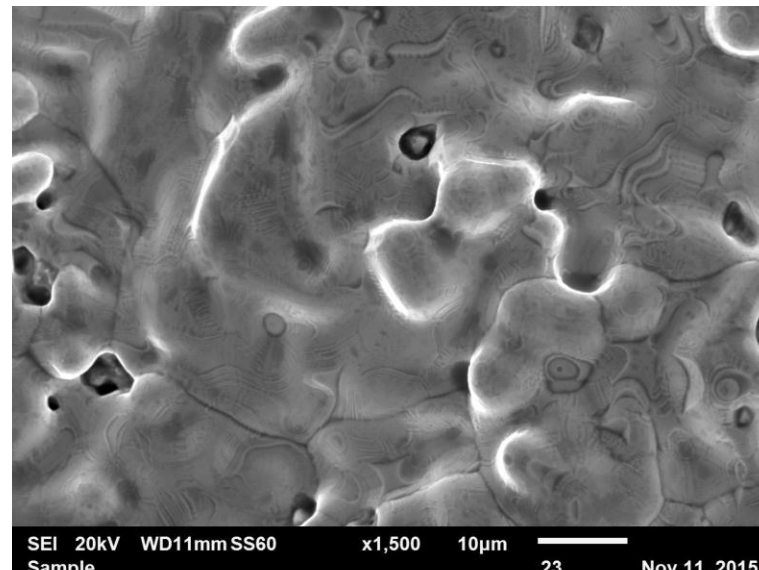
3D printed geometry - sintered

Research – Metals

- Sintered 316L part
  - Micro Structure



Detail of 3D printed geometry - sintered



3D printed geometry - sintered

Comparison with other AM techniques

- Without post processing
  - Perpendicular to build direction.

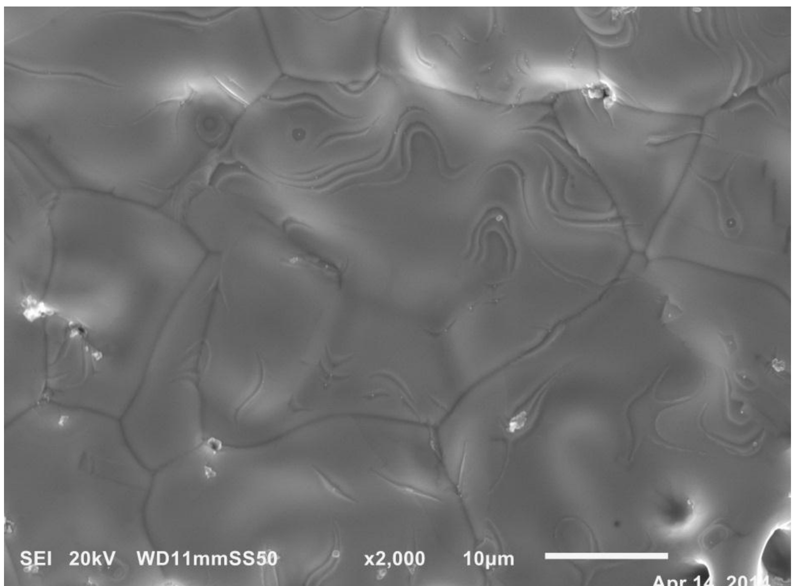
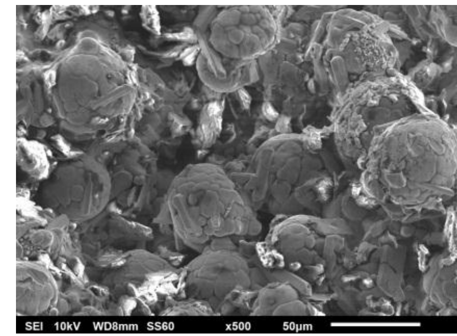
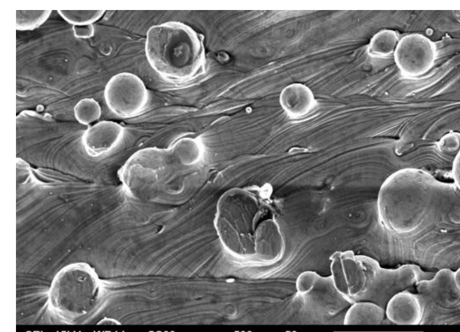


Photo Polymerisation 316L Sintered - ECN
(Indirect Process)



Binder Jet – ExOne
(Indirect Process)



Powder Bed Fusion
(Direct Process)

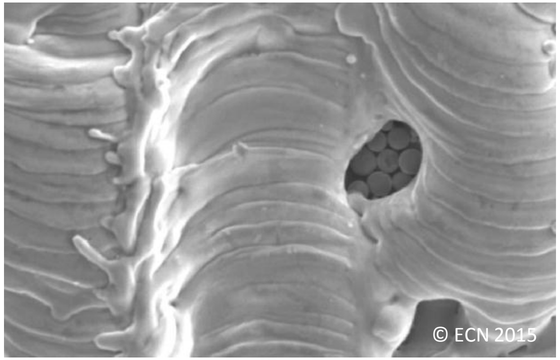
Low Stress SLM a Direct Method

- Research & Development

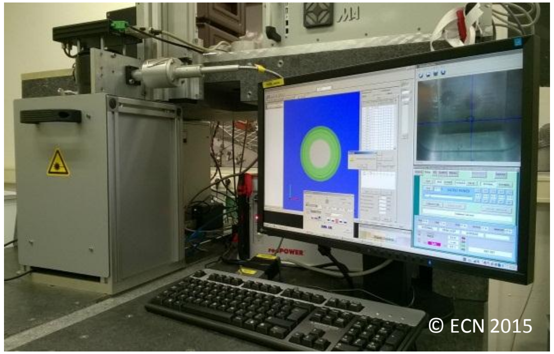
CONFIDENTIAL

New Material system (patent pending)

- Laser based process
- Started from scratch (January 2015)
- Development of test setup



"A peek in the lab"



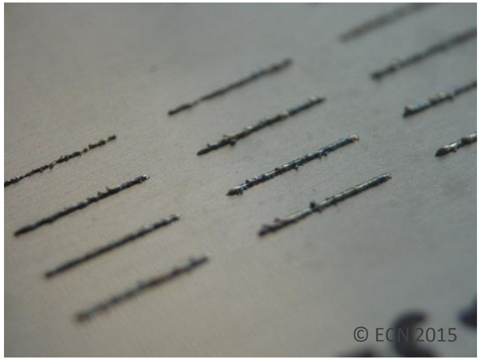
Test setup

Line Scan & Hatch Experiments

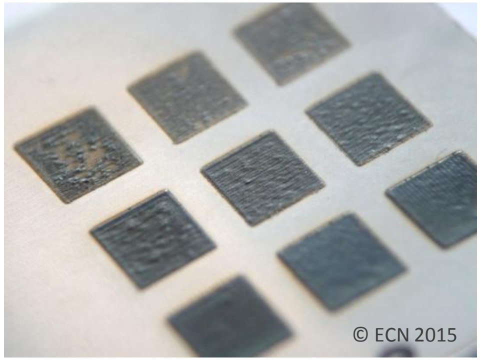
- Multiple experiments to find the correct settings

- Variables:

  - Laser Power
  - Scan Speed
  - Scan Strategy
  - Layer Thickness
  - Material systems



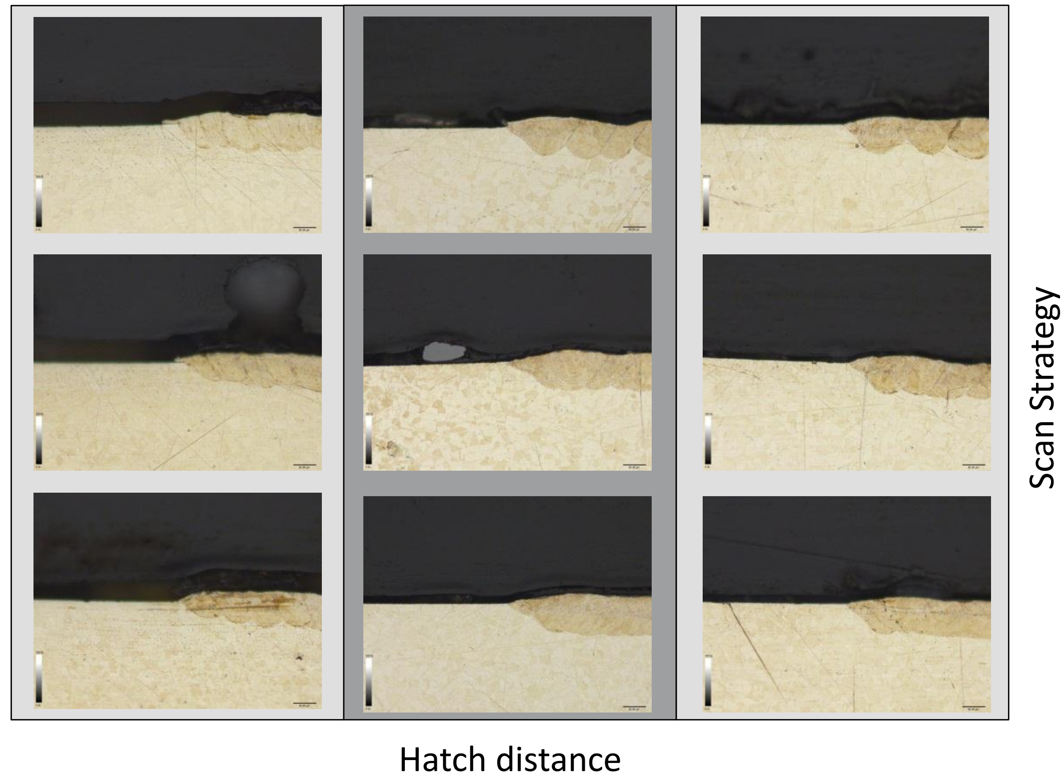
Line Scan



Hatching

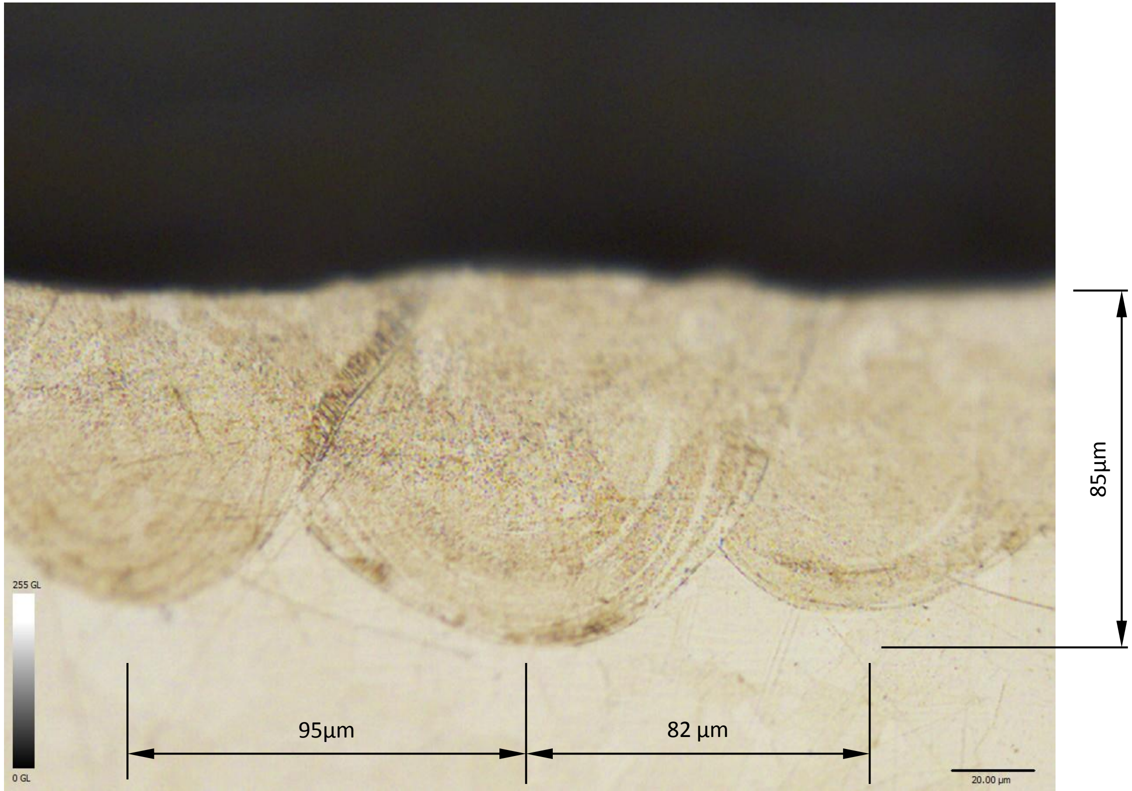
Hatch Experiments: Penetration Depth

- Settings:
  - Scan speed
  - Laser Power
  - Layer Thickness
  - Scan Strategy



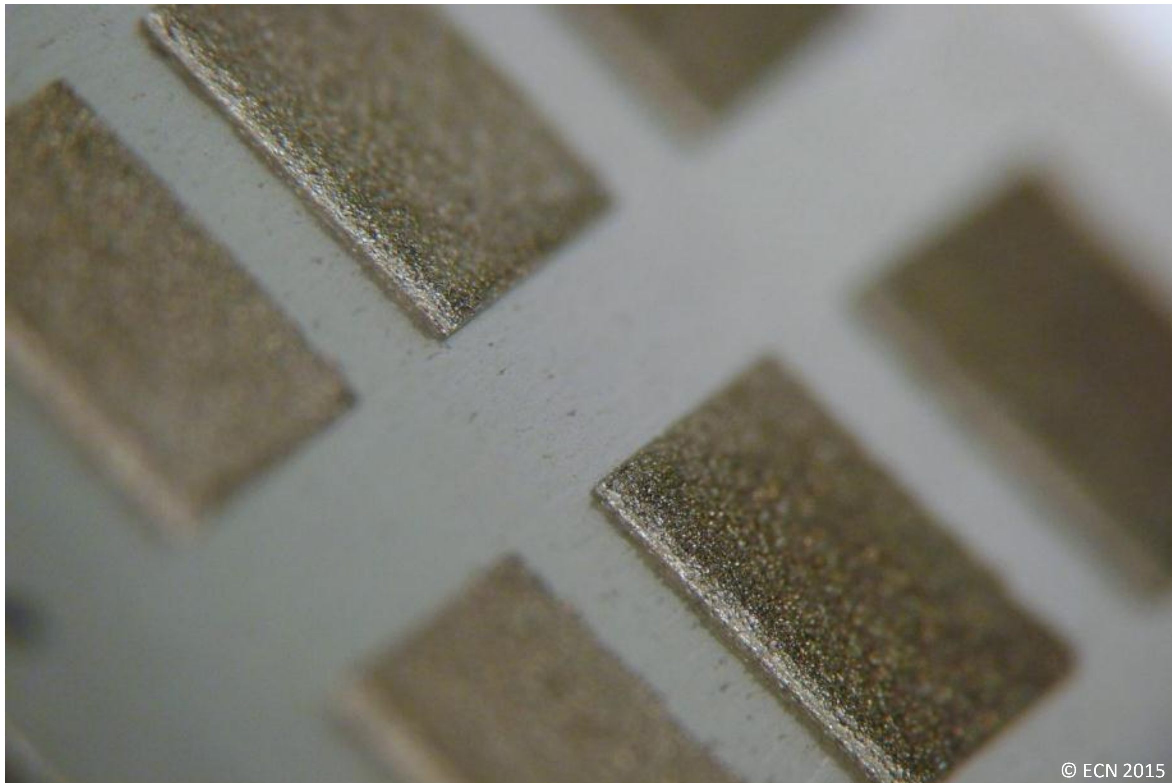
Hatch Experiments: Penetration Depth

- Settings:
  - Single Hatch
  - Hatch distance
  - Scanspeed
  - Laser Power
  - Layer Thickness



Cross section - hatching experiment 316L

Multiple Layers

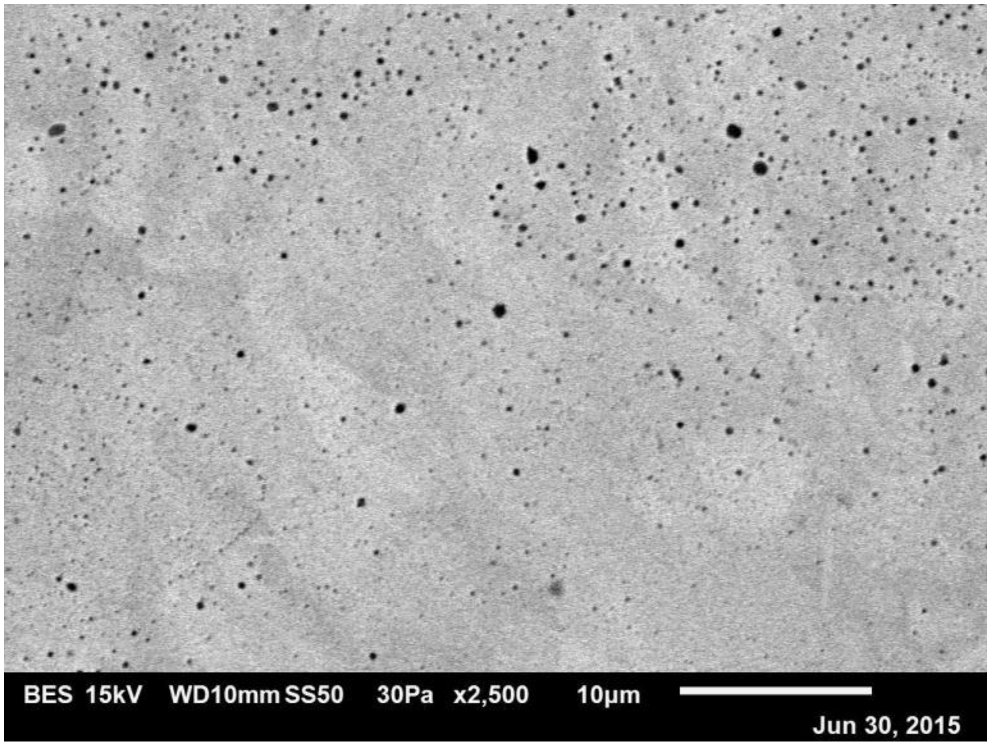


Additive Manufactured Part

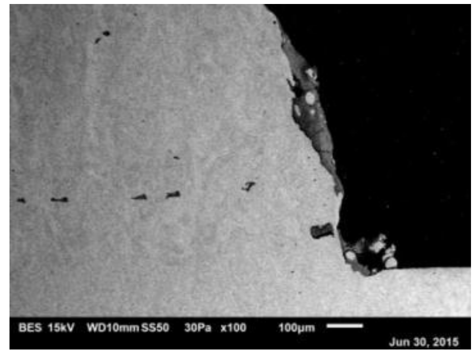
- Micro Turbine
  - Properties
    - ECN test setup
    - 316L Stainless Steel
  - Dimensions
    - Diameter: 20 mm
    - Height: 8.3 mm

Details – SEM images

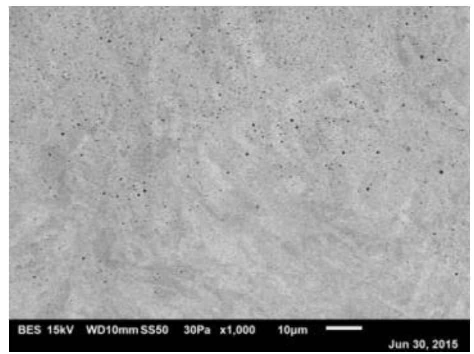
- (sub) Micron porosity



Low Stress SLM 316L – 2500x



Low Stress SLM 316L – 100x



Low Stress SLM 316L – 1000x

Scan & Hatch Optimisation

- Process Optimisation
  - Start / Stop delay times
  - Laser Power / Scan Speed

Initial settings

Optimised parameters

Summary Metal Printing ECN

Indirect method

Pro

- *Isotropic high quality structure*
- *Complex features possible*
- *Low cost printing equipment*

Contra

- *Separate densification process*
- *Shrinkage*
- *Build speed lower than ceramics*

Patents

- *Pending 3x*
- *Assigned 1x*

Direct method

Pro

- *Direct*
- *Low stress compared to SLM*
- *Finer Features / channels possible*

Contra

- *Expensive equipment, comparable to Vat Photo Polymerisation equipment*
- *Anisotropic microstructure*

Patents

- *Pending 1x*

Conclusions and Outlook

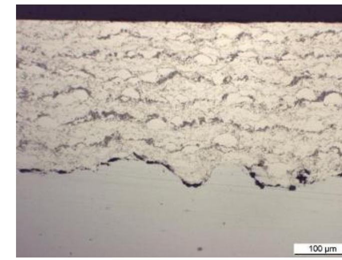
- Additive Manufacturing is no brainless production. It is complex and difficult.
- AM is not a reliable production process. Current machines are still prototyping **+**
- Material knowledge & research are essential.
- A Pilot machine for the Direct Method will be made in Eindhoven, expected end 2016
- A Company for VAT Metal is in formation

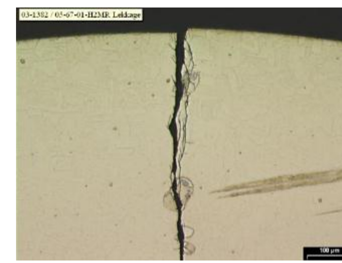
How can we be of service to you?

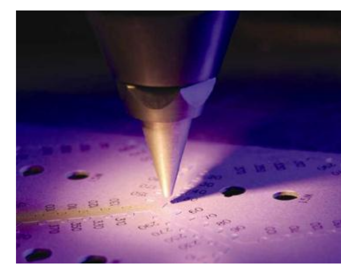
What we do	How we can work with you
Problem solving *Using our knowledge, technology, and facilities to solve our clients' issues*	**Consultancy & Services** *Serving your short-term business and R&D needs*
Technology development *Developing technology into prototypes and industrial applications*	**Contract R&D** *Support your R&D with our knowledge, technology and (test) facilities*
Engineering & Production *Realizing Parts, Equipment and Services based on our competences and facilities*	**Technology development & Transfer** *Implement our technology in products & processes*
	Joint Industry Projects and Joint Ventures *Making tomorrow's technology available together*

Engineering & Materials

- Materials Testing & Analysis (MTA) research group Petten & Eindhoven
  - Collaborative research & B2B
  - Mechanical testing
  - Corrosion & failure analysis
  - Chemical analysis
  - Material Research - Metals & Ceramics
  - Powder Injection Moulding
  - Laser Processing Technology
  - Consultancy
  - **Additive Manufacturing**







Introduction

- Bart van de Vorst
  - Researcher Engineer, Laser Applications & Additive Manufacturing
  - ECN Eindhoven - Materials, Testing & Analysis group
  - Located at the High Tech Campus
  - Solliance Building

Solliance Building – HTC21

Thank you for your attention

ECN – Precisionfair, Booth 131

Jaco Saurwalt
saurwalt@ecn.nl
+31 88 515 4696

ECN – North West
Westerduinweg 3
1755 LE Petten
The Netherlands

Bart van de Vorst
vandevorst@ecn.nl
+31 88 515 4329

ECN – South East
High Tech Campus 21
5656 AE Eindhoven
The Netherlands

T +31 88 515 49 49
F +31 88 515 44 80

info@ecn.nl
www.ecn.nl

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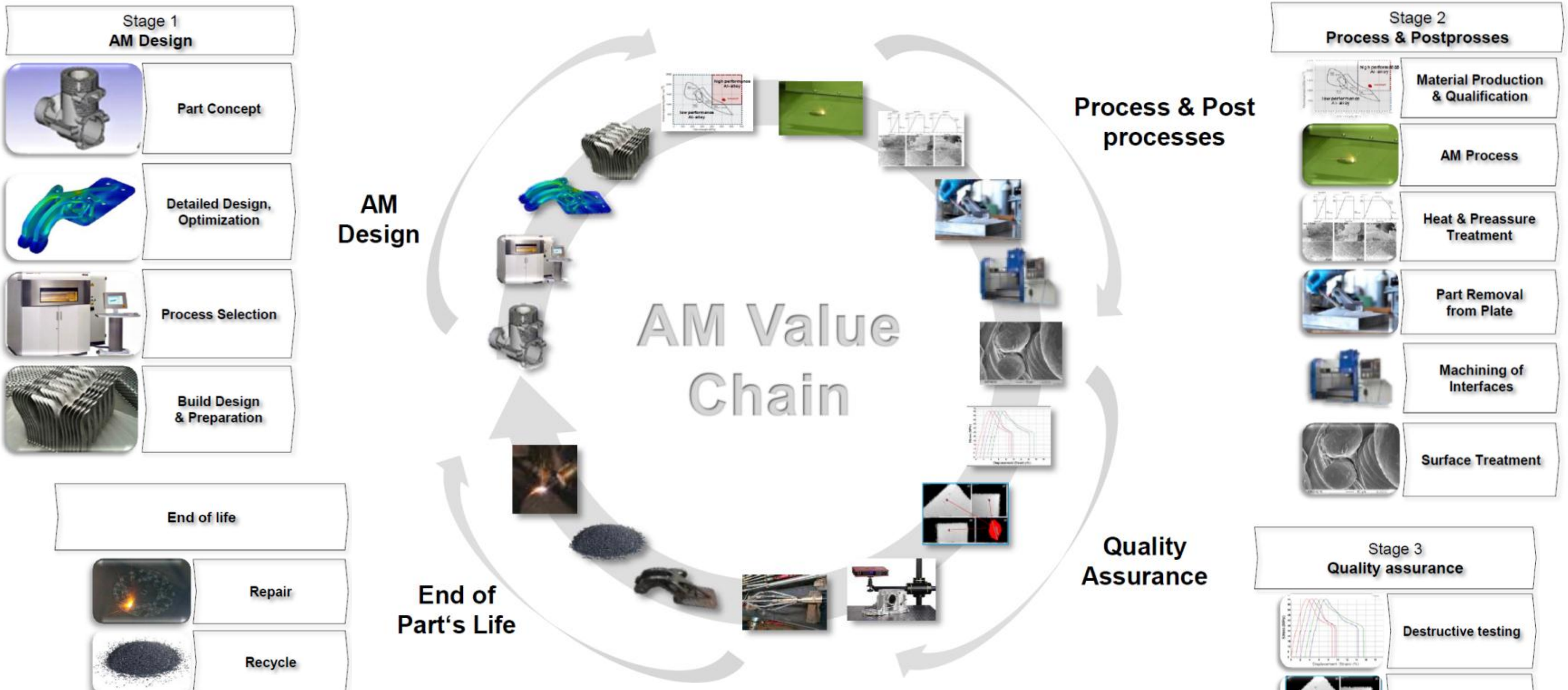
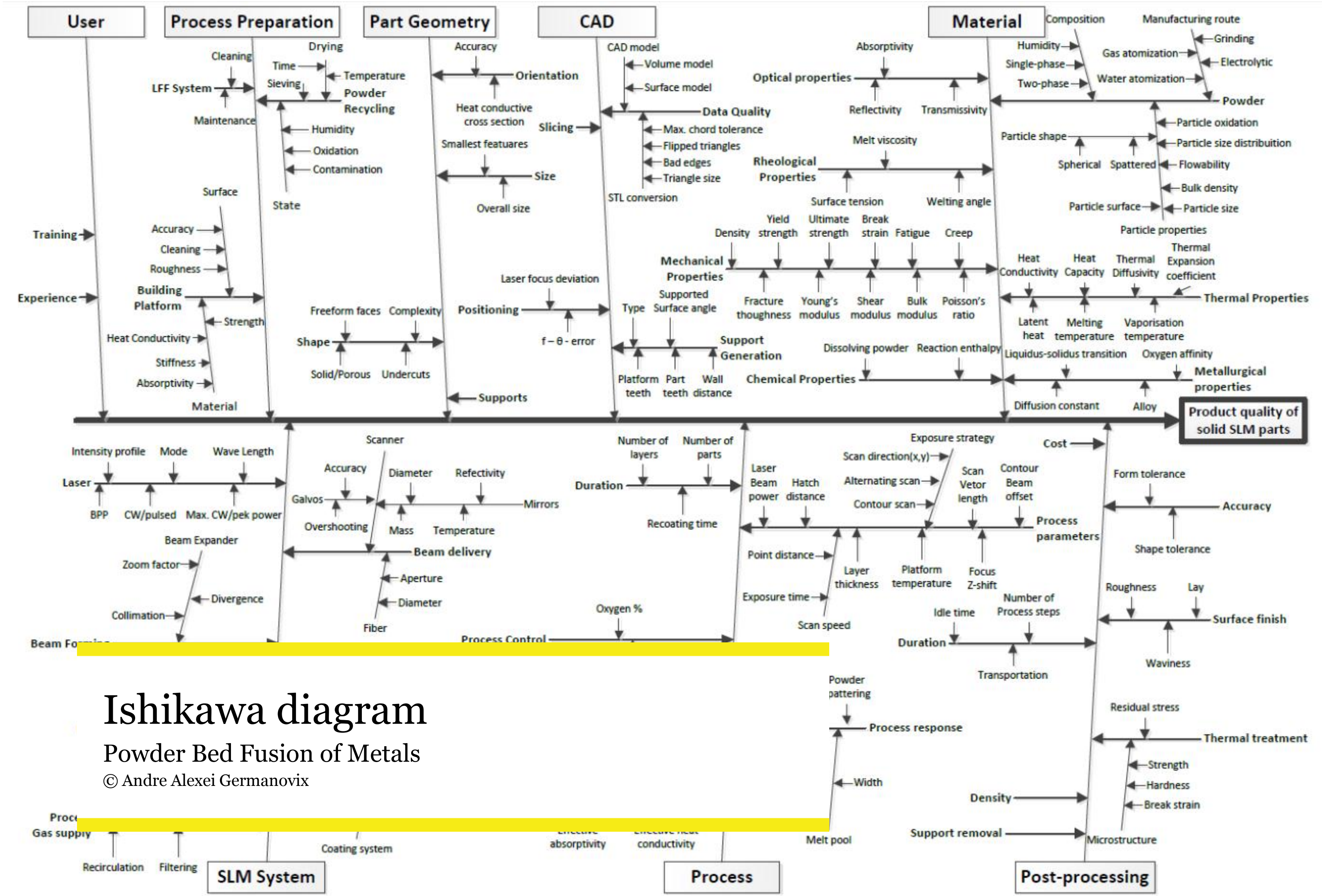
Additional Sheets



Additive Manufacturing Value Chain

Powder Bed Fusion of Metals



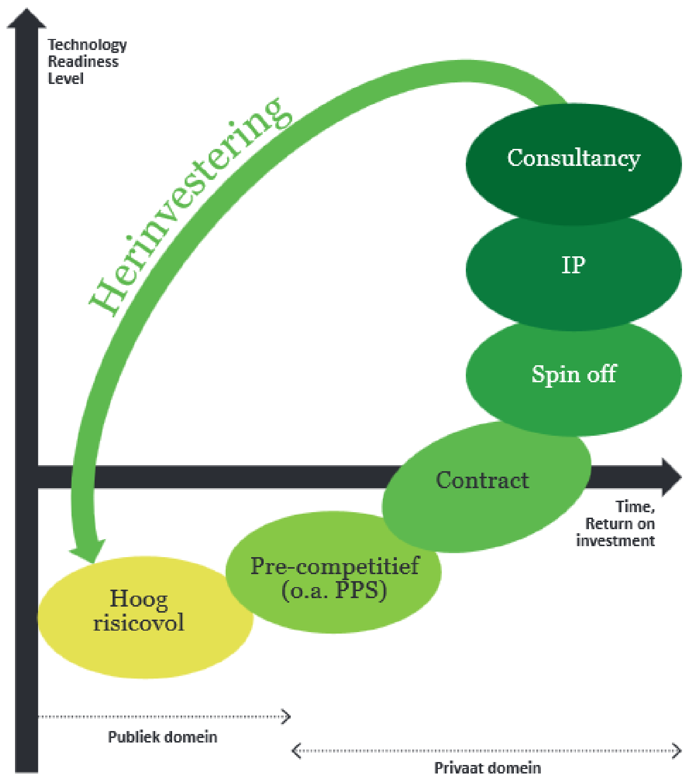
Ishikawa diagram

Powder Bed Fusion of Metals

© Andre Alexei Germanovix

Innovation model ECN

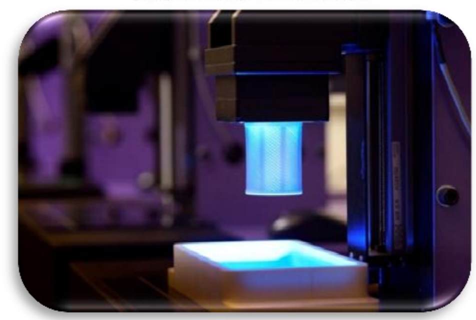
- Bridge between science and corporate innovation



Example

2013

ADMATEC
Additive Manufacturing Technologies



ECN Your energy. Our passion. InnoTech Europe BV FORMATEC CERAMICS Shaping technology and design

- *Slurry / Process development*
- *Characterization*

ECN: A rich and evolving history

≈ 450 employees

≈20 patents a year

≈500 reports a year

≈250 conferences a year

≈5 licenses a year

ECN – Focus Area

- 7 Core Activities

Engineering & Materials

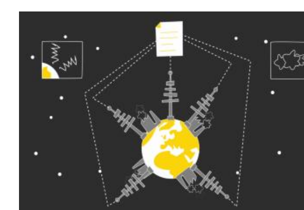
Wind Energy

Solar Energy

Energy Efficiency

Biomass

Policy Studies



Envir. Assessment

ECN

Westerduinweg 3
1755 LE Petten
The Netherlands

P.O. Box 1
1755 LG Petten
The Netherlands

T +31 88 515 4949
F +31 88 515 8338
info@ ecn.nl
www.ecn.nl