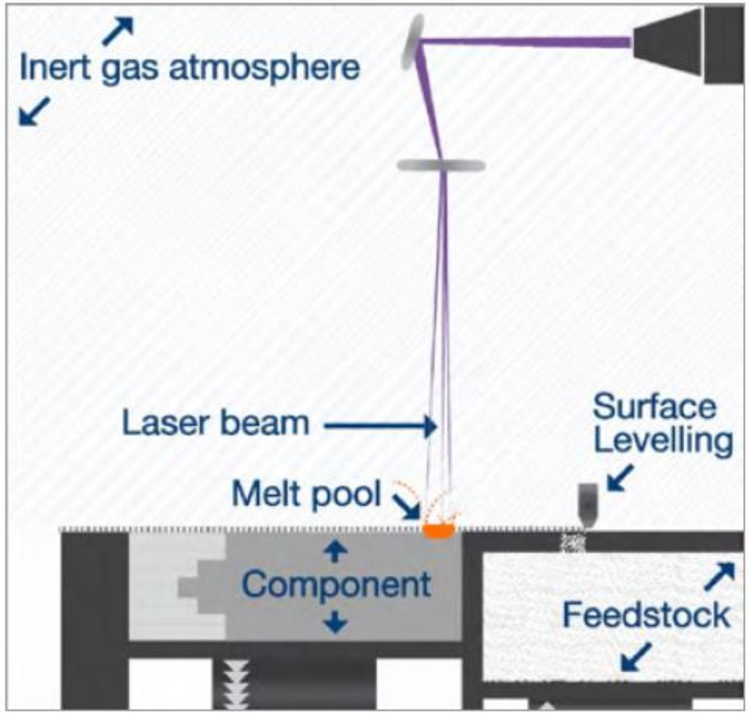
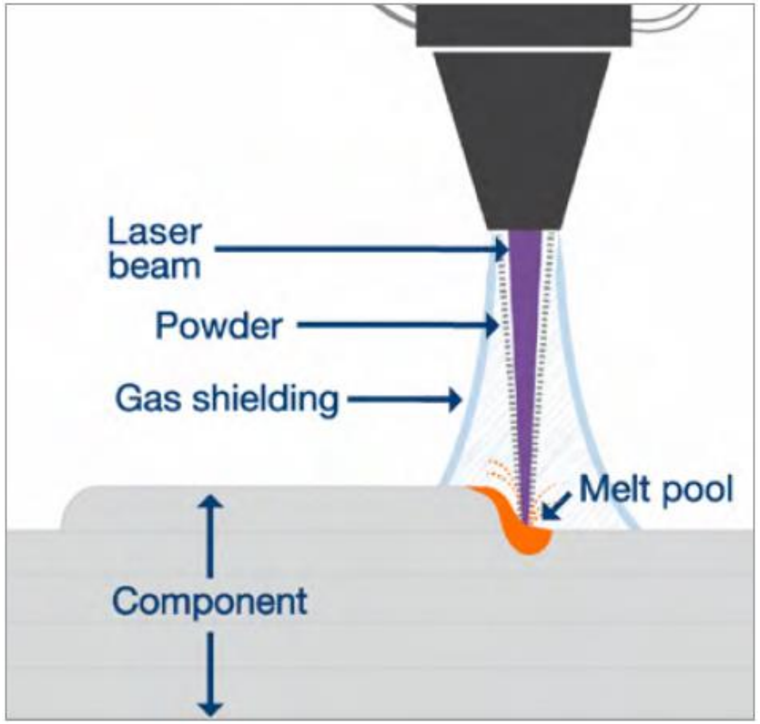
INSIDE Metal AM

AM Technologies

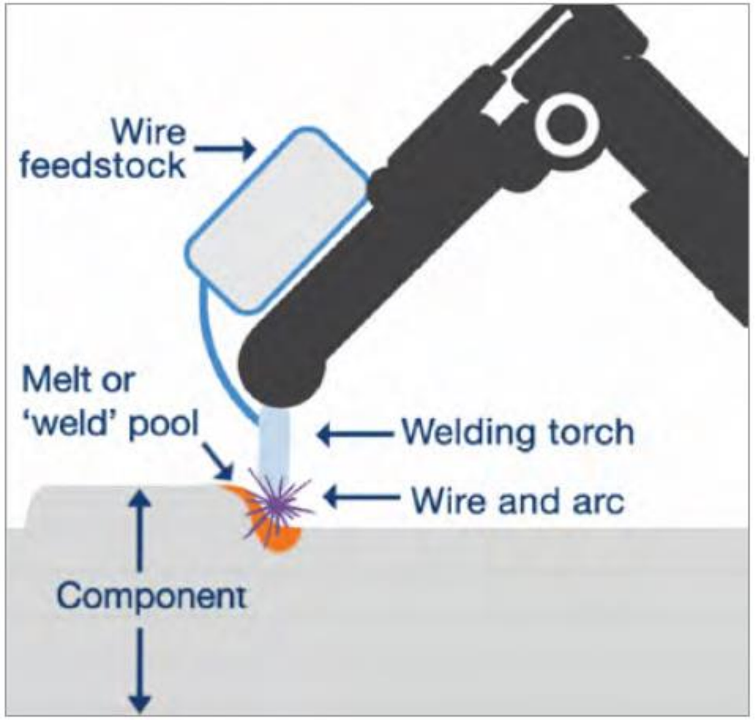
SLM
Powder Bed Fusion by Laser (PBF-LB)



LMD
Directed Energy Deposition by Laser (DED LB)



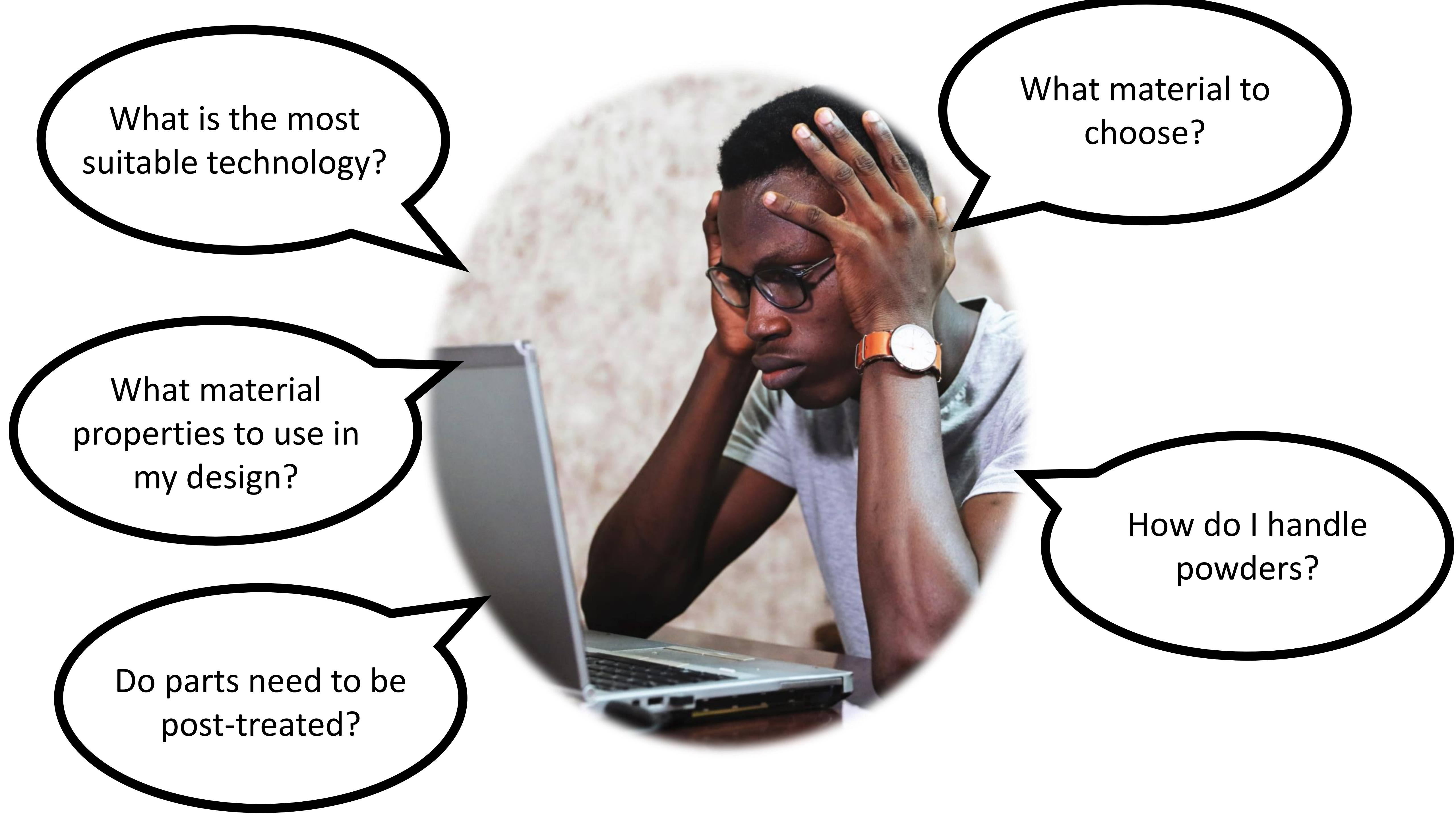
WAAM
Directed Energy Deposition by Arc (DED Arc)



Source: Lloyd's Register & The Welding Institute (TWI) – *"Guidance notes for Additive Manufacturing"*

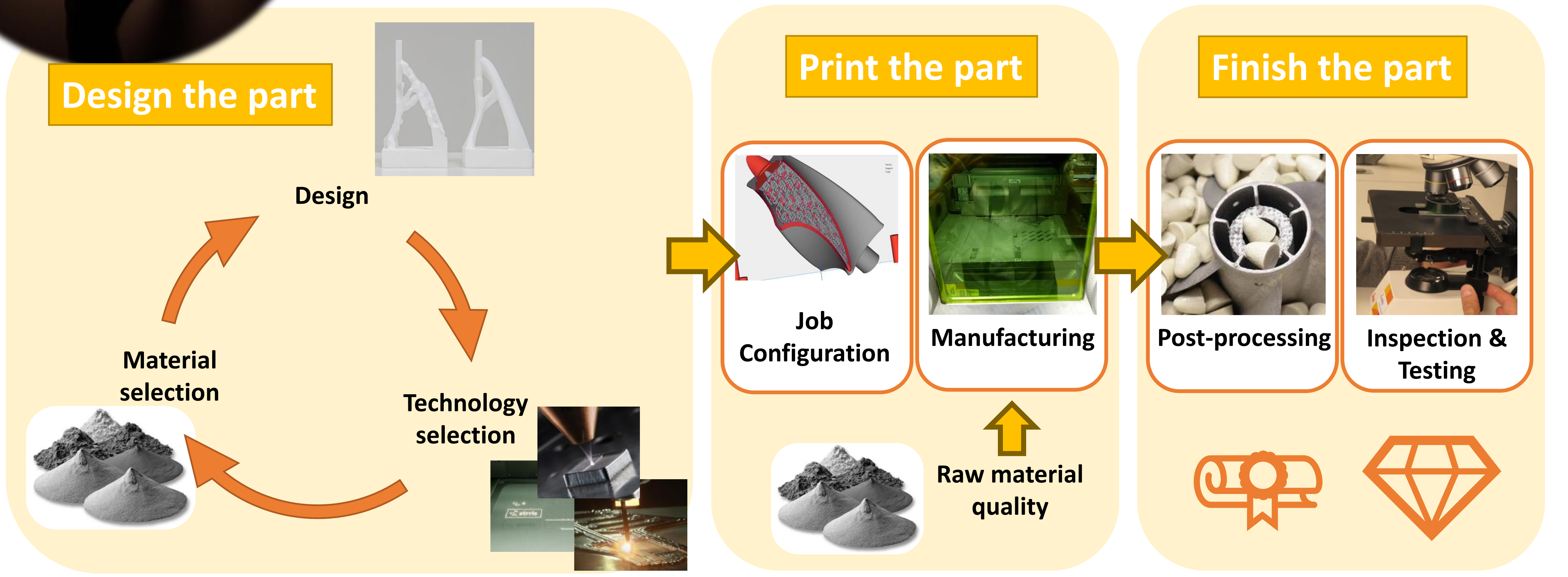
You have an idea to use a 3D printed part.

What now?


What is the most suitable technology?
What material to choose?
What material properties to use in my design?
How do I handle powders?
Do parts need to be post-treated?

Idea :
Protection
Anteriority
AM suitability
Manufacturing :
Monitoring solutions
Follow up procedure
Quality assessment
Post-Treatments :
Bulk (Heat, UV,…)
Surface (polish, coatings)
Cavities cleaning
Machining advices
Material :
characterization
Handling procedure
Testing & development
Optimization :
Topological optimization
Simplify assembly
Textures, labeling
Function integration
Characterization :
Dimensions (3D scan)
Surface quality
Density
Mechanical properties
Aging
Technology :
Selection
Future trends
Advice
Process chain integration
Processability :
Reduce wastes
Define orientation
Integrate post-treatments
Process simulation

AM Process Flow



Design the part

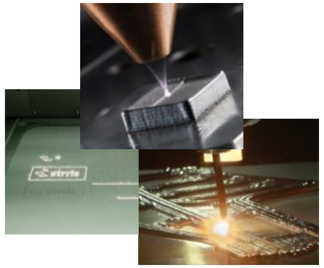
- Start from geometry/function
- Topology optimization

Design

Material selection

List Requirements

- Selection of material
- Linked to choice of technology
- Powder parameters

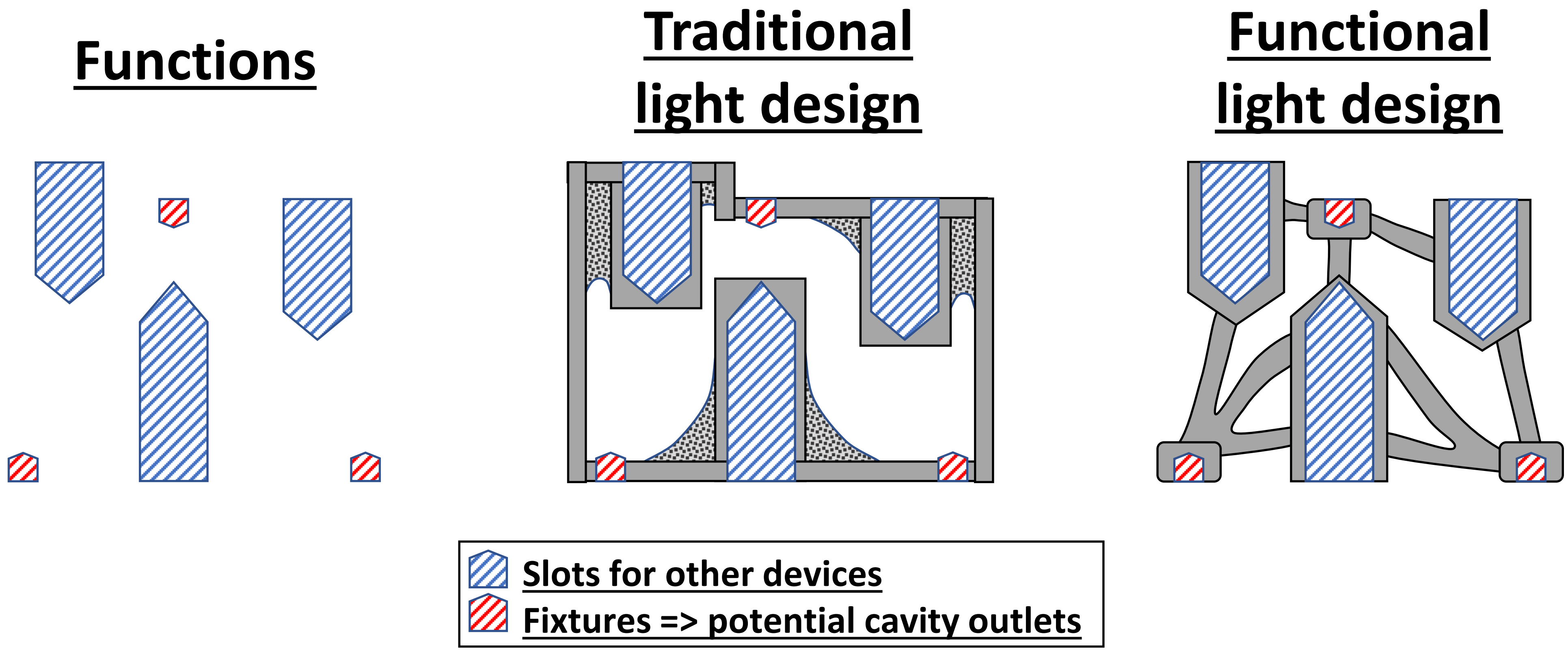


Technology selection

- Selection of print technology
- Printability

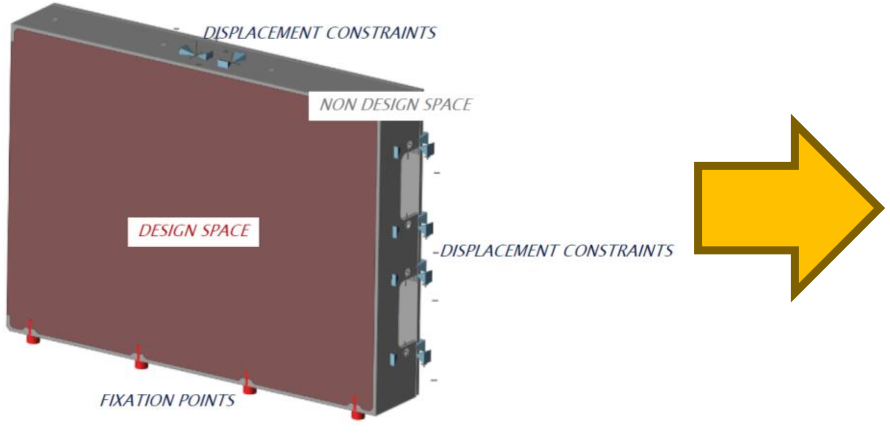
Design

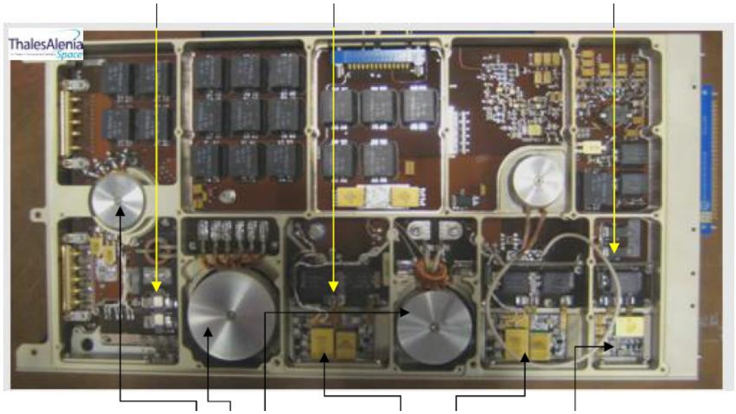
Start from part functions

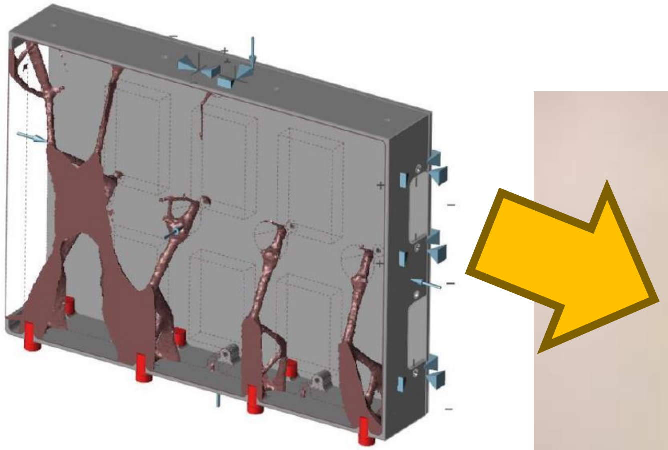


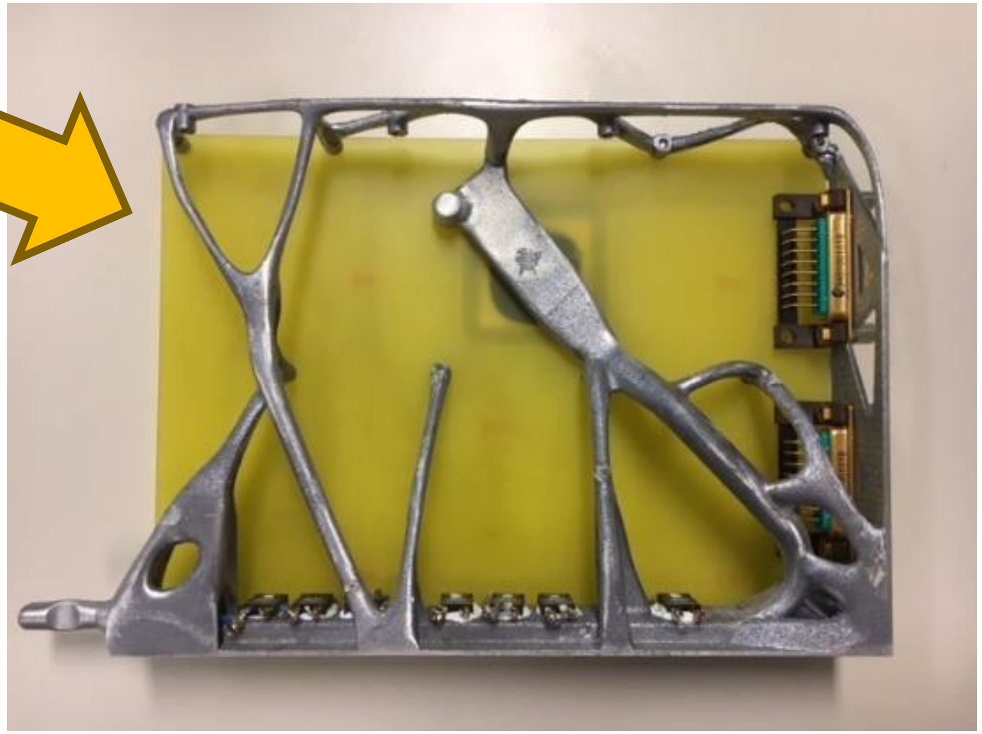
Design

Topology optimization



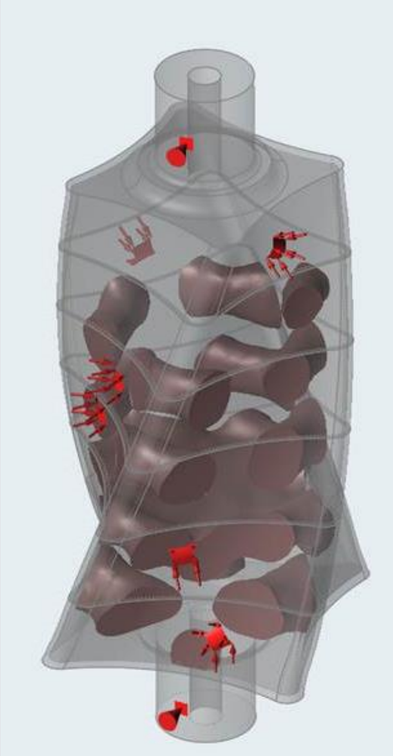






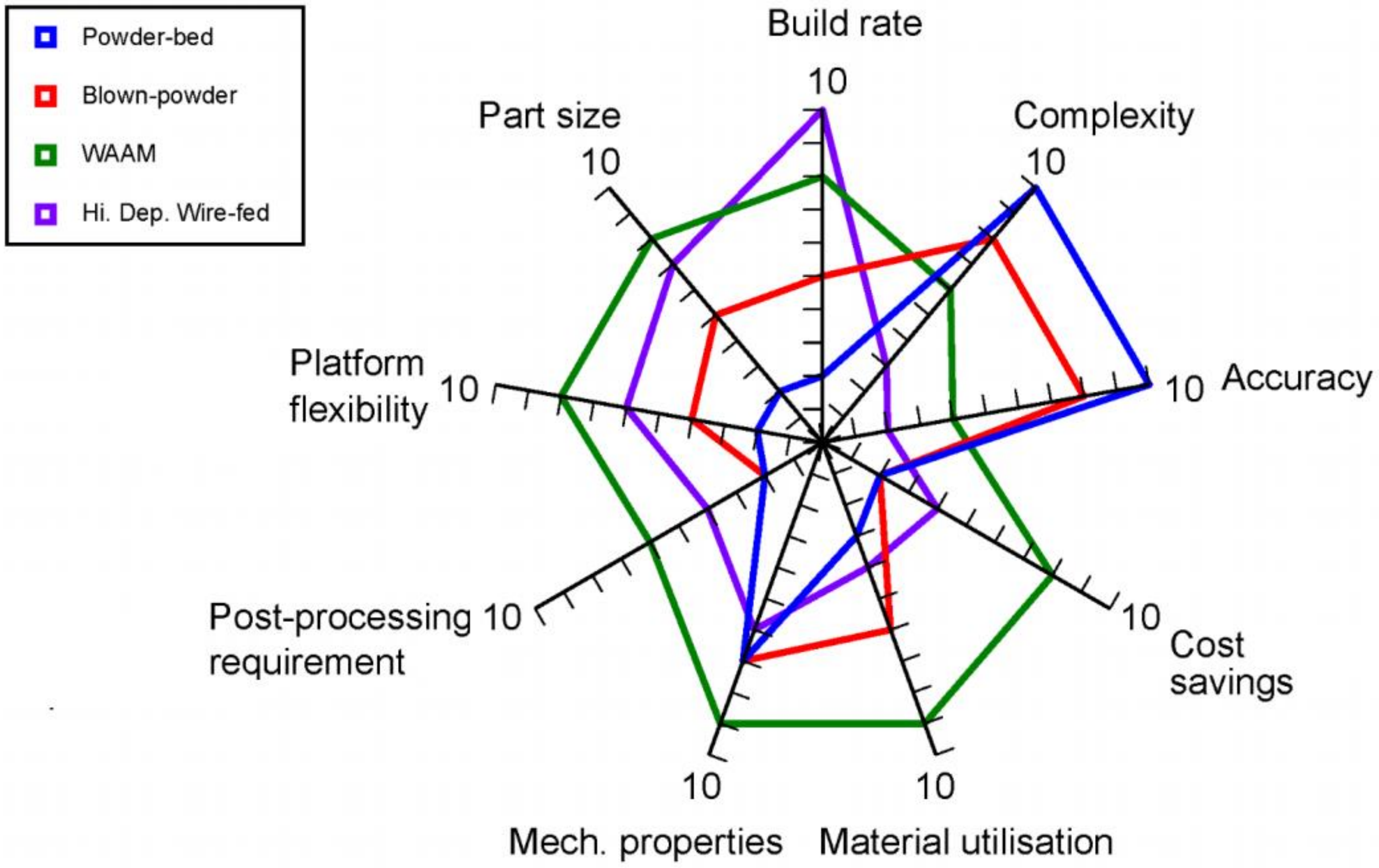
Design

Topology optimization



1. Topology optimization linked to part orientation in AM machine
2. Requires realistic load case
3. Importance of boundary conditions
4. Lattice vs. topology optimization

Technology Selection

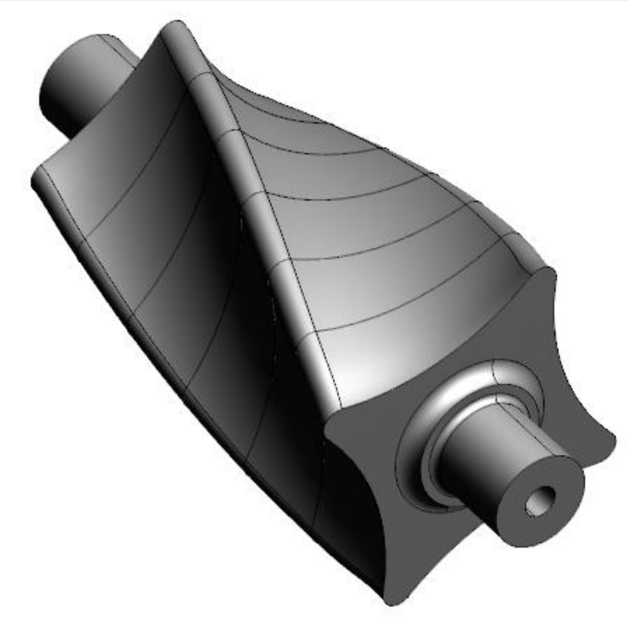


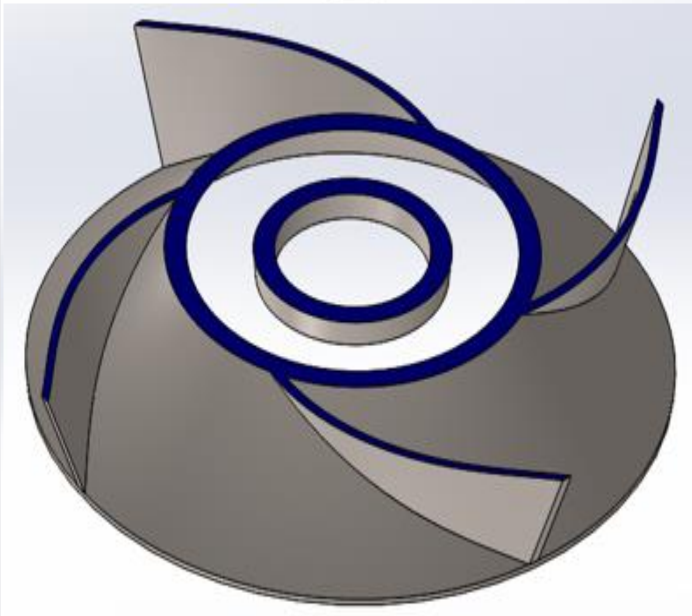
Source: Cranfield University

Technology Selection

SLM/LMD

WAAM/LMD





1. Printing of small features/large parts
2. Free hanging sections (supports?)
3. Inclined walls
4. Need for powder removal
5. Required accuracy
6. What post-processing and when

Technology Selection

Topic	L-PBF	EBM	Binder Jetting	FDM	DED-LB	DED-WAAM	Sheet lamination
Feedstock	Metal powder < 60 µm	Metal powder < 80 µm	Metal powder up to 100 µm	MIM feedstock, wire or pellet	Metal powder < 150 µm or wire	Metal wire ø 0.8-1.6 mm (multi-wire)	Metal sheets
Bonding means	Laser	Electron beam	Polymer binder	Extruded in heated nozzle	Laser	Electric arc	Friction, mechanical
Part size	Std : 250 mm Max : 1000 mm	Std : 200 mm Max : 380 mm	Std : 100 mm Max : 800 mm	Std : 100 mm Max : 300 mm	Up to several m (robot vs CNC)	Up to > 10 m (robot on rail config.)	Up to 4m
Min wall thickness	0.3 mm	0.8 mm	1 mm	1.2 mm	1 - 2 mm (focal spot, material)	2 - 3 mm (ø wire, material)	Depends
Strength	- Accuracy - Surface finish - Fine details	- Limited stress - Handle bulky parts - Low contamination - Manufacturing speed	- Limited stress - Atm. Conditions - High speed	- Limited stress - Clean - Affordable	- Medium size … - AM on existing part - Multi-material and FGM	- High deposition rate - Lower investment/m² - Integrate substrate - Good density	- Sheet mech. properties - As-built accuracy - Sensor embedded - Multimaterials
Weakness	- Supports removal - Internal stresses - Post process	- Powder cake removal - Limited material range - As-built roughness	- Needs sintering (Shrinkage 20%) - OR Infiltration (weakness infiltrant)	- Shrinkage 20% - Needs sintering - Slow technology	- No supports - Limited overhang and precision - Surface finish (waviness)	- Low part complexity and surface finish - High HI, residual stresses and distortions - Under development	- Slow process
Applications	- Large range of thin, accurate parts - Parts with cavities, channels	- Small to medium bulky organic structural components without cavities	- Small parts, with quite thin walls in huge quantities	- Small parts, with quite thin walls in small quantities	- Parts of medium … - Cladding, repair - Customization of existing parts	- Large structural parts (aerospace, marine) - Large machine parts, tooling (machining)	- Quite uncommon
Suppliers	SLM Solutions Concept Laser 3D Systems EOS Trumpf AddUp	Arcam (GE) EBAM (Sciaky)	Digital metal ExOne Desktop Metal HP	Markforged Desktop Metal 3DVigo AIM3D Pollen	Optomec Trumpf DMG Mori Seiki BeAM Hornet (modular)	Gefertec Prodways Hornet (modular)	Stratoconception

Material Selection

D2.1 – Aanbod en selectie van printmaterialen

Project titel: VIS INSIDE Metal AM
Project Type: Speerpuntcluster-VIS-project
Projectduur: 01/04/2018 – 31/12/2020

Dit project werd mogelijk gemaakt door de steun van het Strategisch Initiatief Materialen (SIM Flandres) en het Vlaams Agentschap voor Innoveren & Ondernemen (Vlaio).

Projectpartners: Sirris, CRM, BIL, SIM

Type document: project rapport
Versies: v1.2, 23/06/2020
v1.3, 14/08/2020
Auteur: Jeroen Tacq, jeroen.tacq@sirris.be, 0493 31 06 44

Een beknopte versie van dit verslag verscheen in Metallerie op 30/06:
Selectie van printmaterialen en beschikbare staalsoorten – 3d-printen met Metaalpoeders, Metallerie nr. 2005, 30/06/2020.

Meer informatie over dit project kan u terugvinden op: https://www.sirris.be/node/50468

https://www.sirris.be/nl/inside-metal-additive-manufacturing

- Material selection (steel) linked to implemented technology
- Doesn't need to be the same as conventional part

SLM/LMD

- Limited material choice

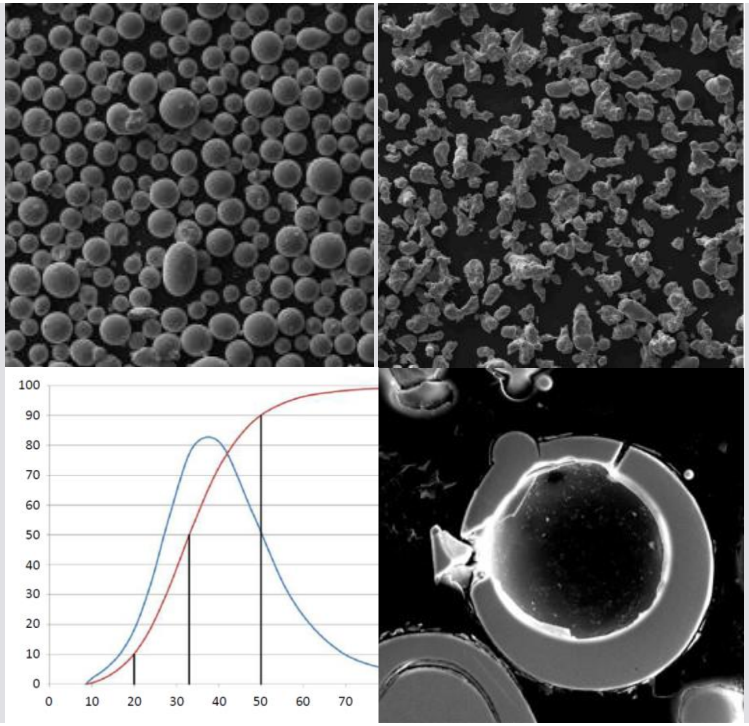
WAAM

- Mostly welding consumables

316L
304
H13
M300
15-5PH
17-4PH
CL 91RW
CX
BLDRmetal L-40
M789
M3
Invar36

Material Selection

Powder quality features

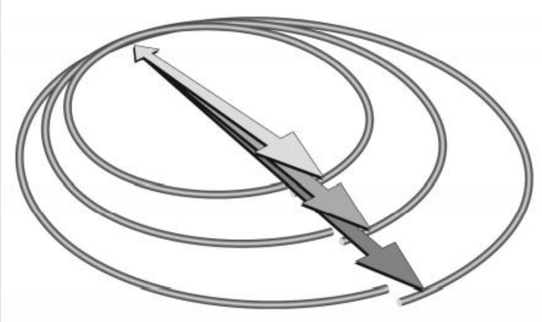


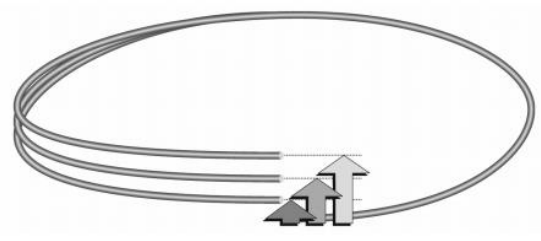
- ✓ Particle size and distribution
- ✓ Shape
- ✓ Flowability
- ✓ Entrapped gas

SLM vs. LMD

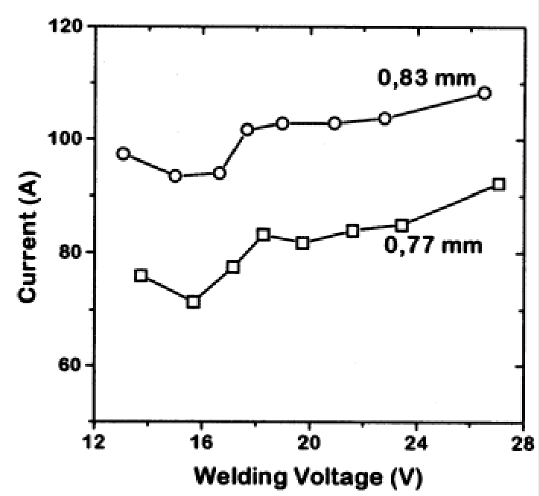
Material Selection

Wire quality features





Source: National Standard

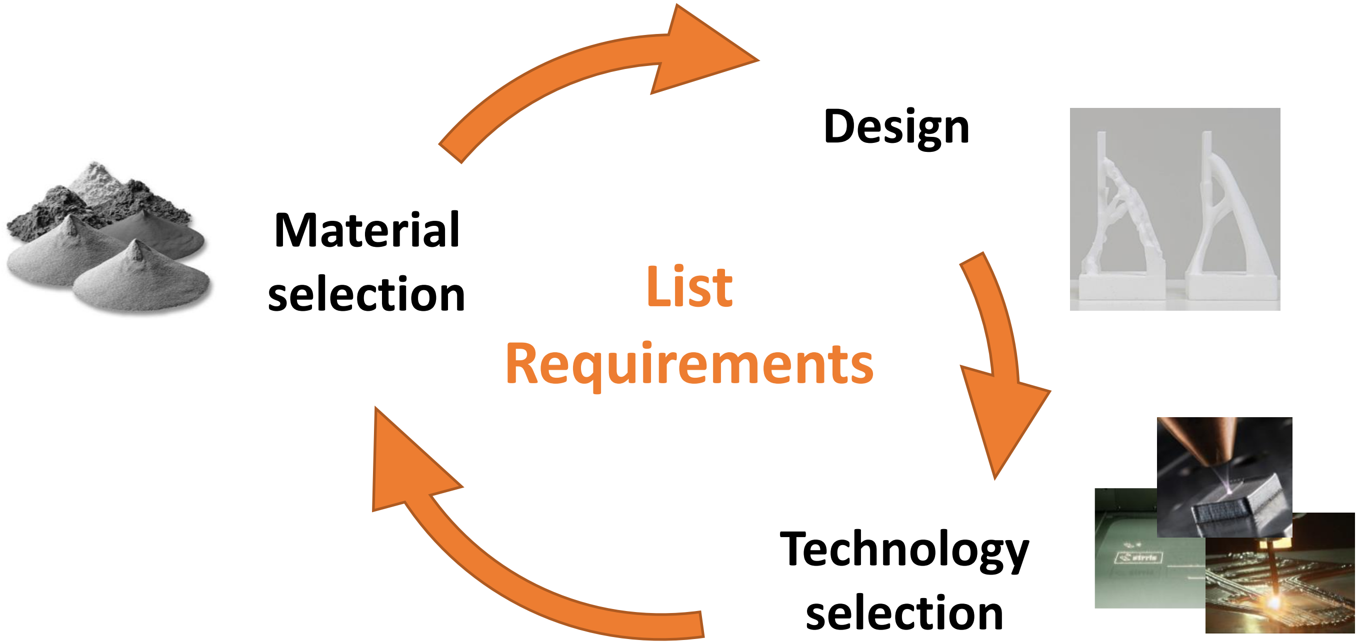


Source: Modenesi & de Avelar
JoMPT 86, 226-232 (1999)

- ✓ Cast and helix (feedability, arc stability)
- ✓ Diameter tolerance (mechanical, electrical)
- ✓ Chemical composition
- ✓ Surface condition (contamination/defects)
- ✓ Internal condition (homogeneity/defects)

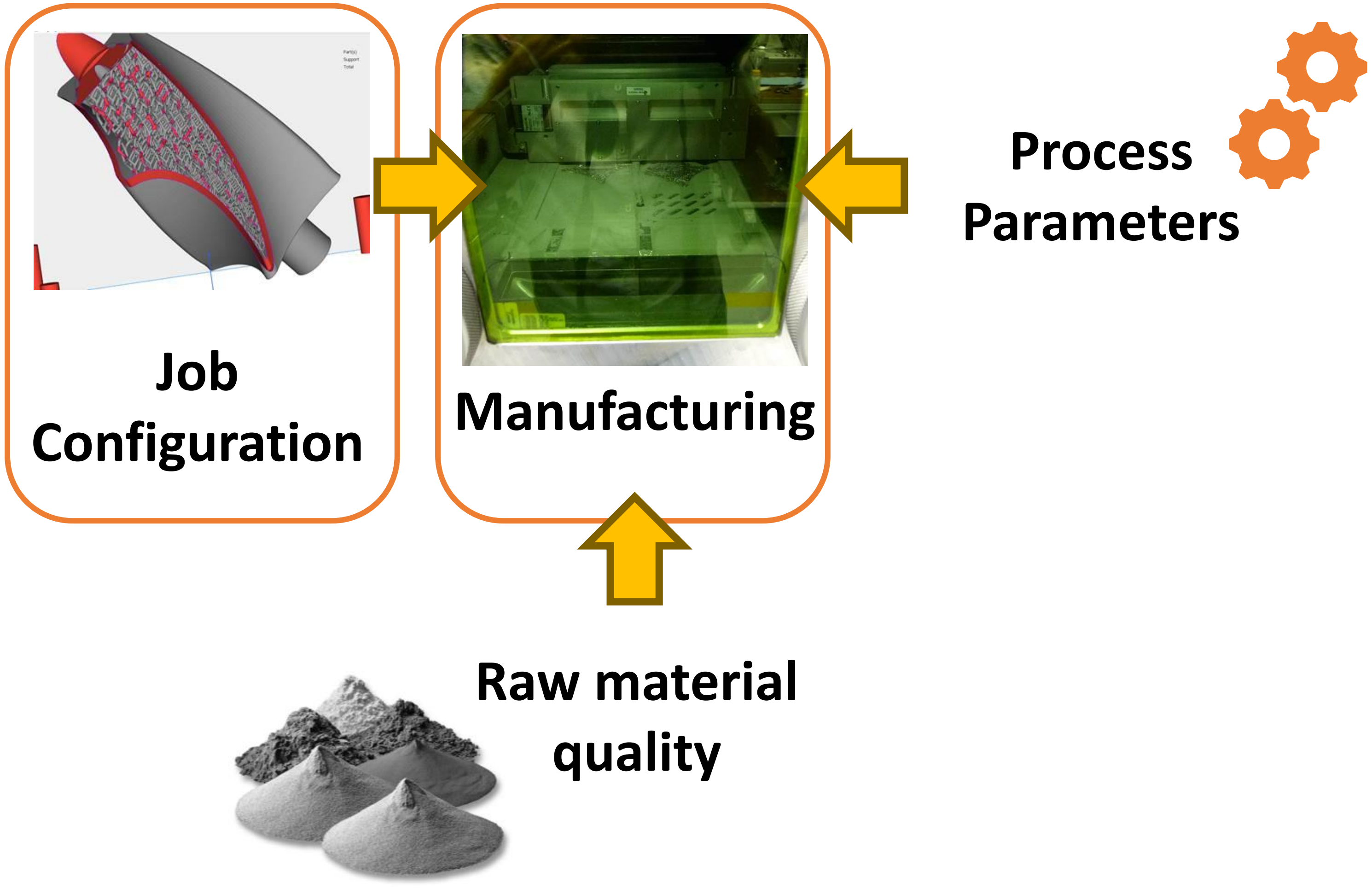
Welding vs. WAAM/WLAM/EBAM

Design the part



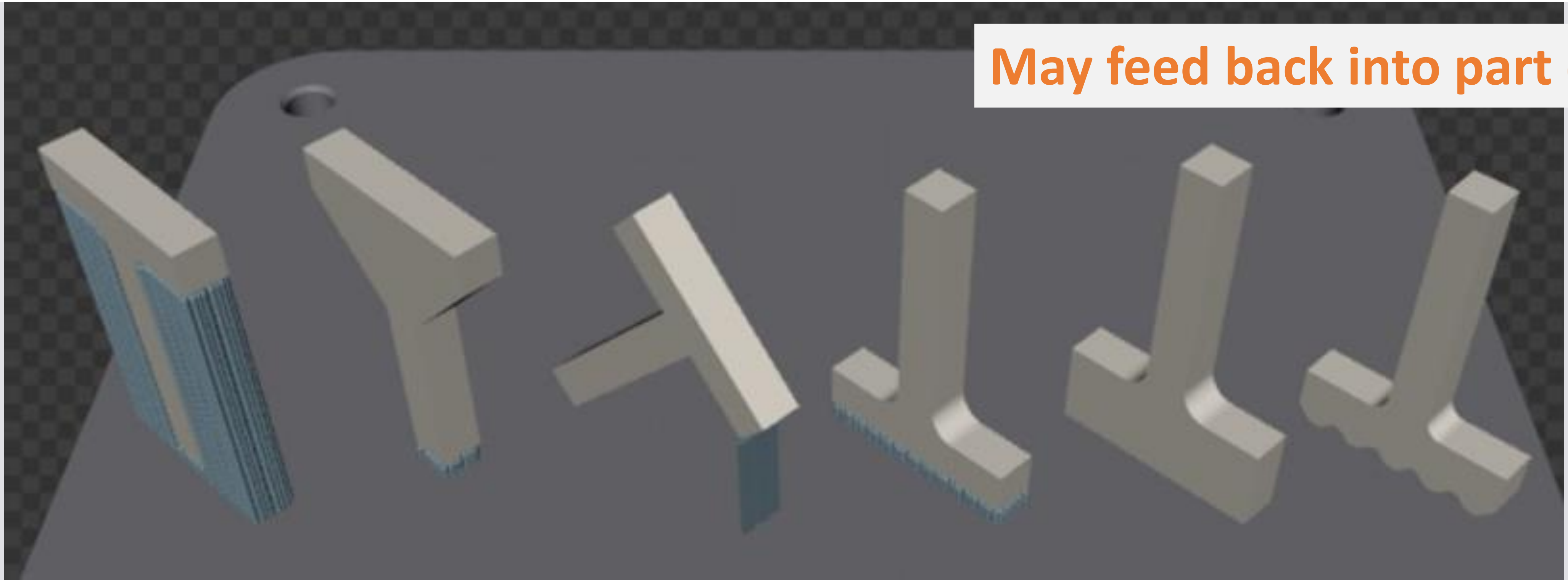
- Requires collaboration between an application expert and a 3D printing expert.
- Keep in mind post-processing steps!

Print the part



Job Configuration

Printability



May feed back into part design

Job Configuration

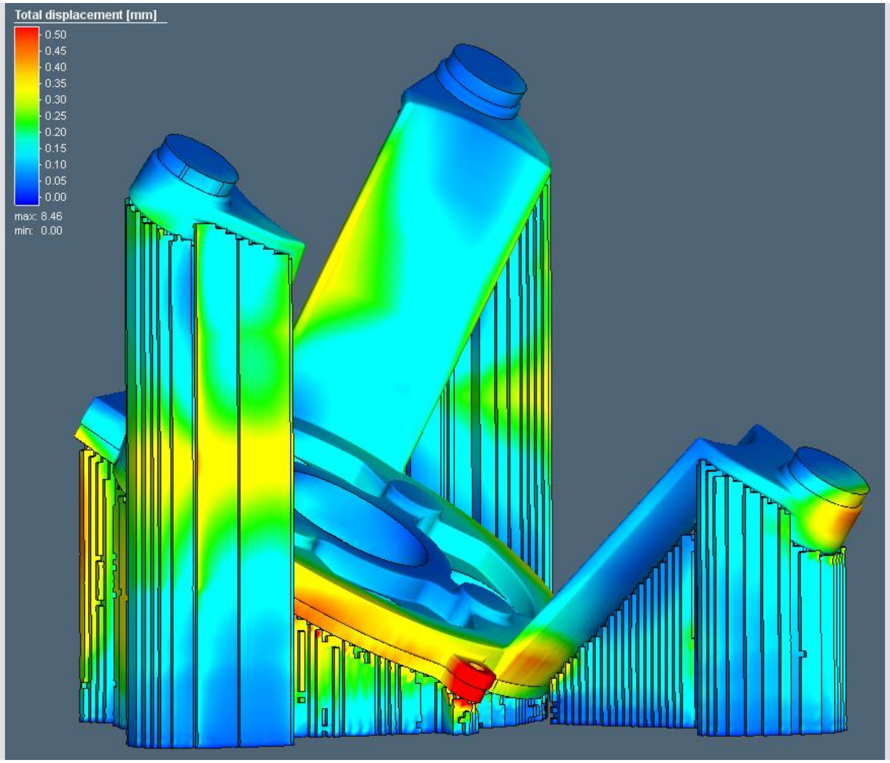
Lessons learned from demonstrators - SLM

1. Reduce overhang
2. Avoid surface orientation close to the limit
3. Avoid large and long horizontal sections
4. Take care about thermal dissipation
5. Take care of powder removal
6. Powder spreading

Job Configuration

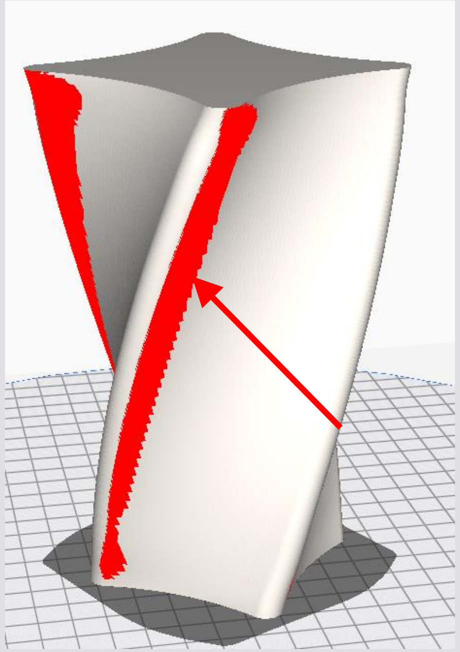
Process Simulation, SimuFact

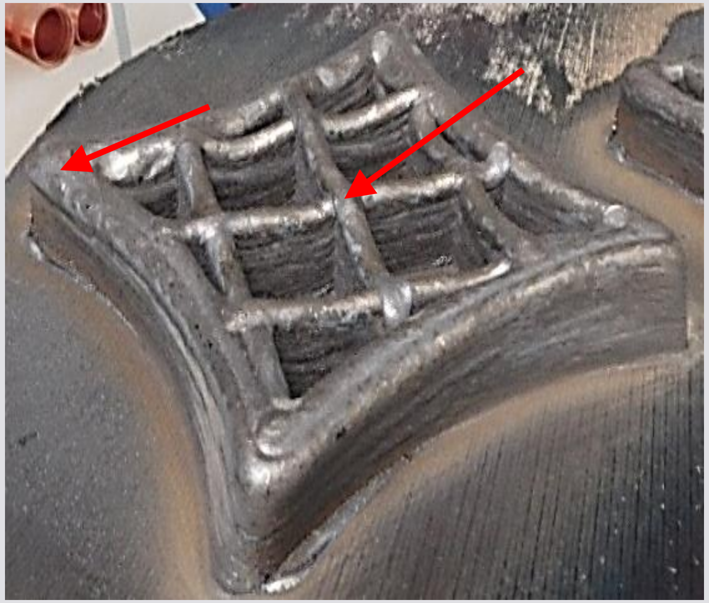
Shorten the road to a successful build



Job Configuration

Lessons learned from demonstrators - LMD

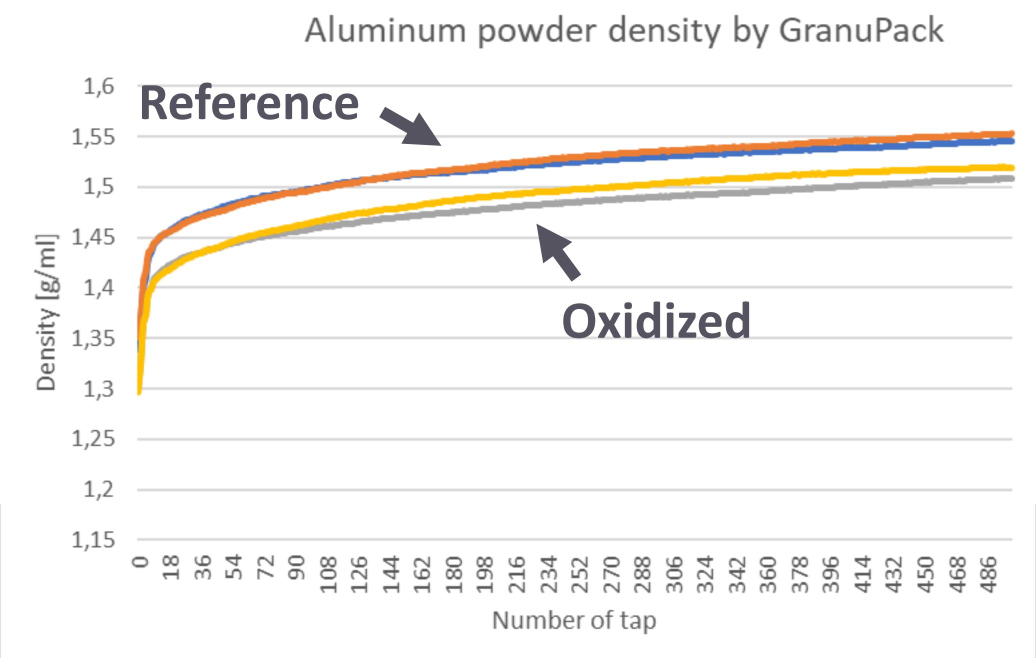




1. Reduce overhang (e.g. 15° if 2D positioning)
2. Avoid “hot spots” (start positions, speeds…)
3. Optimize paths for intersections/filling
4. Optimize “cold” displacements to minimize powder waste

Powder Quality

Process oriented powder analysis



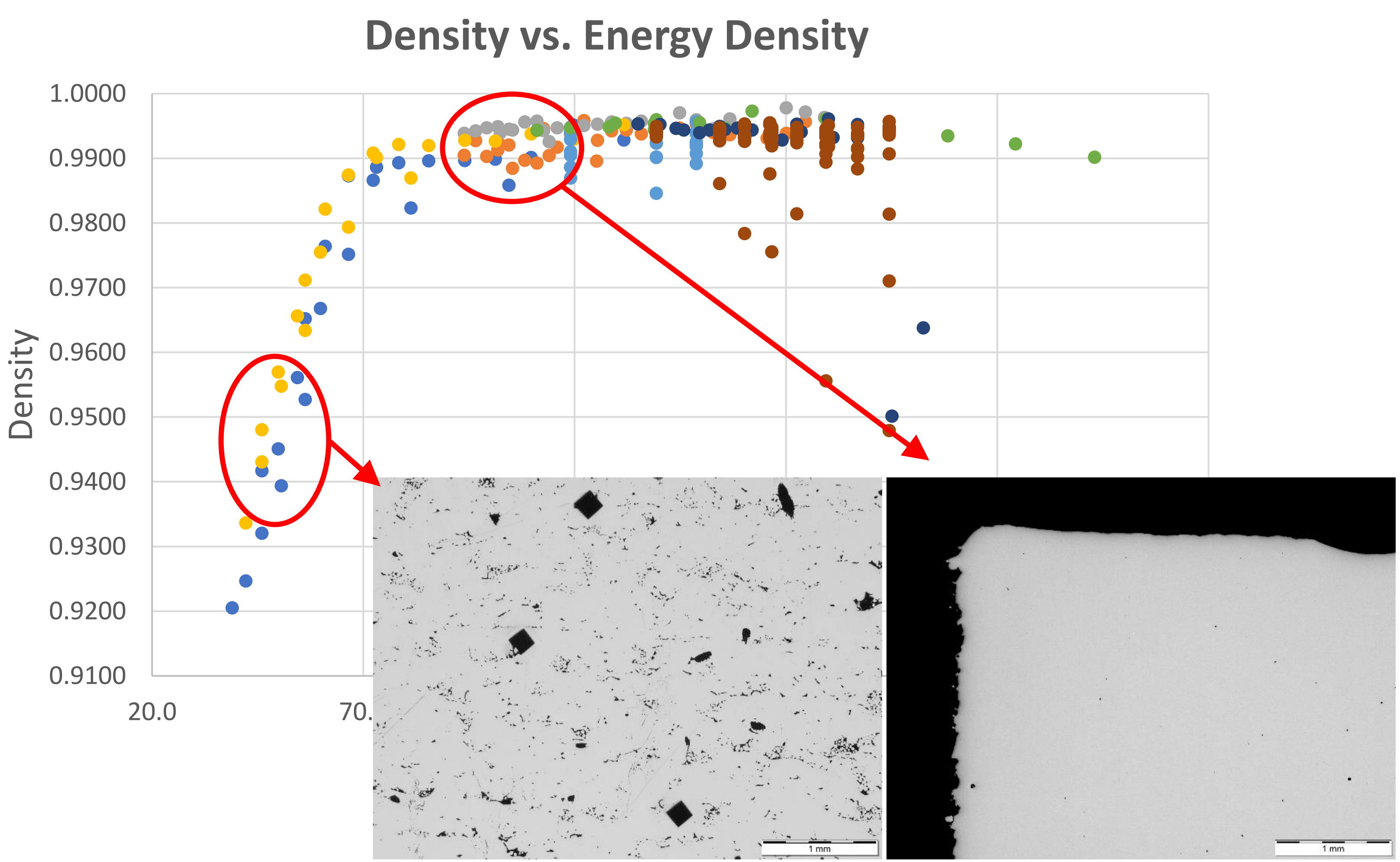
- ✓ Oxidation
- ✓ Humidity
- ✓ Size distribution
- ✓ Spreadability
- ✓ Segregation

Build up a history for your printing equipment in your environment and define a threshold for powder acceptance

Process Parameters

What are good settings ***for your machine***?
What ***material properties*** do you get?

SLM - Process Parameters (17-4PH)



At low Energy Density

Energy Density ↗

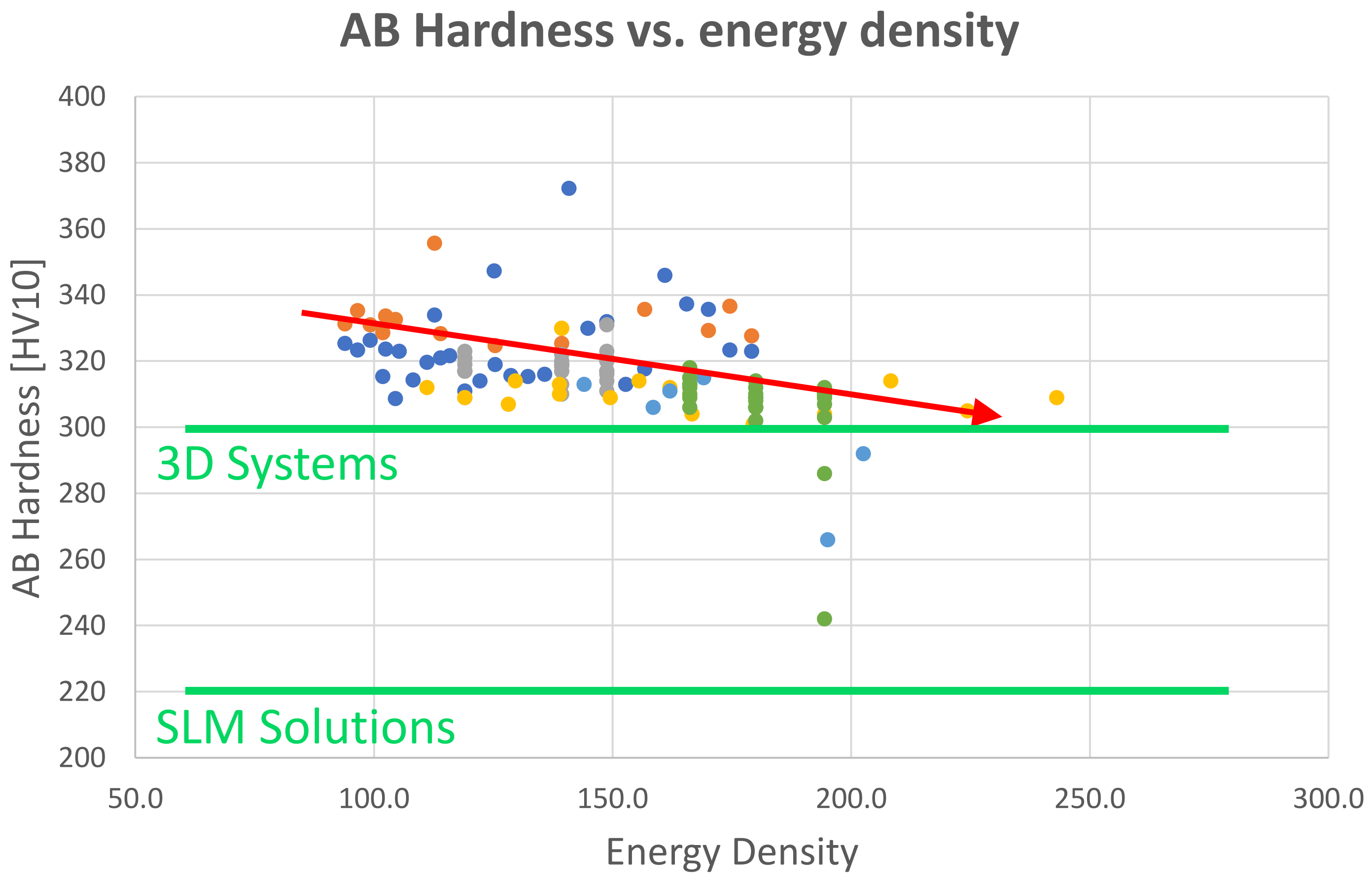
Material Density ↗

At high Energy Density

Energy Density ↗

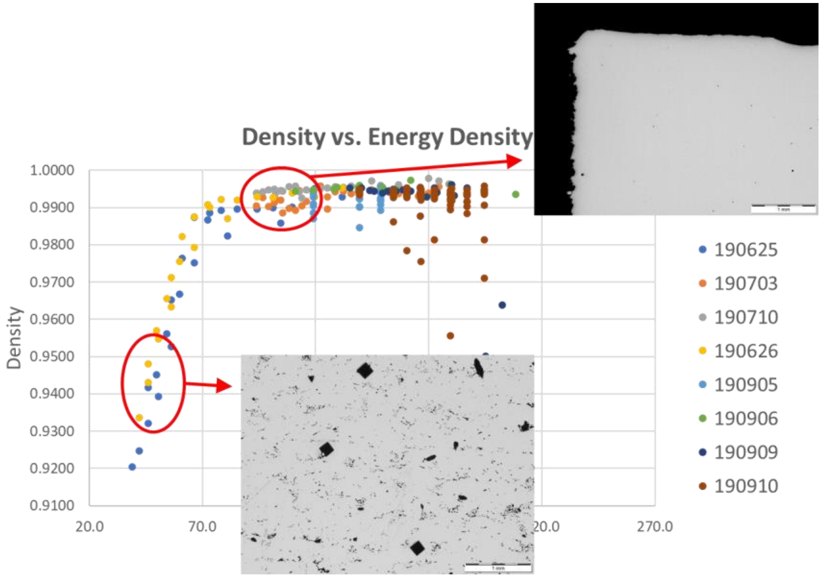
Material Density ↘

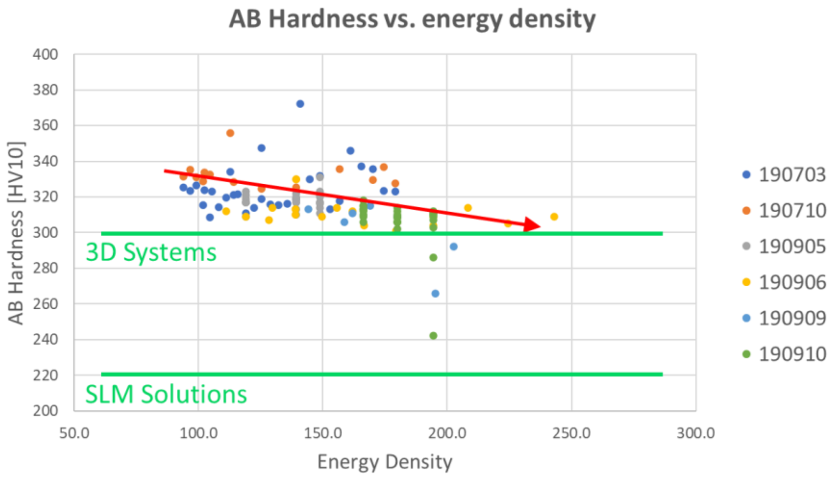
SLM - Process Parameters (17-4PH)



	Job 190710	Job 190906
Scan speed	700-1200	200-900
Laser Power	355-395	175
Av. Hardness [HV10]	***333 (≈35 HRC)***	***309 (≈32 HRC)***

SLM/LMD - Process Parameters (17-4PH)





SLM:

Step 1: optimize for density

Step 2: optimize for speed

(Step 3: optimize for hardness)

LMD: (similar to SLM)

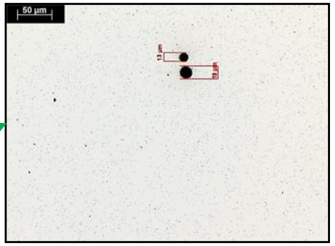
Step 1: optimize for density (99.95%)

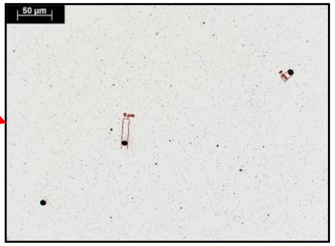
Step 2: optimize stability/HI control

LMD - Process Parameters (17-4PH)

Test	P-laser	V-laser	P/V	Powder flow	Wall height
1	2000	1	2	40	6.77
2	2500	1	2.5	40	6.55
3	3000	1	3	40	7.64
4	2500	1	2.5	40	8.32
5	2000	0.75	2.7	30	7.15
6	2000	1.2	1.7	50	4.4
7	2500	1.2	2.1	50	4.4
8	3000	1.2	2.5	70	10.2

Test 17-4PH	Porosity (%)
1	0.03
2	0.05
3	0.06
4	0.05
5	0.05
6	0.13
7	0.05
8	0.04



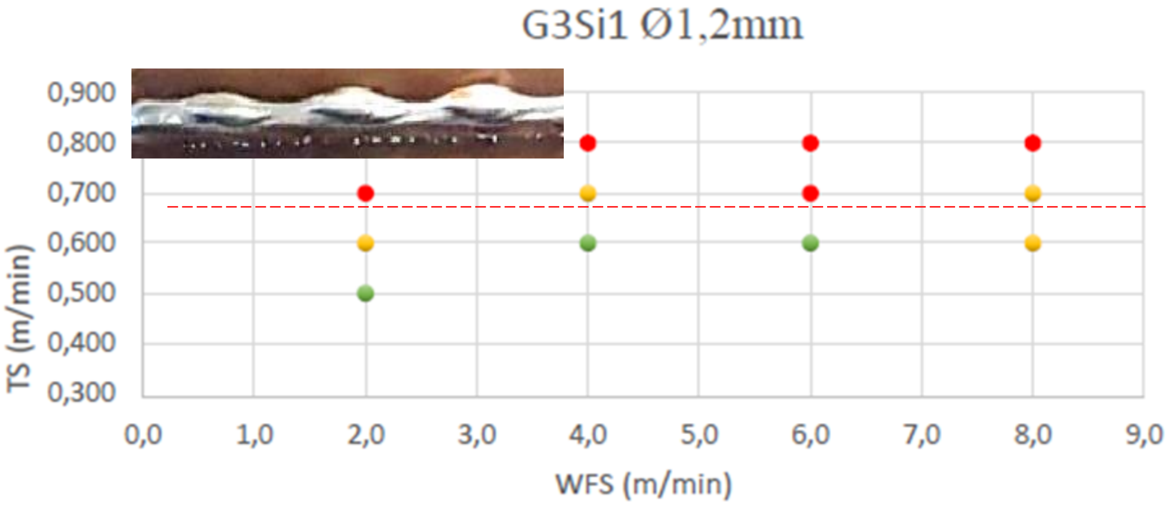


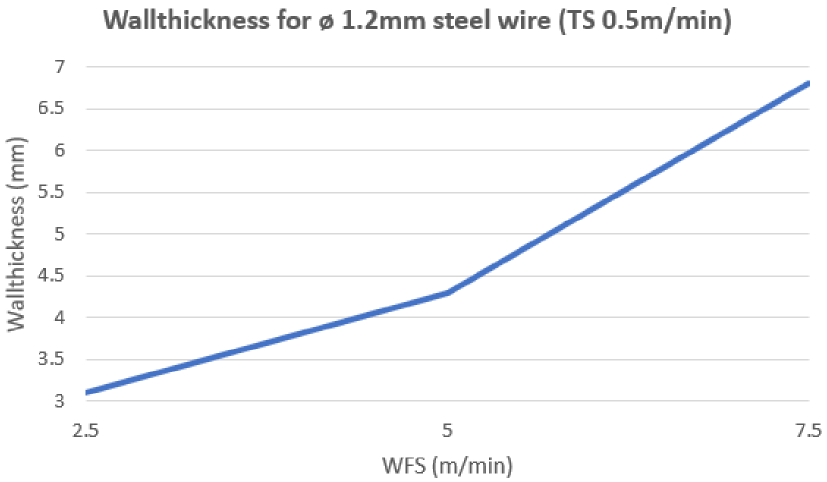
HV2 of 17-4PH in AB condition (LMD)
Center: 343-352 (1) vs 361-396 (7)

For steels & stainless steels

- Set average power/flow rate and change speed for modifying layer height (*)
- Repeat (*) for various power/flow rate for screening processing window (stability & porosity)
- Track width mainly acc. to focal spot
- Typically 30% overlap (multi-pass)
- Optimized paths & HI control (acc. features)

WAAM - Process Parameters





For steels & stainless steels

- Select wire ø for wallth. & productivity
- ≠ synergic curves & advanced U/I control
  → *≠ width & height for same WFS/TS*
- Typically limit TS to avoid humping
- Respect WFS/TS for approx. constant HI
- Optimized paths & overlap (multi-pass)

Process Parameters

- SLM - **Variation in hardness** as a function of print parameters, but less significant as compared to **variations in part density**.
- Properties can deviate from those in **powder data sheets.**
- LMD/WAAM - Hardness values in 'as-built' condition are **fluctuating along the build direction**.
- **Anisotropy**.
- Influenced by **post-build heat treatments.**

Keep track in an internal database

- ✓ Machine
- ✓ Date
- ✓ Parameters
- ✓ Material
- ✓ Build configuration
- ✓ Properties
- ✓ …

What are good settings ***for your machine***?
What ***material properties*** do you get?

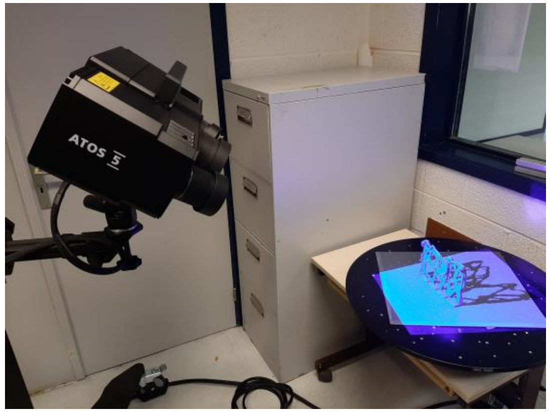
Feedback on material properties to use in design phase.

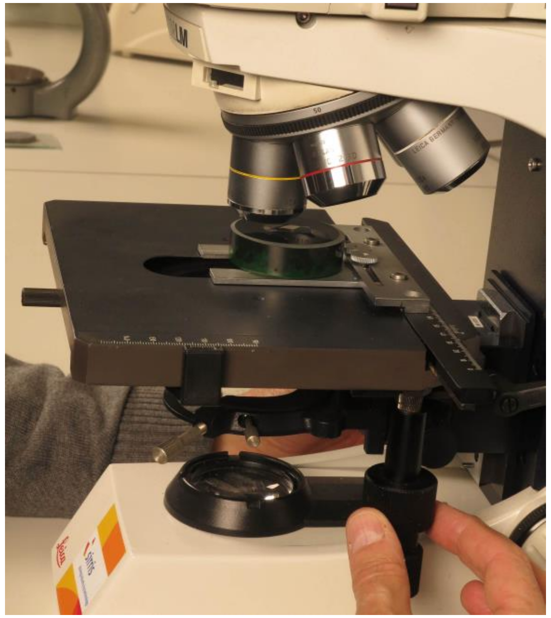
Quality Check

- ➢ Destructive testing
- ➢ Non-destructive testing

- ✓ Dimensional tolerances
- ✓ Material properties
- ✓ Tomography

Perform a first check prior to finishing to avoid unnecessary costs.



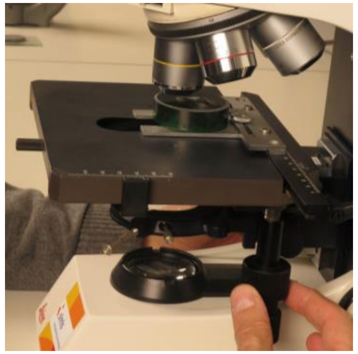



Finish the part

- Locally vs globally

- Bulk (Heat, HIP,…)
- Surface (polish, coatings)
- Cavities cleaning
- Machining

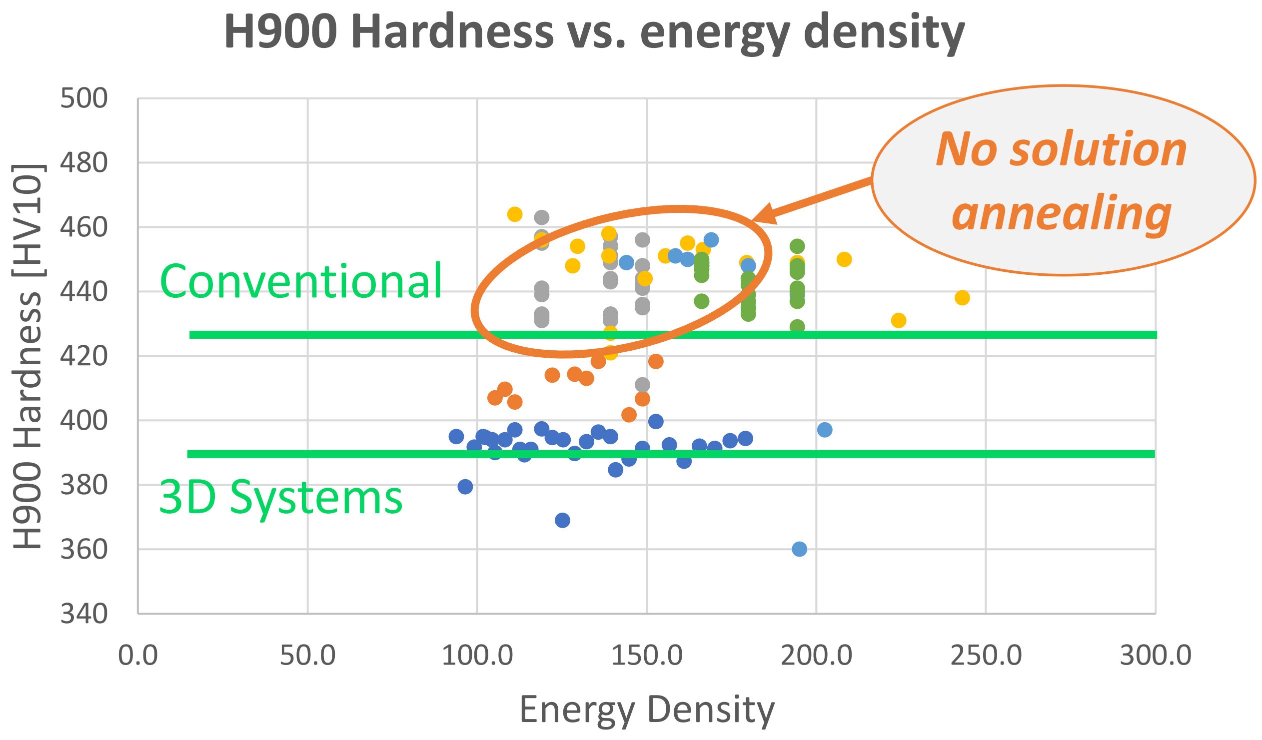
Post-processing



Inspection & Testing

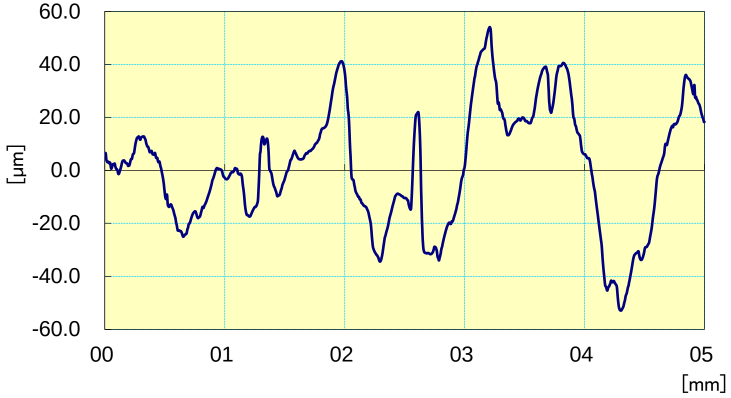
Heat Treatment (17-4PH SLM)

- Tune material properties: What properties do you want?
- Reduce residual stresses

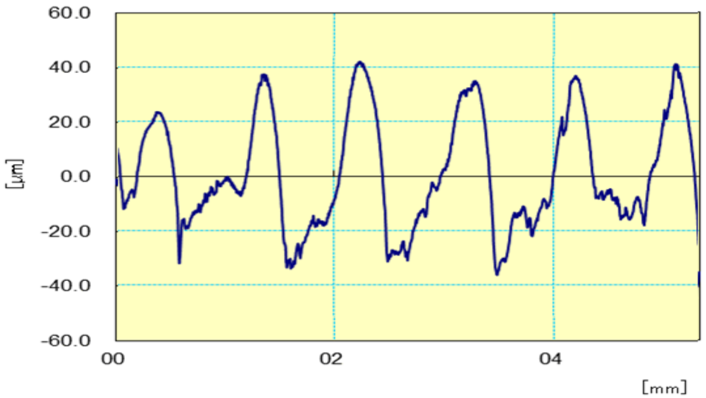


Surface Finish

SLM: Ra 8-18µm



LMD: Ra approx. 20µm



WAAM wall surface

Which surface finishing method to apply?

- AM technology (roughness vs waviness)
- Application (abrasion, aesthetic …)
- Material & geometry (cavities, edges…)
- Environmental (disposal chemicals, slurry…)

Specifications?

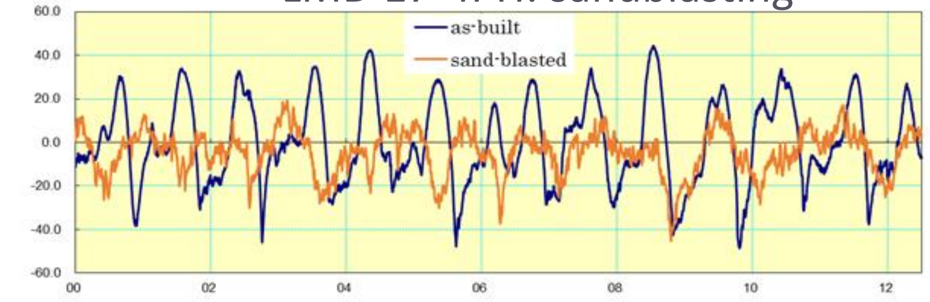
- Roughness/waviness vs peaks/valleys
- Achievable Ra 4-8µm (SLM), 10-15µm (LMD)

Pronounced WAAM waviness reduced by :

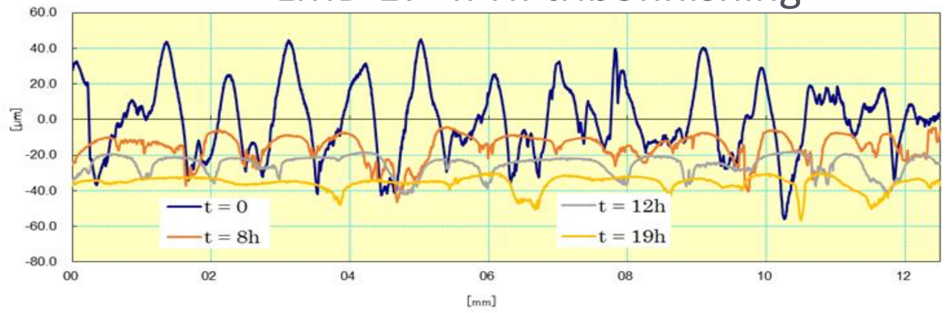
- *Shielding gas (couple % He)*
- *Wire composition (melt pool viscosity)?*

Surface Finish

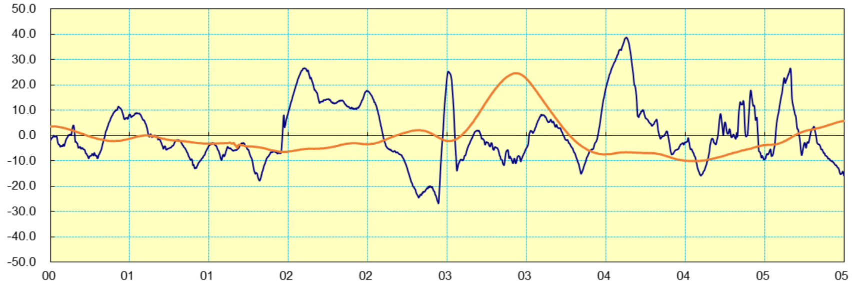
LMD 17-4PH: sandblasting



LMD 17-4PH: tribofinishing



SLM 17-4PH: EP



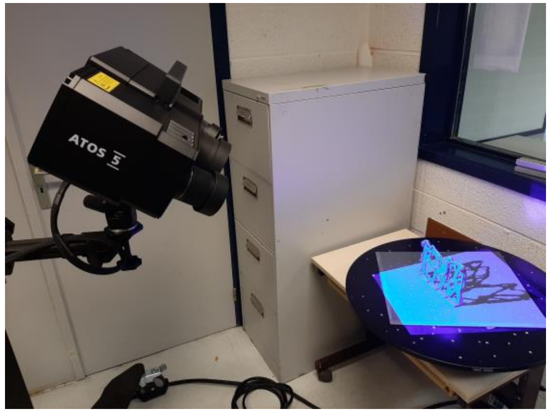
- Comparison on SLM and LMD wall surfaces
- Sand blasting (good preparation, Ra 16µm)
  - *mainly peaks removed*
- Tribofinishing (fixed sample & ceramics)
  - *slow, smoothens entire topology*
- Electrolytic polishing (EP)
  - *organic electrolyte works best, mainly high freq. roughness removed*
- Chemical polishing (CP)
  - *slower than EP for 17-4PH*

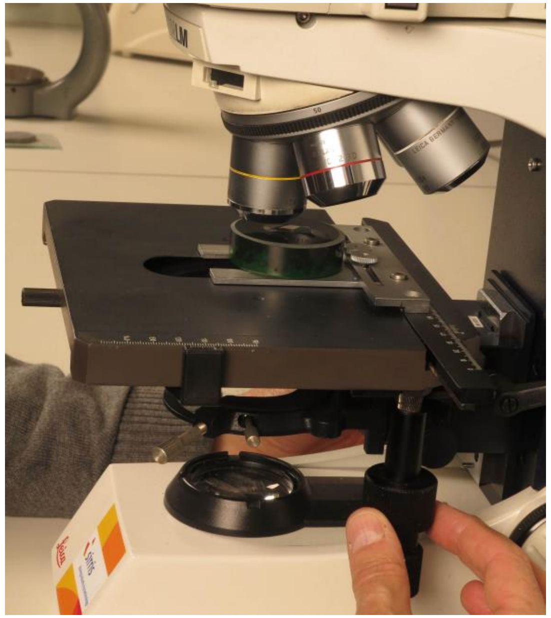
- **No significant difference between AB and H900!**
- **Typical finishing cycle 1-2h**
- **For WAAM typically local or general machining**

Quality Check

- ✓ Dimensional tolerances
- ✓ Material properties
- ✓ Tomography
- ✓ Surface Quality
- ✓ Residual stresses

✓ *Potentially also to be done before post-processing*





You don’t have to make this journey on your own.

Knowledge and experience is available within Belgium to support you in your journey.

What's next – INSIDE AM project

You'd like to discuss a specific topic with us ?

Request a personal meeting and mention your topic: jeroen.tacq@sirris.be

Recording & slides will be made available through mail

Don't miss out on our final event! (foreseen January 2021)

https://www.sirris.be/nl/inside-metal-additive-manufacturing

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