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Application de la fabrication additive métallique dans le domaine des accélérateurs : compatibilité ultra vide et propriétés de l'acier 316L

(IS IT POSSIBLE TO USE ADDITIVE MANUFACTURING FOR ACCELERATOR UHV BEAM PIPES?)

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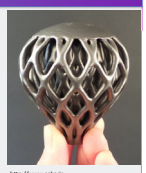
Motivation

- In particle accelerators under construction or planned, some systems are actually used to the limit of their possibilities
- The performance of components involved in accelerator technology is closely related to the characteristics and capabilities of the materials (morphology/finishing of surfaces, chemical purity, crystallographic quality, presence of defects)
- To face the challenges for the construction of the next-generation particle accelerators, technologies must evolve: new materials, new approaches of manufacturing must be considered
- Additive manufacturing (3D metallic printing)
- Main advantages
  - Rapid production of mechanical components with complex shapes
  - Rapid prototyping
  - Reduced Tooling Costs



http://www.sokaris-ingenierie.com/fabrication-additive/#

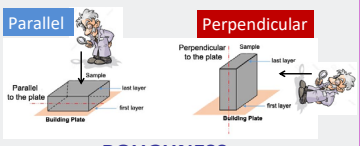
gooseneck bracket, a part of an airplane wing

Microstructural characterization

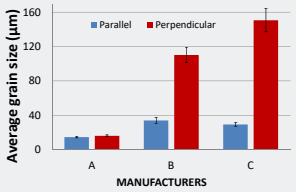
Material : 316L stainless steel

manufacturing was sub-contracted to different companies by SLM (selective laser melting)

Manufacturers	Method	Powder granulometry (µm)	Layer thickness (µm)
A	SLM	20 - 125	40
B	SLM	20 - 50	40
C	SLM	?	40



GRAIN SIZE



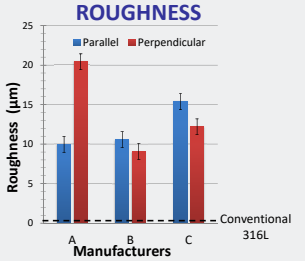
Grain size depends on manufacturers

size in the perpendicular direction > size in the parallel direction

→ elongated columnar grains oriented along the build direction (perpendicular to the building plate)

→ large directional thermal gradients during the layer by layer deposition process

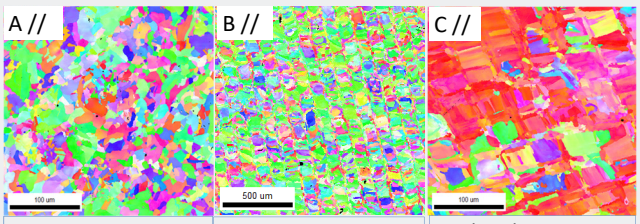
ROUGHNESS



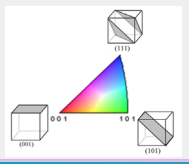
Surface roughness is much larger for AM

→ It could be a severe drawback for accelerator applications?

TEXTURE



No texture | (101) and (111) | (001) texture



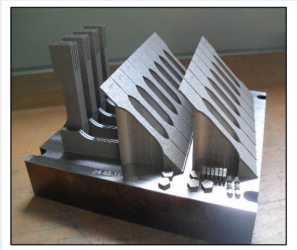
- If grain orientations are fully random = no distinct texture (no color is predominant)
- If a preferred orientation exists = texture (a color dominates)

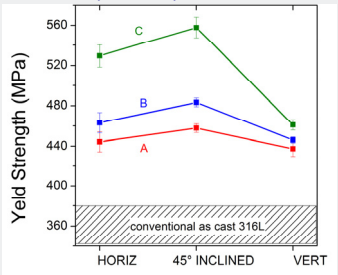
Microstructure of AM samples depends on manufacturers

microstructural anisotropy → anisotropic properties

Mechanical properties

Tensile specimens: 3 directions, printed horizontally, vertically and inclined at 45°





- Mechanical properties depends on the orientation : they are anisotropic (related to the microstructure anisotropy)
  - →The inclined specimens exhibit the higher yield strength
- Samples C exhibit the higher mechanical properties
- AM samples have better mechanical properties than conventional counterparts

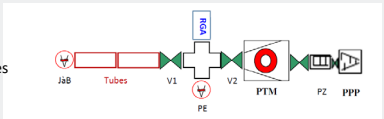
Outgassing tests

DN40CF tubes in 316L stainless steel by AM

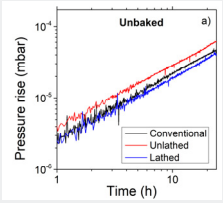
- The surface quality of 3D printed tubes is very different of that obtained from conventional techniques.
- The surface roughness of the raw tubes : Ra = 8.5 µm to 10 µm.
- A previous work showed that the flanges must be lathed to avoid leaks!
- 2 cases were studied : - only the flanges are lathed (to avoid leaks)
  - both the flanges and the tube inside are lathed

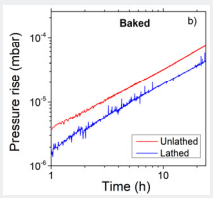
Outgassing measured by the gas accumulation method

copper joints
all-metal UHV valves



-Tubes are pumped down
-Valve 1 is closed
-Pressure rise is measured by a spinning rotor gauge





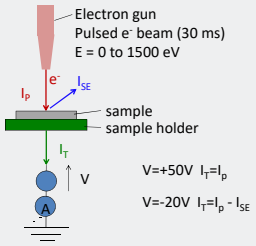
Outgassing rates for 100h of pumping after baking under vacuum at 200°C during 72h.

Treatment	Tube	Outgassing rate (mbar.l/s.cm²)
Unbaked	Conventional	6.0×10^{-12}
	Unlathed AM	5.6×10^{-12}
	Lathed AM	7×10^{-12}
Baked at 200 °C	Unlathed AM	3.6×10^{-13}
	Lathed AM	3.4×10^{-13}

- Values of AM tubes and the conventional one are equivalent, in agreement with literature data
- The surface roughness has no impact on these results (Unlathed vs lathed)
- Outgassing rate is one order of magnitude lower for baked tubes than for unbaked ones
- Monitoring of the vacuum quality by RGA shows no traces of impurities

UHV compatibility : OK!

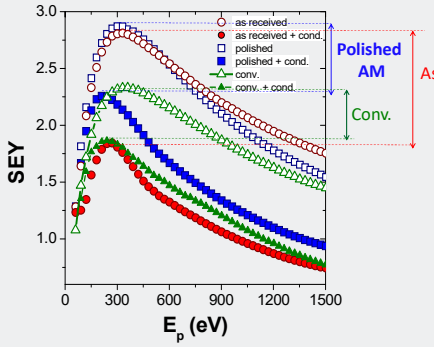
Secondary Emission Yield



$$\delta = \frac{I_{SE}}{I_p} = \frac{I_p - I_T(+50V)}{I_p} = 1 - \frac{I_T(+50V)}{I_T(-20V)}$$

Before conditioning + after conditioning

(E_p=500 eV - Q=1.5x10^{-2} Cb/mm^2)



- A higher decrease in the SEY due to the surface conditioning induced by the e- beam is observed for the as received AM sample (the surface scrubbing is more efficiency for this sample!)
- Is it due to the higher surface roughness for this sample?
- A further investigation is needed!

Conclusion

316 L stainless steel samples were fabricated using AM *via* SLM in order to investigate :

- Anisotropy induced by the manufacturing processing
- Outgassing (UHV compatible?)
- Secondary Emission Yield

- Using the same method of additive manufacturing (SLM) does not guarantee to get the same properties
  - → Problem of reproducibility !
  - → Heterogeneity / anisotropy of properties
  - → Higher mechanical properties can be reached
  - → **It is important to control the conditions of manufacturing !!!**
- Outgassing rates : same values are obtained for AM tubes than for conventional counterparts → **UHV compatible** !
- SEY values are comparable after electron conditioning

The high surface roughness of AM components seems not to be a too high drawback : further investigations are needed!

Is it possible to use additive manufacturing for accelerator UHV beam pipes ?

Yes! But for specific components : e.g. Beam Position Monitor

G. Sattonnay *et al.*, "Is it Possible to Use Additive Manufacturing for Accelerator UHV Beam Pipes?", in *Proc. IPAC'19*, Melbourne, Australia, May 2019, pp. 2240-2243. doi:10.18429/JACoW-IPAC2019-WEXXPLS3