Design for Metal Additive Manufacturing

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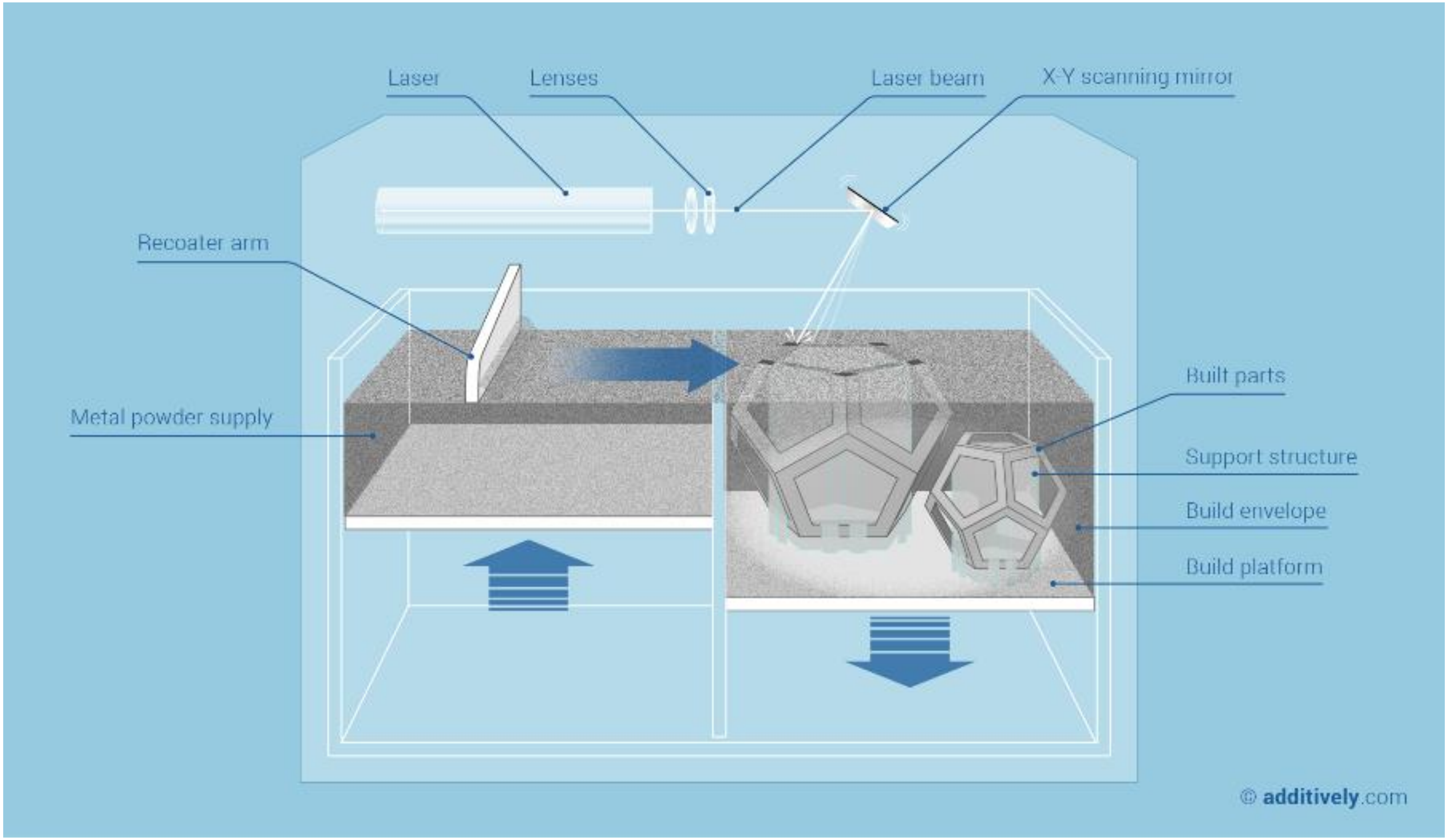
CAD USER FORUM – 16th of February 2017

Outline

I. What is Laser Powder Bed Fusion or Selective Laser Melting (SLM) ?
II. Brief introduction to metallurgy and mechanical characteristics of SLM at CERN
III. What are the specificities of SLM and does that translates into design considerations ?

Metal Additive Manufacturing with Laser Powder Bed Fusion



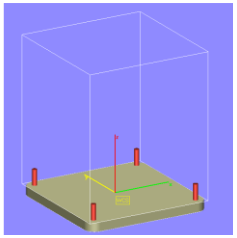
EN-MME Workshop in figures

Machine:

- SLM 280HL (SLM Solutions)
- 400 W laser (1070 nm)
- Tri-axis scanning system

Build volume:

- 280 x 280 x 360 mm^3

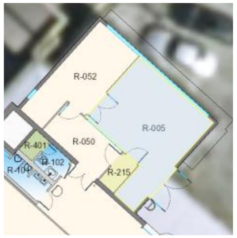


Materials:

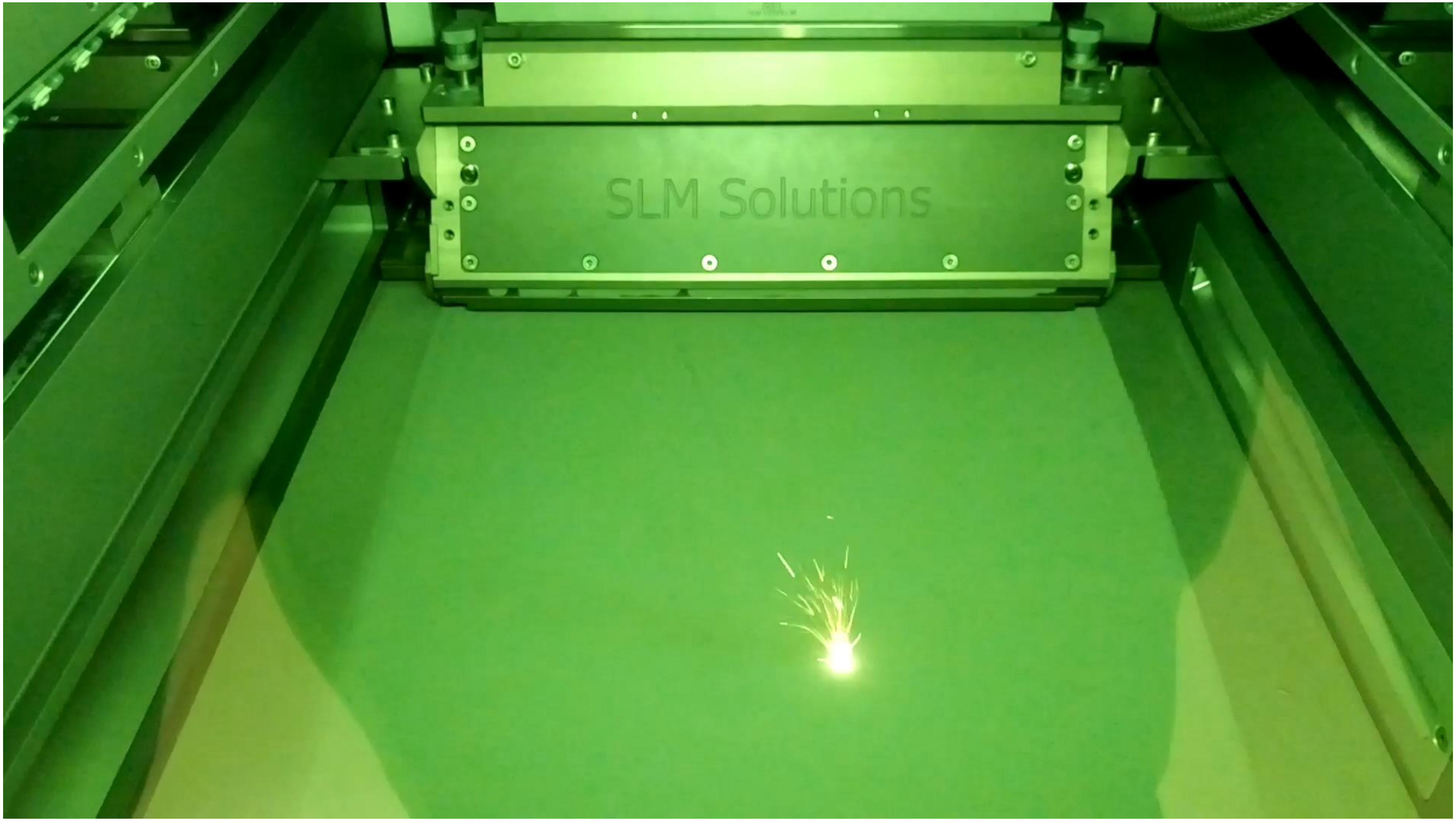
- Currently: Ti6Al4V gr. 5
- Next: SS 316 L
- Available: Aluminium (AlSi10Mg) – Nickel superalloys (In718) – Steels
- R&D: niobium and copper

Location

- 156-R-005
- Opposite of Main Workshop

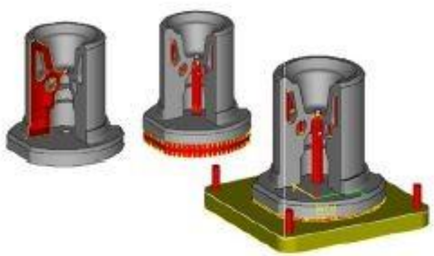


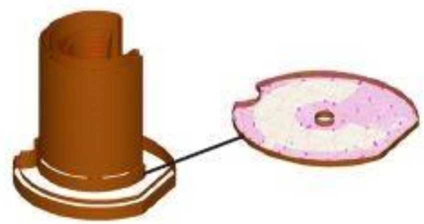
EN-MME Metal AM Workshop



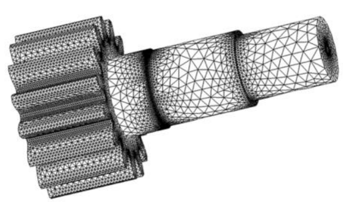
SLM Data processing

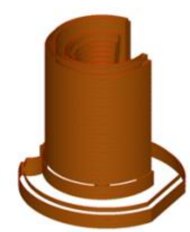
Fix, Edit, Support Place, Nest, etc. → Assign Parameter → Slice → Hatch → Build → Quality Control

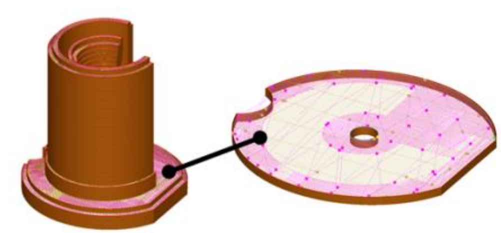




STEP (Volume) → STL (Surface) → Scan VECTOR (2D)







Rescaling | Slicing | Sub-Division | Hatching

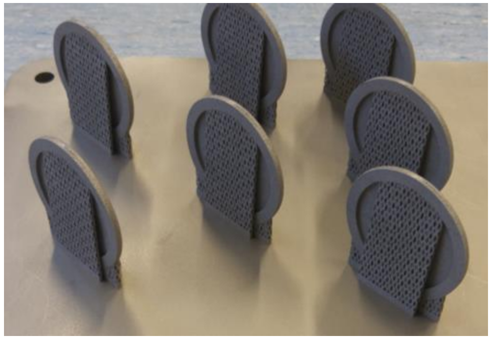
Metallurgy of SLM parts: density, tensile properties, anisotropy and microstructure

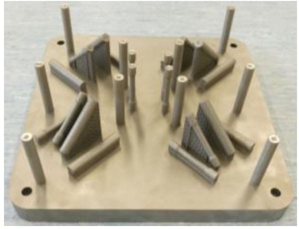
Porosity:

- <0.5% for densely packed build
- <0.1% for light builds

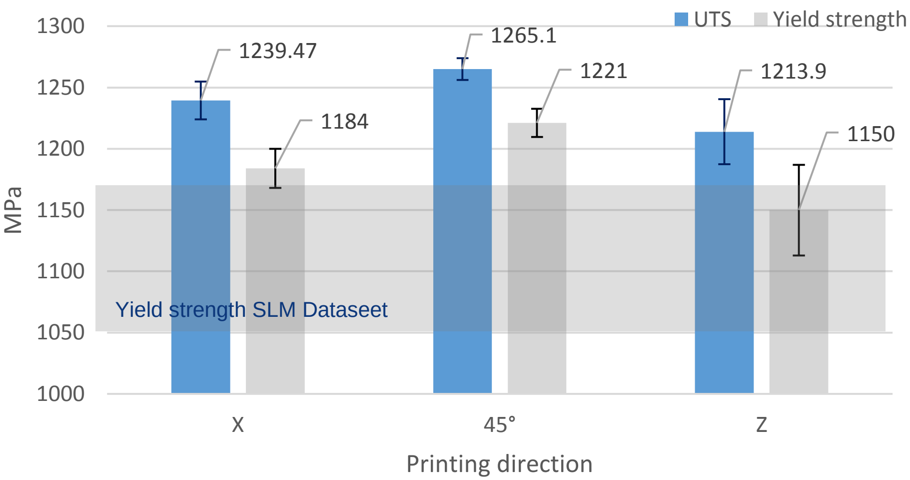
He leak test:

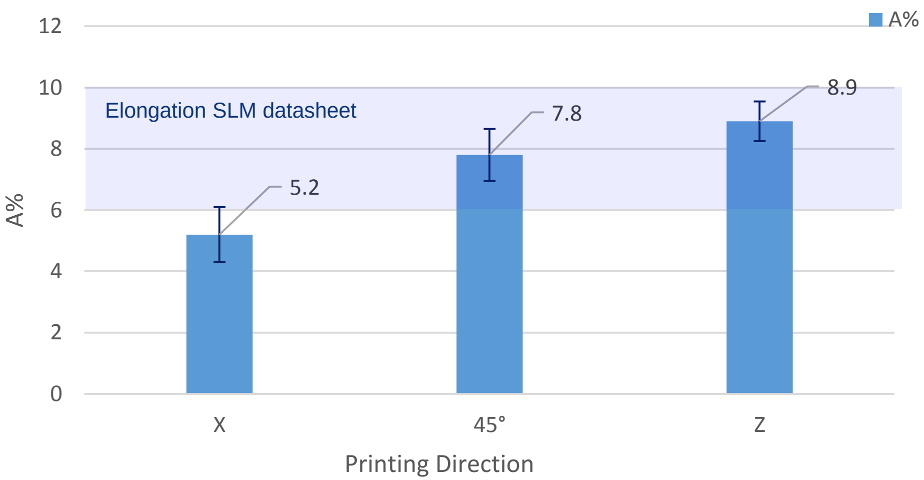
Leak tight at 0.5 mm vertical wall thickness ($\mathrm{He} \ @ \ 10^{-10}$mbar)





Tensile properties:



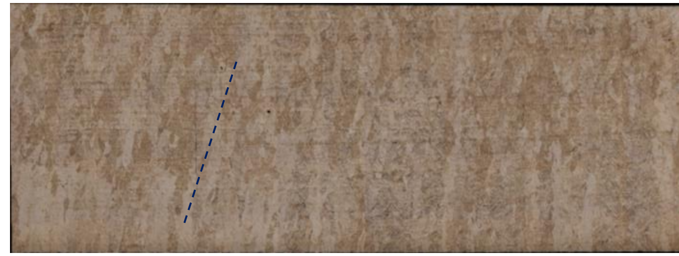


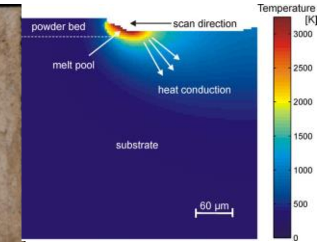
Grade	UTS	A%	E Modulus	Rp 0.2
Ti6Al4V	895	10	113.8	828

Values given for Ti6Al4V at annealed temper (*ASTM B381)*

Microstructure (EDMS 1736674)

Build direction



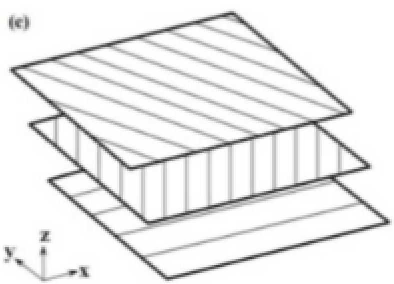


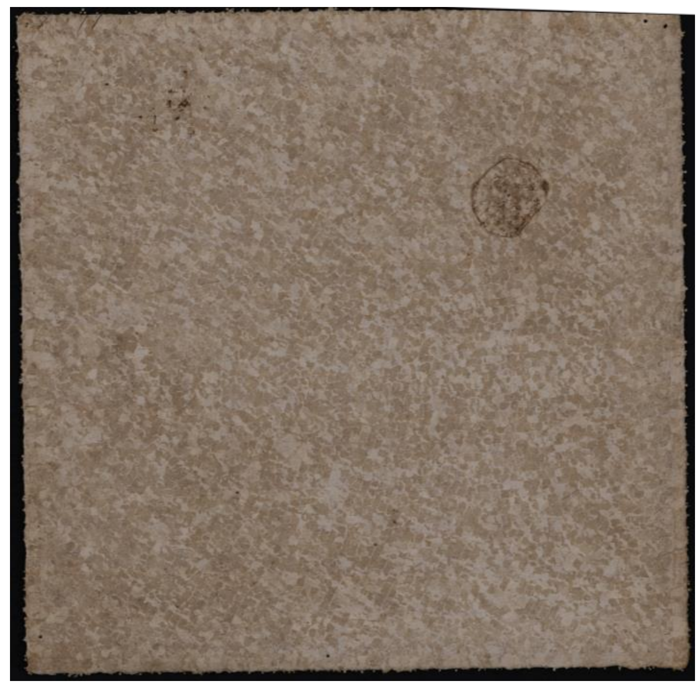
Microstructure features elongated grains in vertical direction

- Each new layer re-melts the tip of the grain, adding the new layer to the grain

In-plane microstructure looks like a **chess board**

- Due to the scanning strategy which rotates the scanning patterns every layer

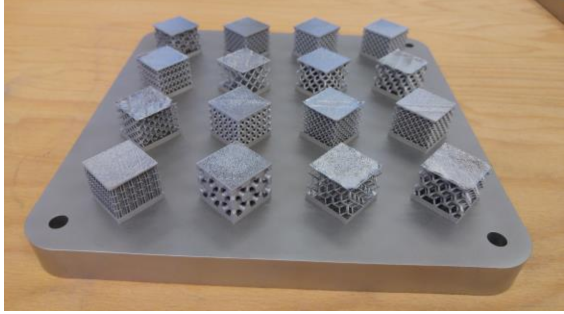




Build direction

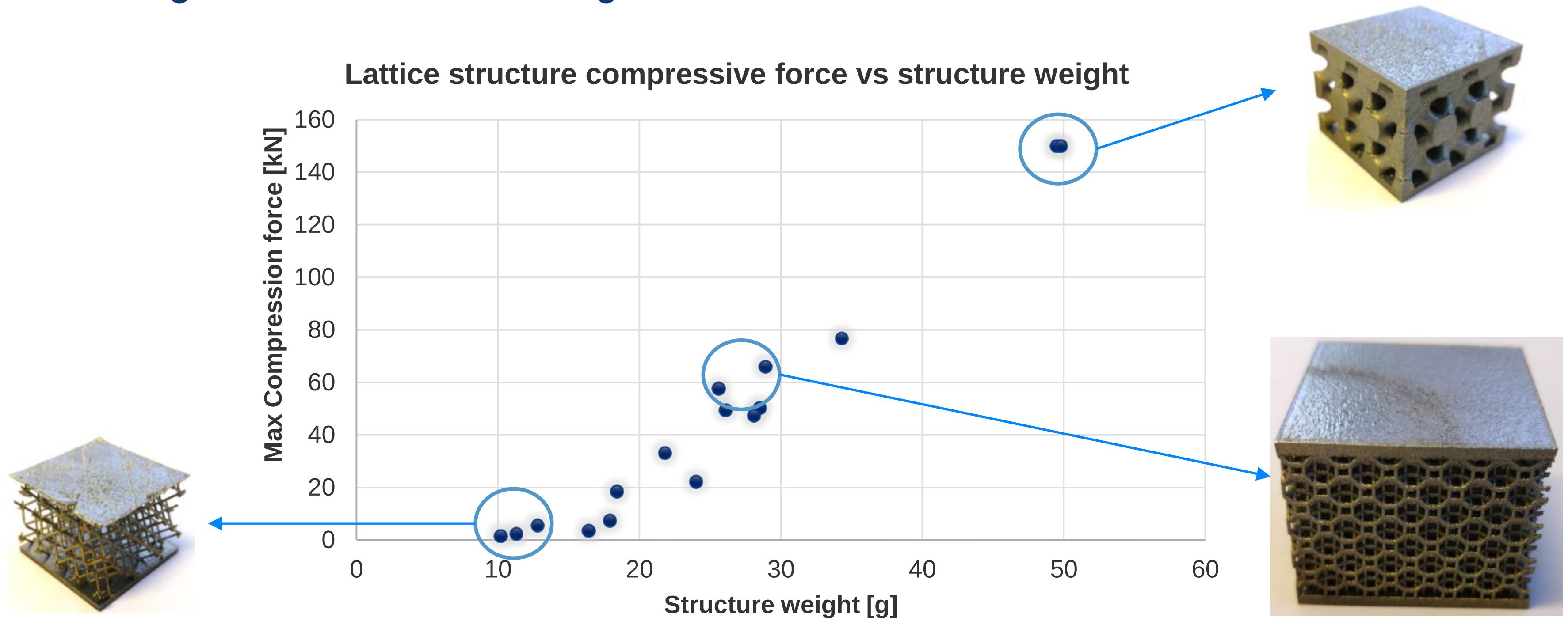
Wrought Ti gr.5 hardness 310 – 350 HV

Lightweight structures



Different lattice configurations were tested in static compression

- Initial results show a relatively good correlation between mass of the structure and force with a few outliers in the low force region
- Challenges related to modelling of the behaviour of such structure



Design rules

Common Myth with additive manufacturing:

You can create pretty much anything !

➢ Wrong. There are very strict design limitations !

But the strength of Additive Manufacturing is to enable very different components compared to conventional Manufacturing

Ti6Al4V A380 Turbine cover door hinge cut 10kg per aircraft vs conventional cast steel bracket

Design Rules

Design Rules:

- Minimal overhang angle and support structures
- Staircase effect
- Residual stresses and the influence of massive volumes
- Machining interaction

Sources (CDS):

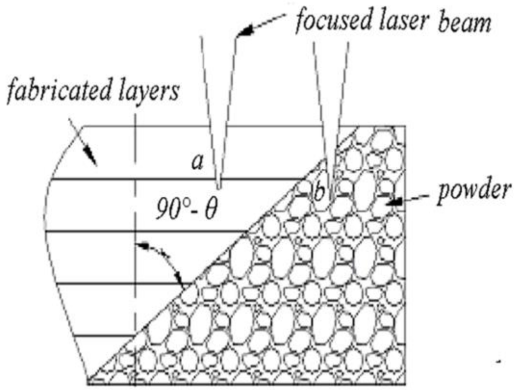
- VDI 3405 Part 3: *Additive manufacturing processes, rapid manufacturing. Design rules for part production using laser sintering and laser beam melting*
- ISO/ASTM DIS 52910.2 *Guidelines for additive manufacturing design*
- J. Kranz, D. Herzog, C. Emmelmann, *Design guidelines for laser additive manufacturing of lightweight structures in TiAl6V4*

Problems with overhangs

Overhangs are surfaces with <45deg elevation angle

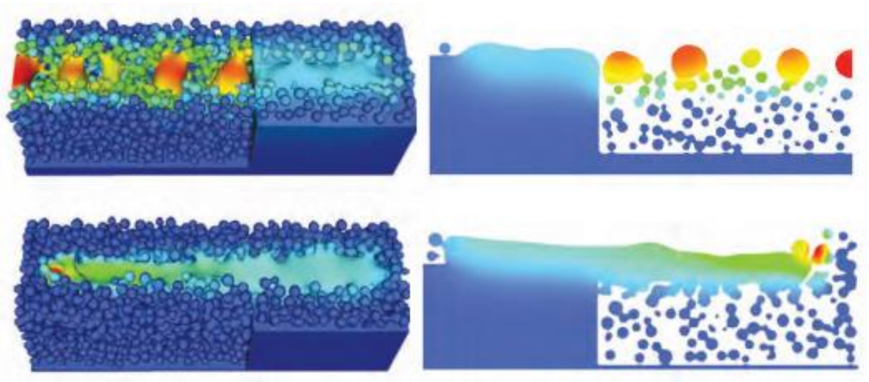
The powder is considered as a thermal insulator compared to bulk material

- Leading to very different thermal behaviour depending on the underlying layers



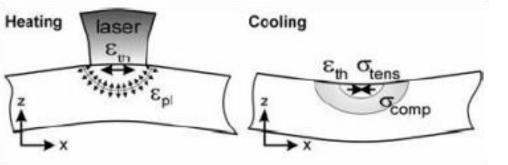
FEM simulation of the SLM process showing the difference of temperature as the new layer is exposed over powder or over the part

- A balling effect is visible due to melt-pool instability



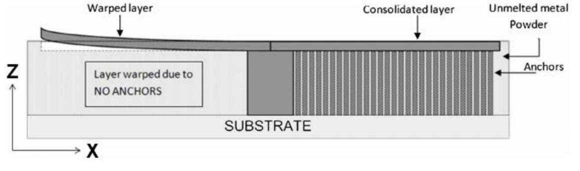
Lawrence Livermore National Laboratory, S&TR January/February 2015

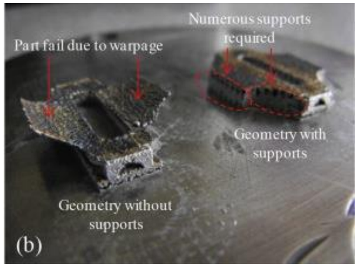
Why support overhangs ?



Support structures have two functions:

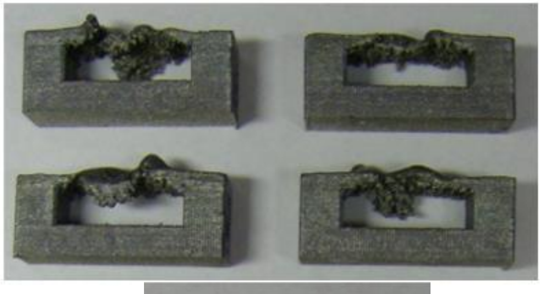
Avoid Warping
(unwanted deformation due to residual stresses)
Unsupported downfacing features "peel-off"

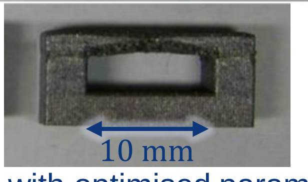




P. Vora et al. / Additive Manufacturing 7 (2015) 12–19

Provide a good surface roughness
for downfacing area



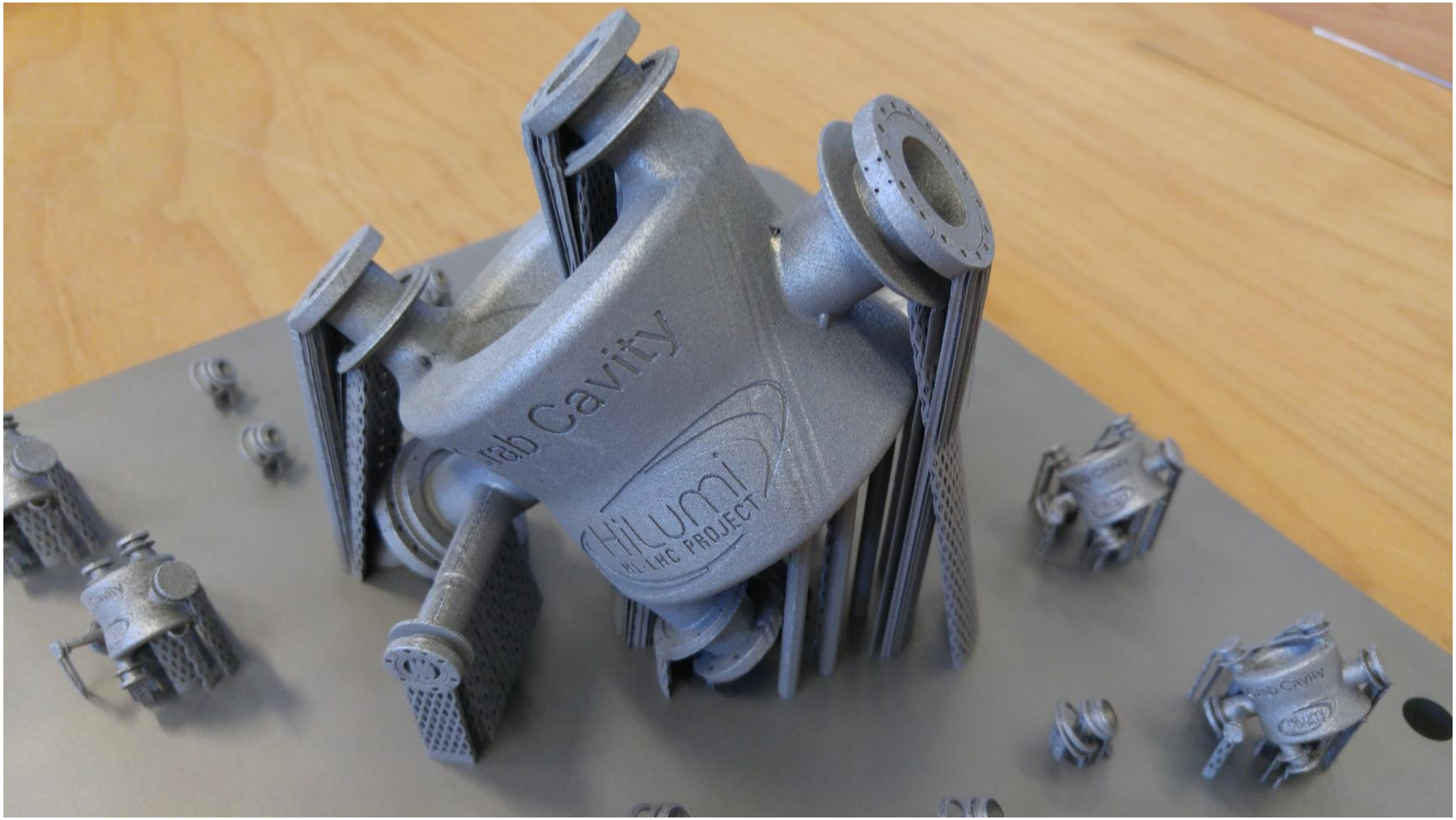


Part with optimised parameters

R. Mertens et al., Journal of Manufacturing Science and Engineering (2014)

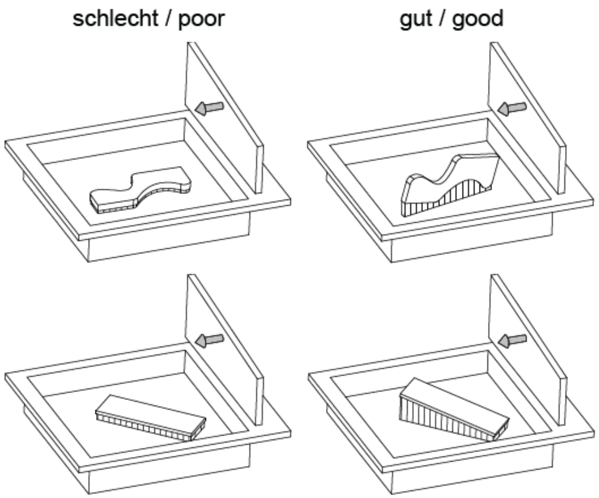
Why support the overhangs ?

Example of a model not optimised for additive manufacturing:

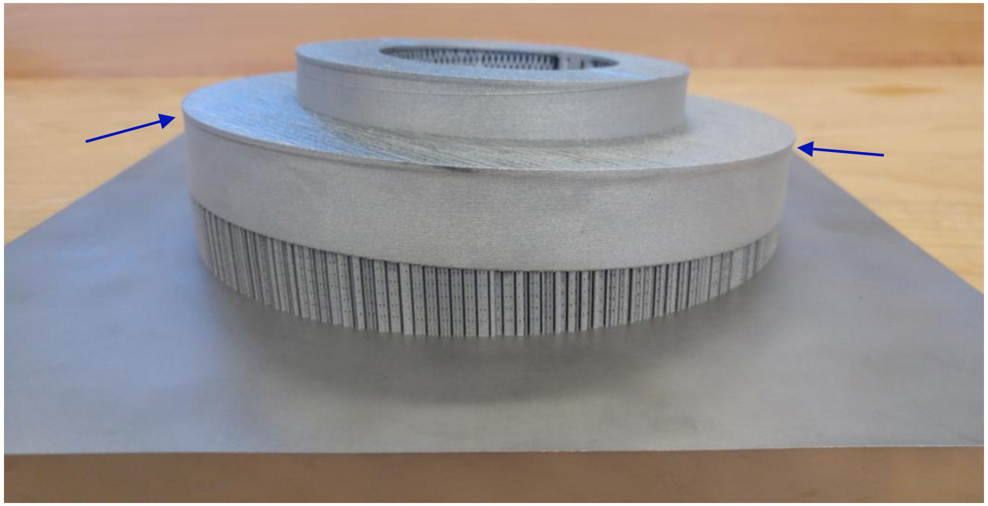


Warping

- Residual stresses may reach the yield strength of the material during the build process
- Orientations parallel to the build surface shall be avoided
  - Large changes of cross section in Z direction is not recommended

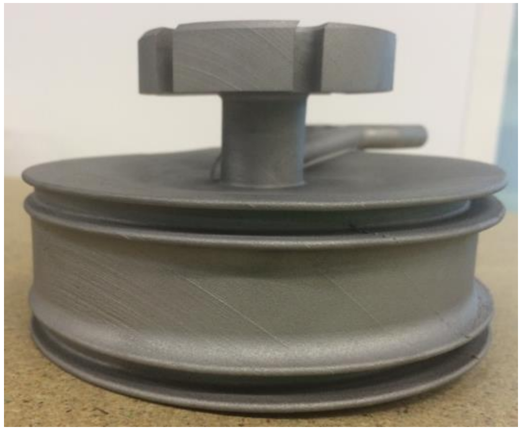


Examples showing how to avoid the curl effect when irradiating large surfaces - VDI 3405 Part 3



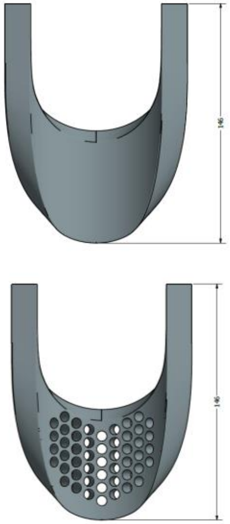
Practical trade-off between Warping/curl and build height
PACMAN Rotor (lightweight structure)

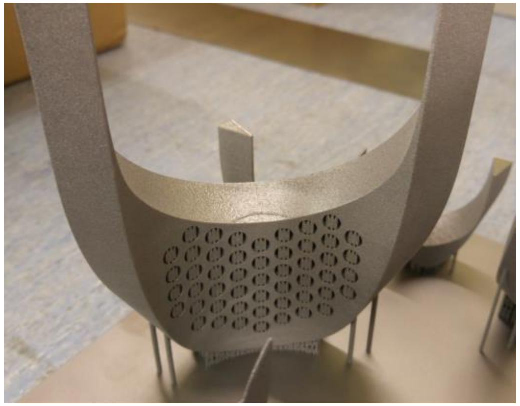
Warping: brutal changes of cross sections are problematic



Typical examples are UHV Flanges: Large masses next to thin walled connections

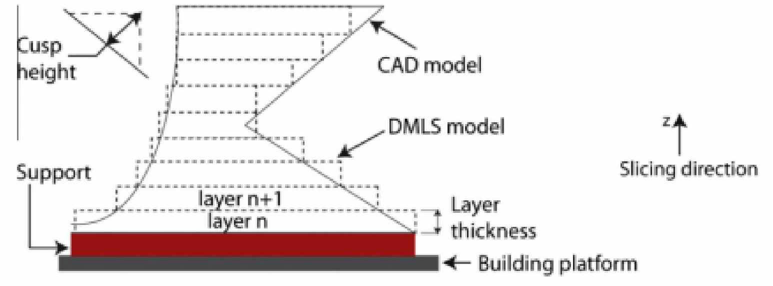
- Quick workaround is to hollow the massive parts





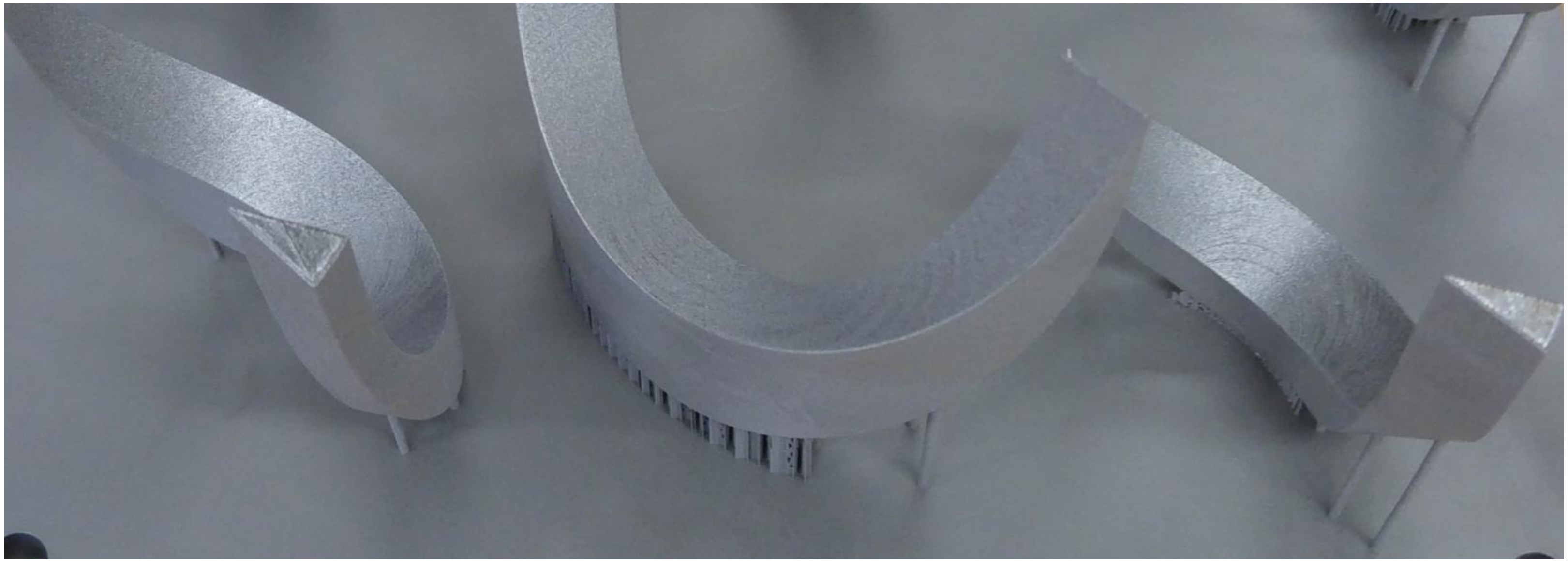
Massive objects may cause major deformations due to heat accumulation

Staircase effect



The staircase effect is a surface texuration due to the layer slicing of the CAD model.

It is more pronounced for low elevation angles

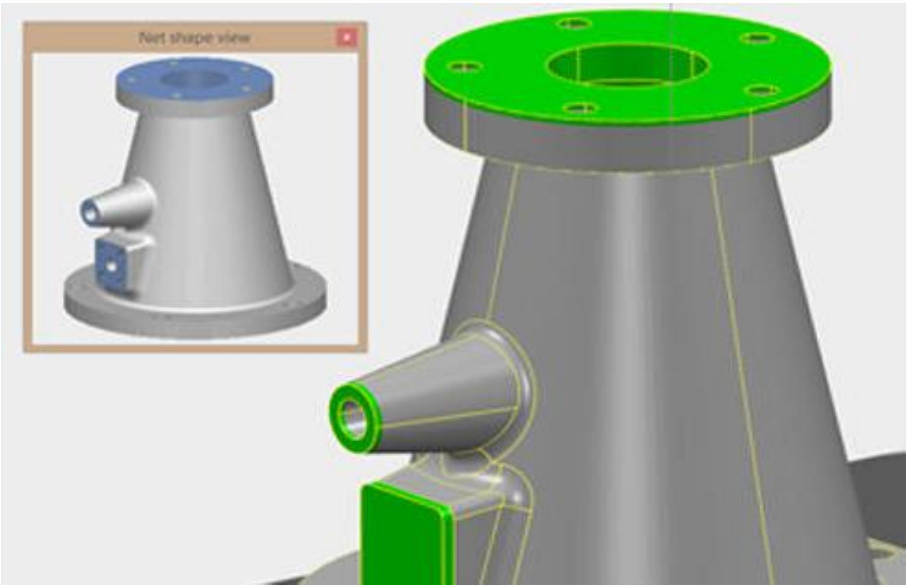


Example of staircase effects on end-spacers

Machining interactions

Interfaces often needs to be machined.

- For machining, over-thicknesses must be thought in the design
- Typical values :0.5 to 2 mm depending on the size of the part
- Centring holes can be designed in 3D but should be avoided for precise positioning
- Good idea: make a drawing for the rough plan (SLM) and one for final dimensions



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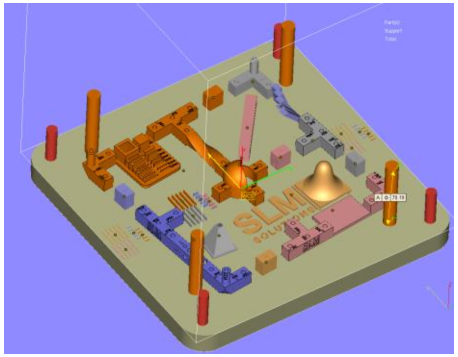
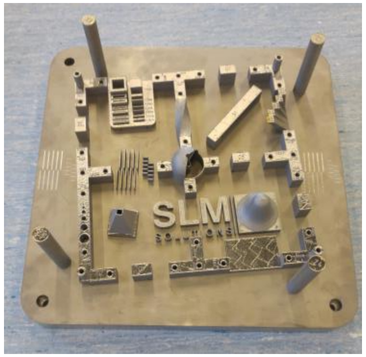
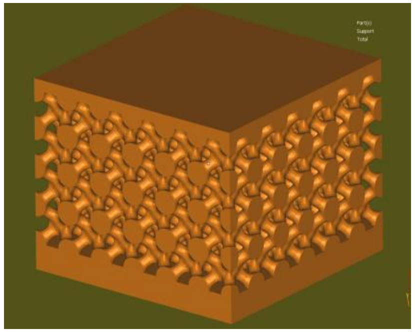
Is it possible to convert STL files back into STEP ?

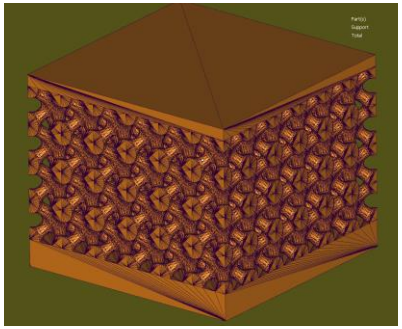
Example of a conversion trial for metrology:
Demonstration job from SLM Solutions:
STL: 16Mb
STEP: 800Mb
Opening time on CAD workstation: 2h+





Non-planar and complex structures requires a lot of triangles.





371 472 Triangles
STL file size:18 MB