Material Quality or Quality Material? by Additive Manufacturing

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Materials of the Future Conference
M2I
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Sint Michielsgestel
8 December 2015

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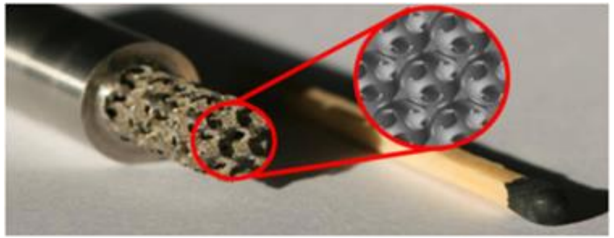
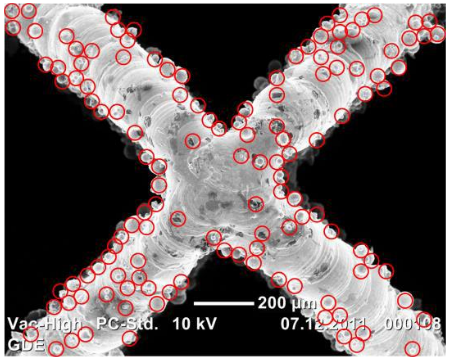
Current and Future application fields of Additive Manufacturing

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	 © VTT

Limitations in accuracy and features



Hidden Additive Manufacturing issues



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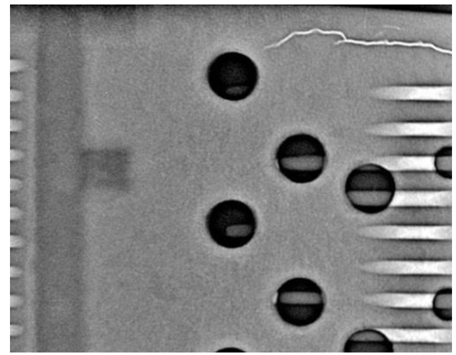
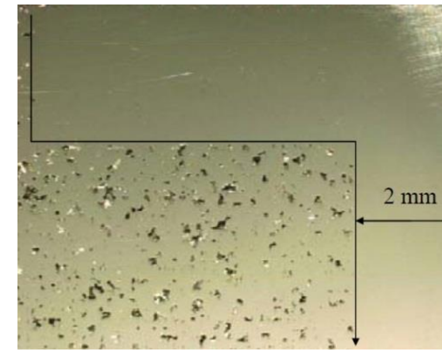
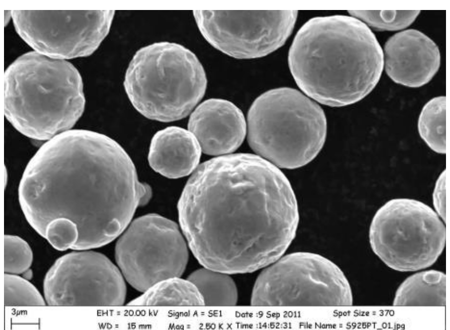
Adhered powder particles



Internal cracks & Stress

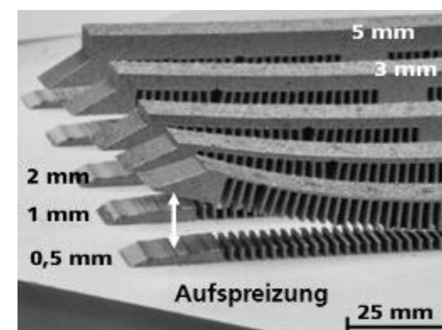


Process dependent porosity



Material Source & History

Non Uniform Microstructure



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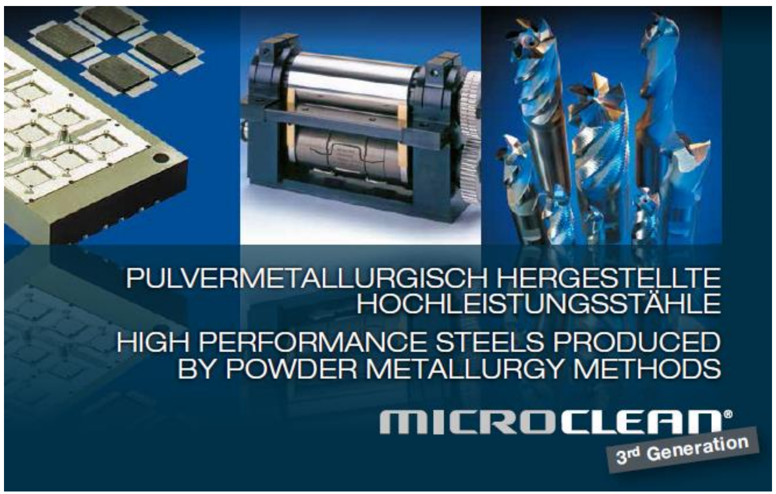
Stress build-up

But PM Steel can have the advantage

Homogeneous, segregation-free, Isotropic properties



BÖHLER MICROCLEAN have the following advantages:

- *Extremely high wear resistance*
- *Excellent corrosion resistance*
- *Optimum grindability*
- *Easily polishable to a high mirror finish*
- *High toughness*
- *Only minor isotropic dimensional changes*
- *Repeatable production processes*
- *Better resistance to vibrations*
- *More resistance to mechanical shocks*

enable

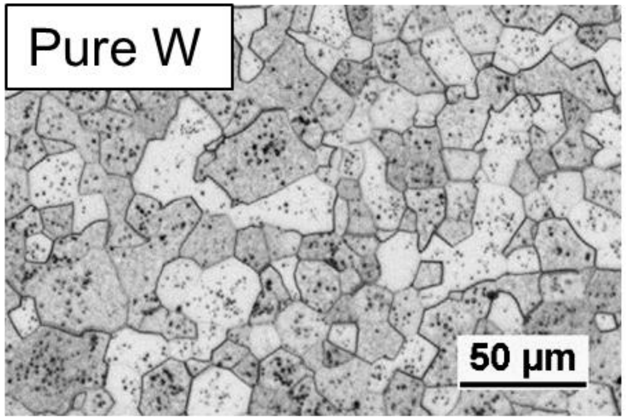
- *High precision components*
- *Long tool life*
- *Consistant tool life*

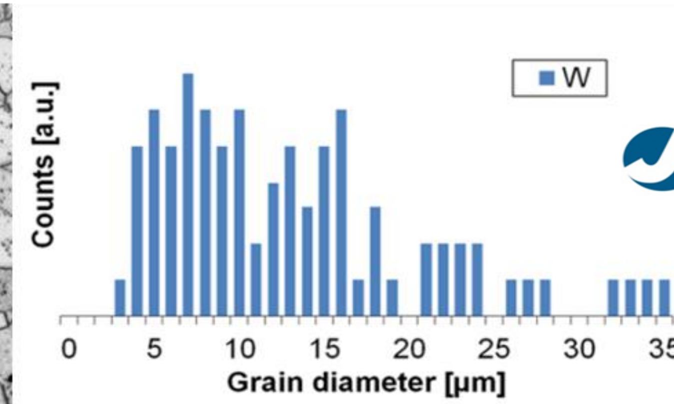
ensuring

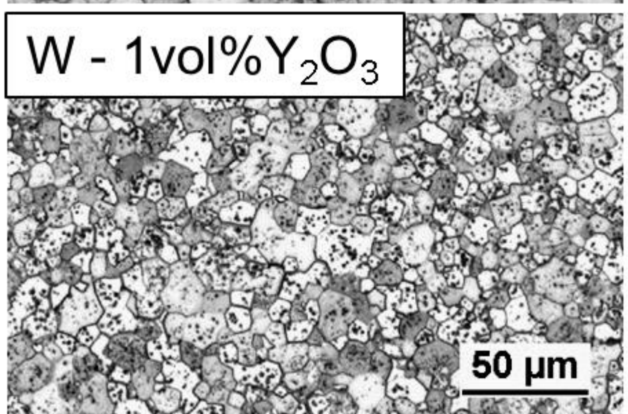
- ***Increased productivity***
- ***Reduced unit costs***

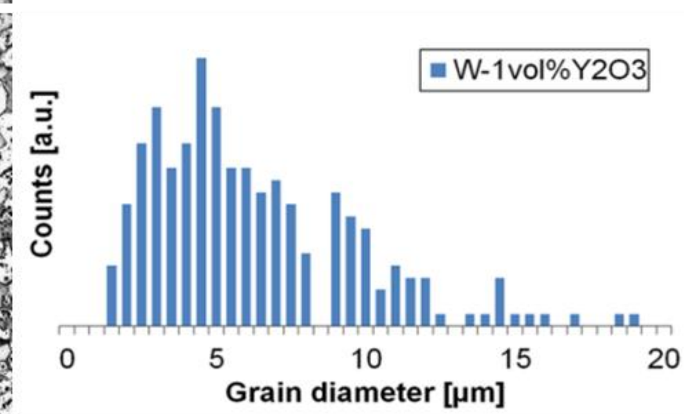
Source Bohler

Controlled Microstructure by doping alloying (MIM W by ECN)



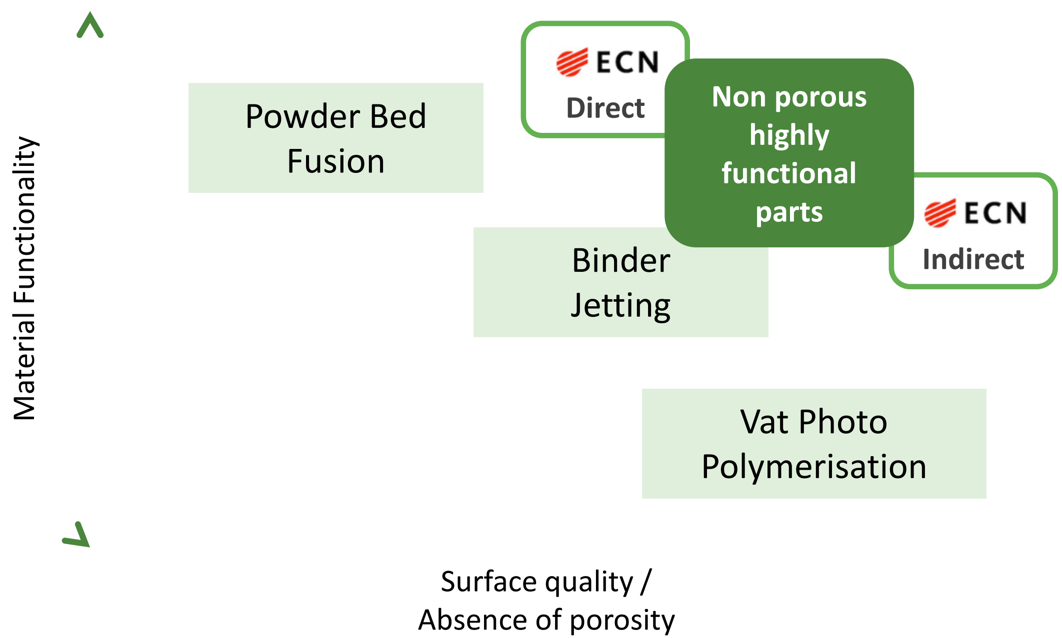






Material knowledge the base for PM and Additive Manufacturing

new Direct & Indirect Additive Manufacturing method,



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

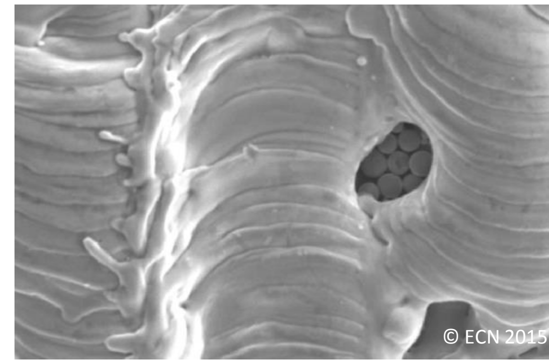
Stress relieved
(Near) Net shape
part

Low Stress SLM a Direct Method

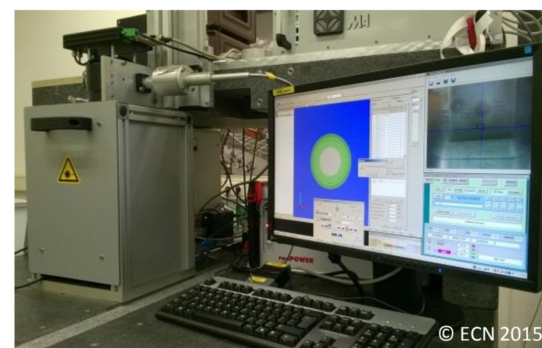
- Research & Development

New Material system (patent pending)

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



"A peek in the lab"



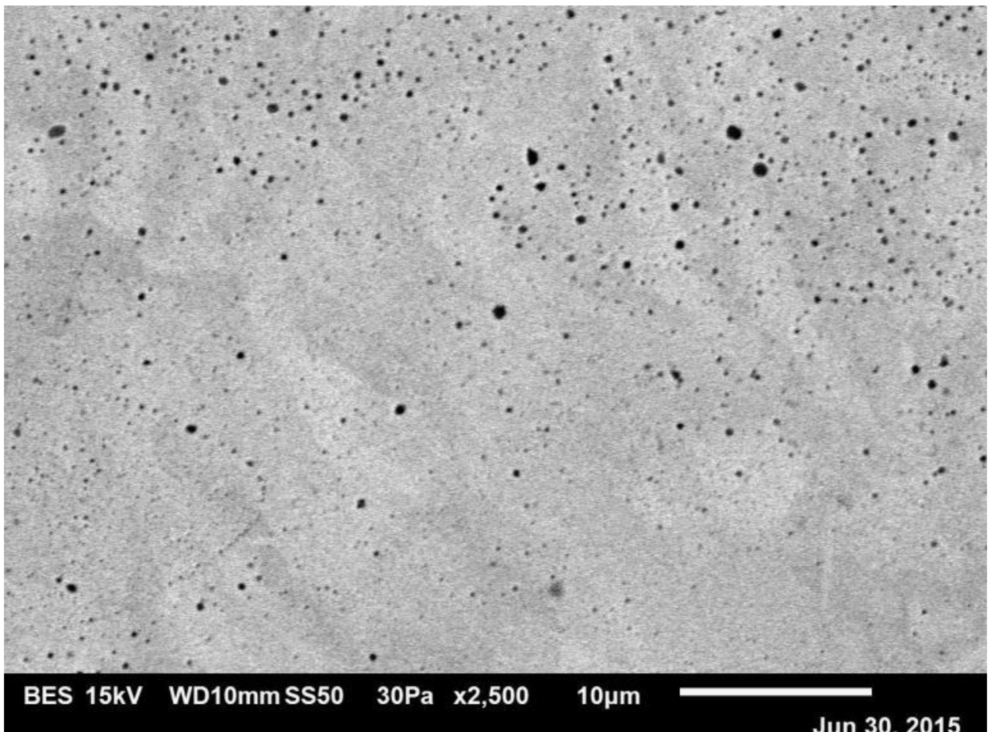
Test setup

Additive Manufactured Part

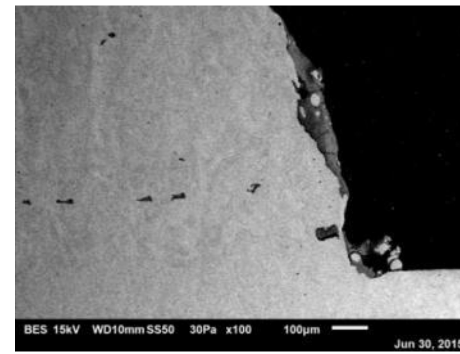
- Micro Turbine
  - Properties
    - ECN test setup
    - 316L Stainless Steel
  - Dimensions
    - Diameter: 20 mm
    - Height: 8.3 mm

Details – SEM images

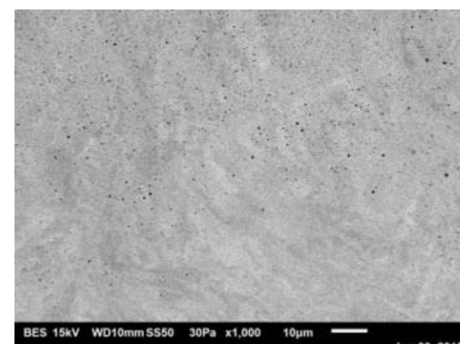
- (sub) Micron porosity



Low Stress SLM 316L – 2500x



Low Stress SLM 316L – 100x



Low Stress SLM 316L – 1000x

Scan & Hatch Optimisation

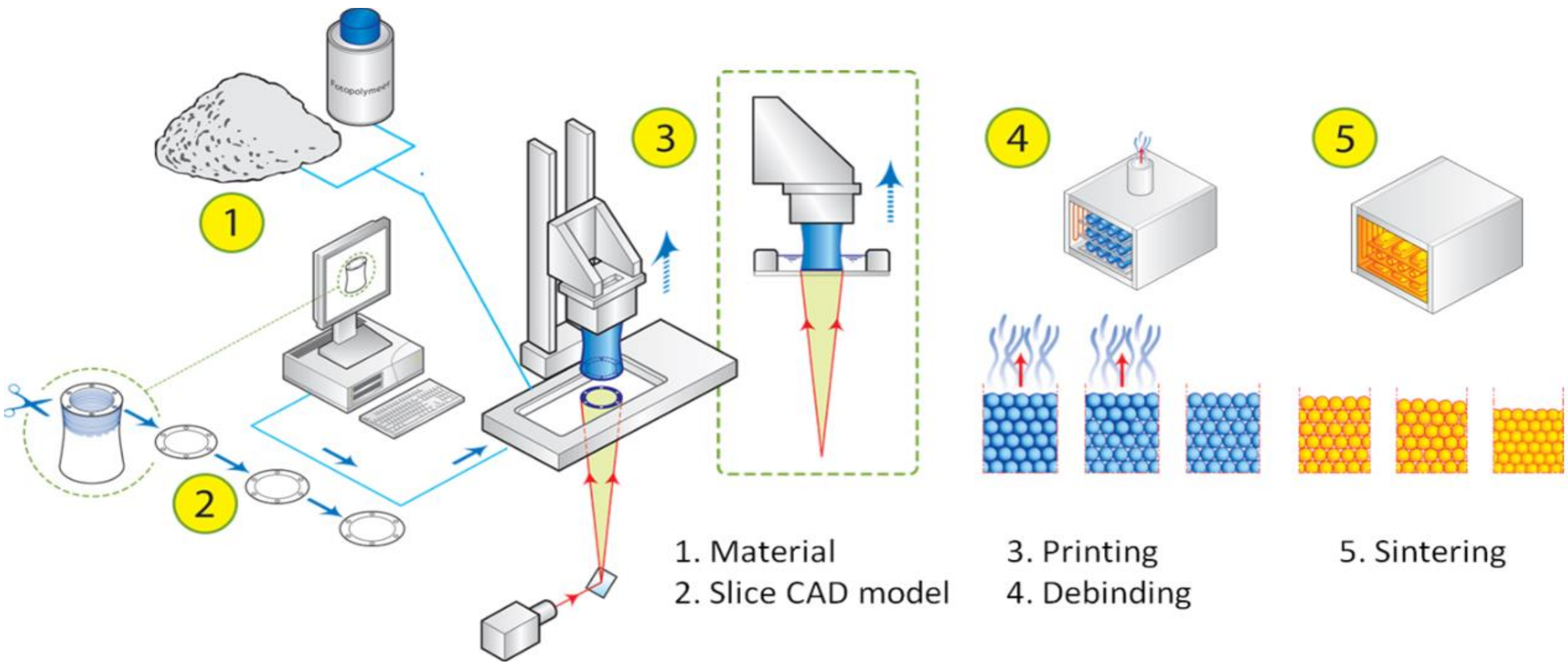
- Process Optimisation
  - Start / Stop delay times
  - Laser Power / Scan Speed

Initial settings

Optimised parameters

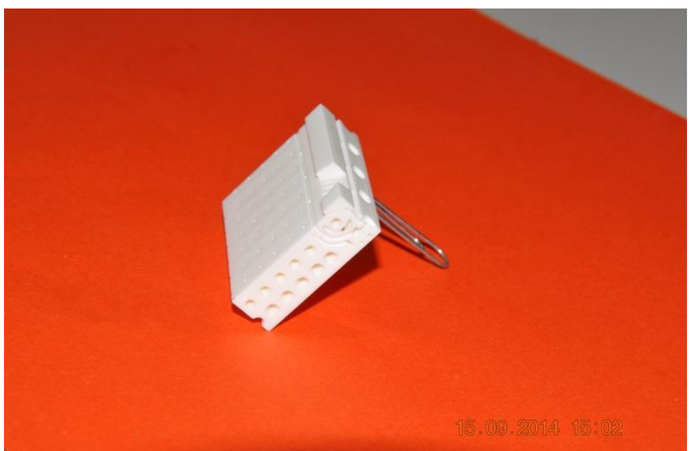
Vat Photo Polymerisation of Metals

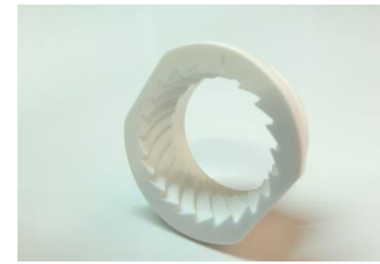
- Indirect, Slurry based process



"Proven" Technology for translucent ceramics

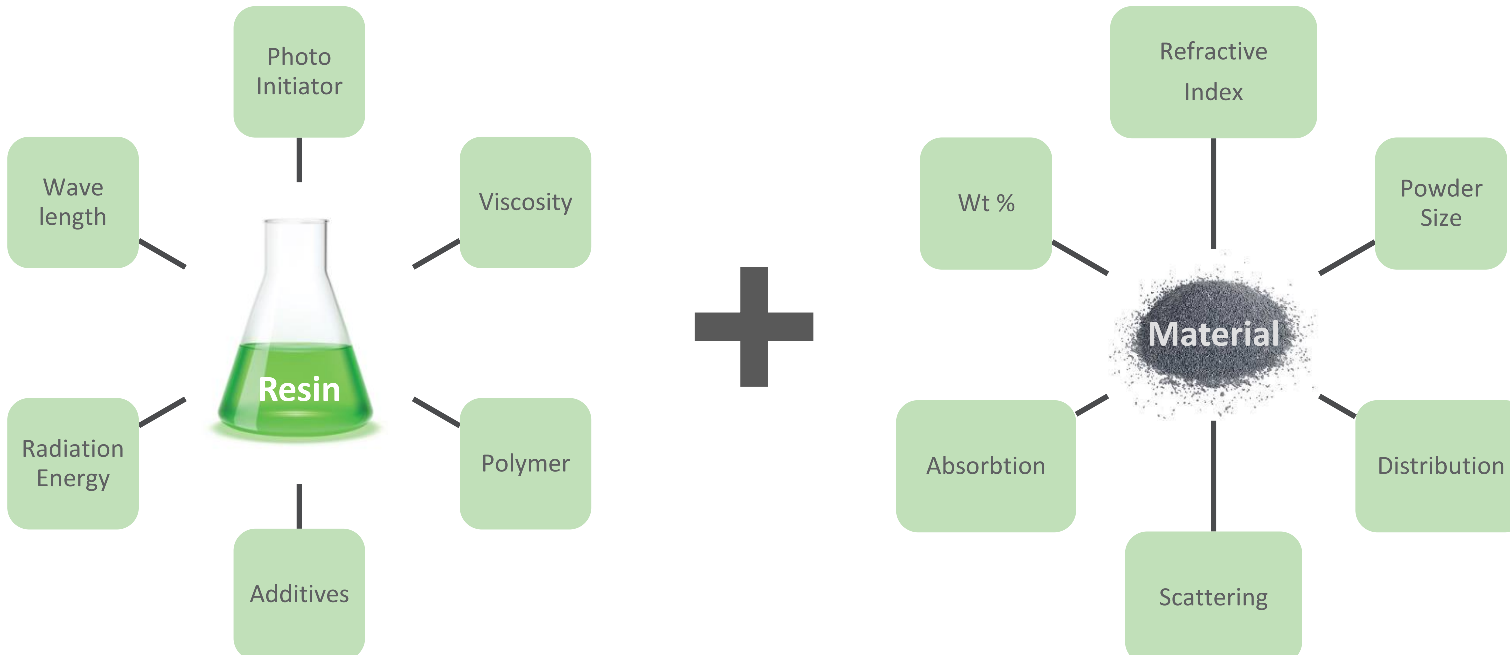
- Ceramic Materials
  - Al_2O_3 & ZrO_2
- High Quality,
  - small features,
  - accurate details
  - low roughness





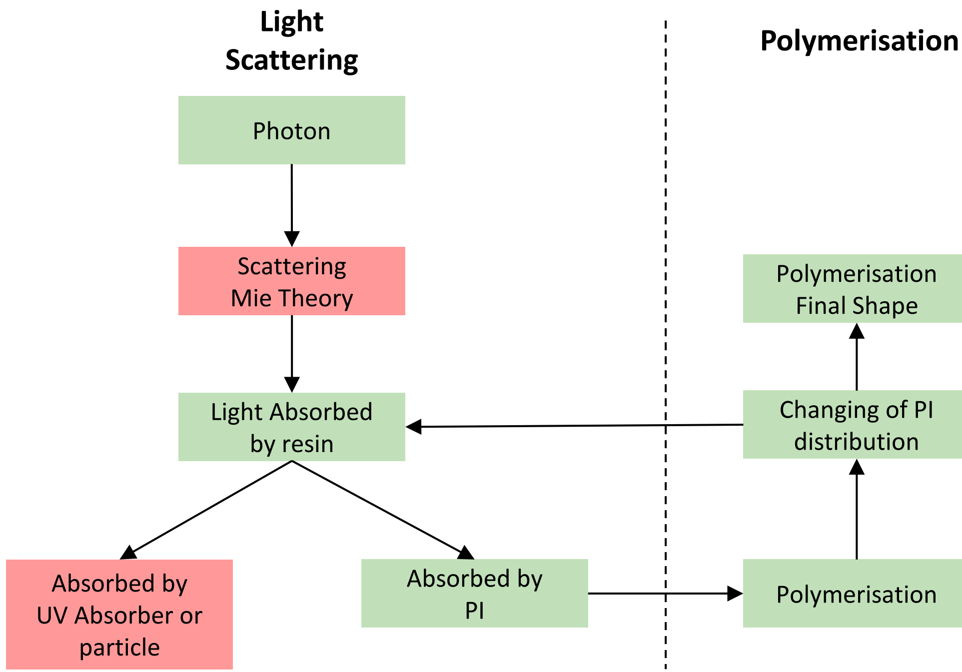
To be succesfull…

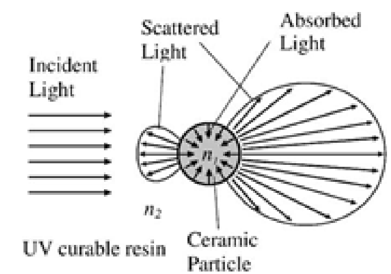
- Preparing a “good” slurry to match your process is key.

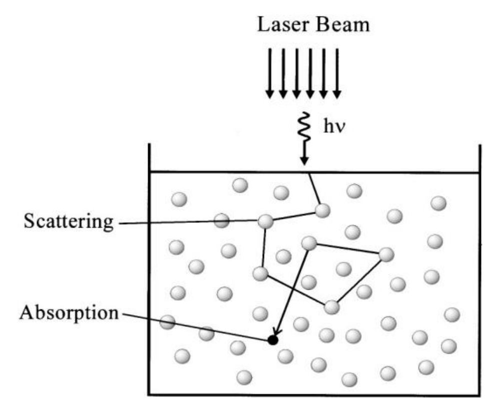


“Limiting” material properties; “black powders”

- Absorbtion & Light Scattering

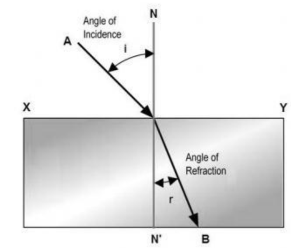






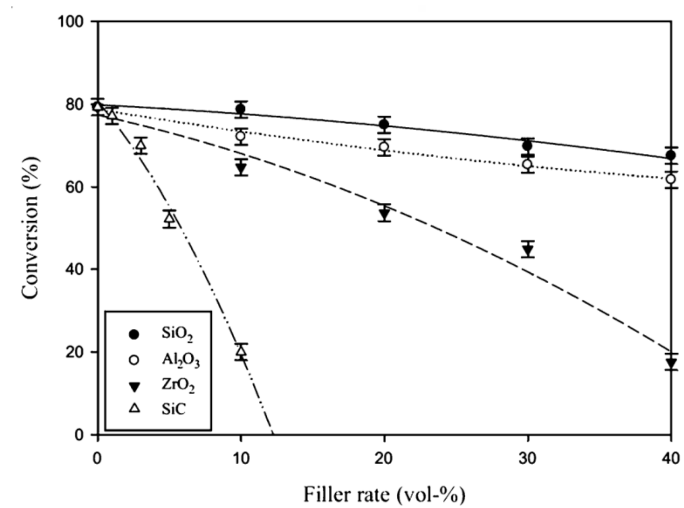
Mismatch in refractive Index

- 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		

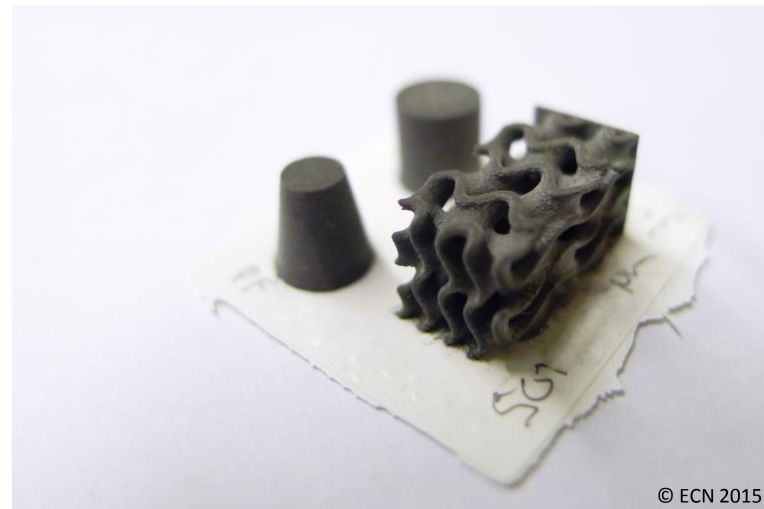
* *P.J. Bartolo (ed.), Stereolithography: Materials, Processes and Applications, Materials for Stereolithography: S. Corbel et al.*

Printed (first results) in SiC and Stainless Steel 316L

Development – Metals

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

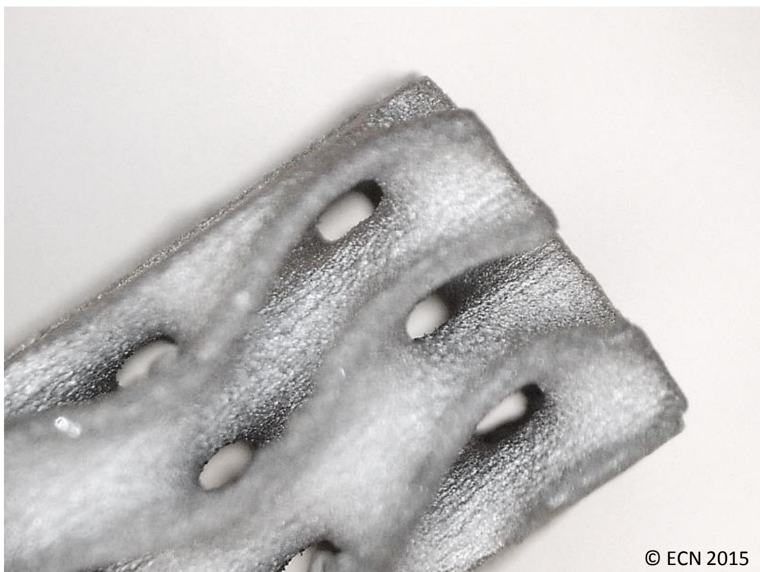
Detail of 3D printed geometry - green



Build platform with 3D printed parts

Development – Metals

- Sintered 316L part
  - Size: 5x5x10 mm

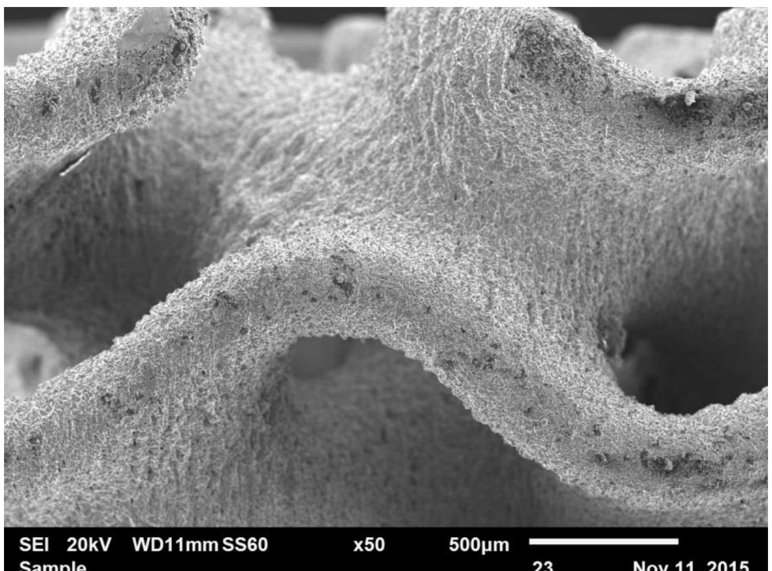


Detail of 3D printed geometry - sintered

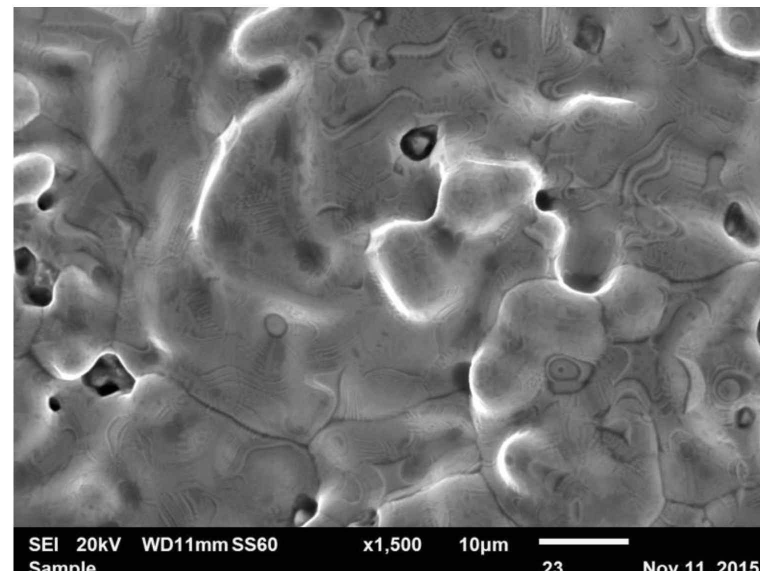
3D printed geometry - sintered

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.

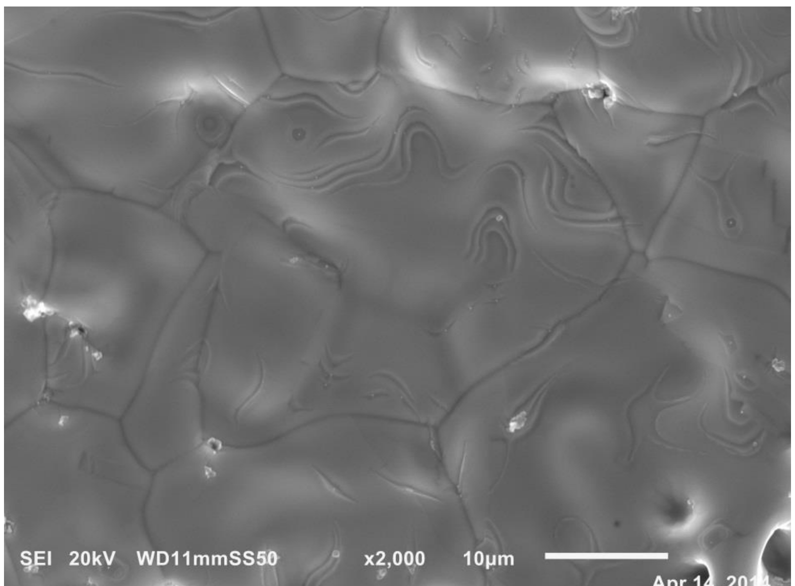
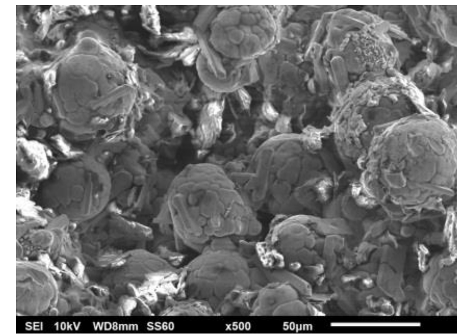


Photo Polymerisation 316L Sintered - ECN
(Indirect Process)



Binder Jet – ExOne
(Indirect Process)

Powder Bed Fusion
(Direct Process)

Conclusion

- AM processes for Metals by
  - Liquid solidification (melted droplets)
  - (spot) welding (selective laser melting)
  - Thermal spraying (preheated powder deposition / impact)
  - Sintering

- Best AM metals by Sintering!

  A production comparable tot PM Steel production and or Metal Injection Molding > possible by VAT polymerization as intermediate binder even for Metals

- Production speeds of cm / hour (full area) are realistic

Summary Metal Printing ECN

Indirect method	Direct method
Pro - *Isotropic high quality structure* - *Complex features possible* - *Low cost printing equipment*	**Pro** - *Direct* - *Low stress compared to SLM* - *Finer Features / channels possible*
Contra - *Separate densification process* - *Shrinkage* - *Build speed lower than ceramics*	**Contra** - *Expensive equipment, comparable to Vat Photo Polymerisation equipment* - *Anisotropic microstructure*
Patents - *Pending 3x* - *Assigned 1x*	**Patents** - *Pending 1x*

Thank you for your attention

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ECN – Focus Area

- 7 Core Activities

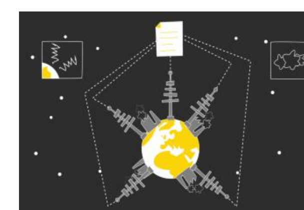
Wind Energy

Solar Energy

Energy Efficiency

Biomass

Policy Studies



Environmental.
Assessment

Engineering & Materials

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