This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

AM Manufacturing of Superconducting cavities

Ist Annual Meeting/May, 4-2022

A. Pepato/TASK 10.4/INFN PD

iFAST

Task 10.4: *Development of superconductive RF cavities, made by Nb or Cu coated by an Nb thin film, to be tested at room and at cryogenic temperature.*

Beneficiaries in the task: INFN, CNRS

Subcontracting:

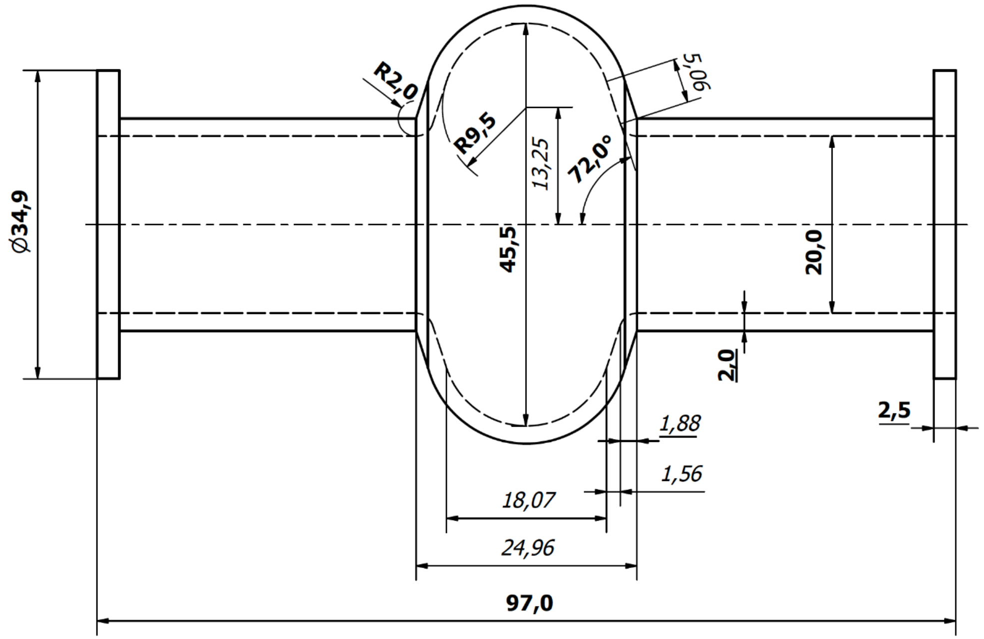
Rösler Italiana Srl (ROS), a company of Rösler Holding Gmbh as a provider of surface finishing solutions of additively manufactured parts

Taniobis (Tantalum and Niobium) GmbH (HC) as process developer and supplier of suitable feedstock powders.

Objectives:

- Develop the design approach and test relevant properties of Additively Manufactured Nb made RF cavities, to be tested at room and at cryogenic temperature.
- Develop the design approach and test relevant properties of Additively Manufactured Ultra Pure Cu made RF body cavities, coated by an Nb thin layer at the inner surface, to be tested at room and at cryogenic temperature.

The 6 GHz Superconducting cavity.



- **Deliverable (Time: 18 months):**
- *Superconductive RF cavities, made by Nb or Cu coated by an Nb thin film, to be tested at room and at cryogenic temperature.*
- **Content:**
- ***Production*** *of superconductive RF cavities, made by Nb and/or Cu coated by an Nb thin film.*
- ***Milestone (Time: 30 months):***
- **Performance** of Superconductive Cavities made by AM technology by Nb or Cu with Nb thin spattered film on the internal surface

Members of the Research Group (DIAM@INFN PD)

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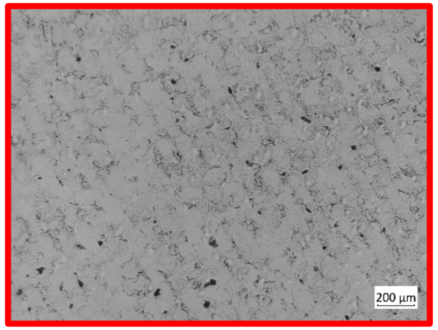
SLM Machines & Tools

Technical data	EOS M100	EOS M280	SHAREBOT METALONE
Building volume	Ø 100 mm x 95 mm	250 × 250 × 325 mm	65 × 65 × 100 mm
Laser type(maxpower)	Yb (200W)	Yb (400W)	Fiber (250W)
Focus diameter	40 μm	100-500 μm	40 μm
Scan speed	up to 7 m/s	up to 7 m/s	up to 5 m/s
Inert gas supply	max 50 L/m	max 100 L/m	0,25 L/m

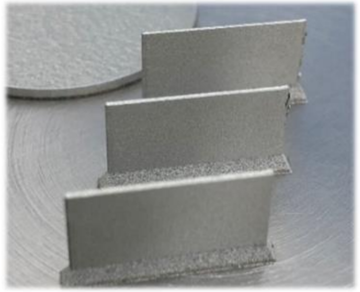
- **SLM Printers**
  - EOS M100
  - EOS M280
  - SHAREBOT METALONE
- **Internal Special Facilities (OFM):**
  - EDM - Electrical Discharge Machining
  - Okuma MILLAC 800 VH Multi-Plane Machining Center
  - CMM facility Zeiss ACCURA MASS

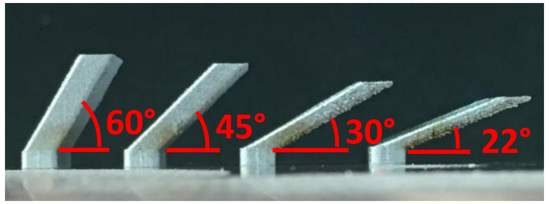
Characterization AM materials



Study of porosity to optimize best quality density in AM Process (Density measurements and inspection of defects with SEM)

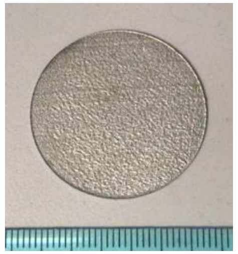
Transient Hot Disk TPS 2500 S, Dept. of Management and Engineering University of Padova

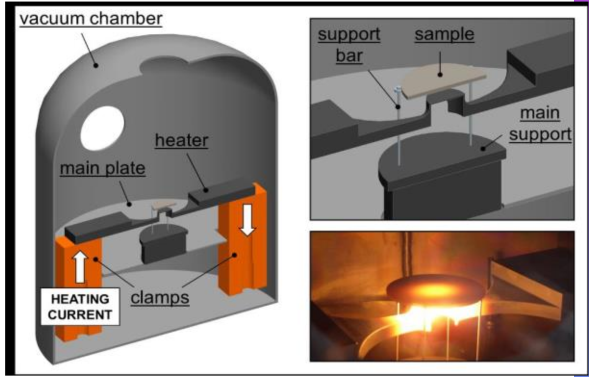




Tensile tests (Young Module, Yield strength, tensile strength)

Thermal conductivity tests

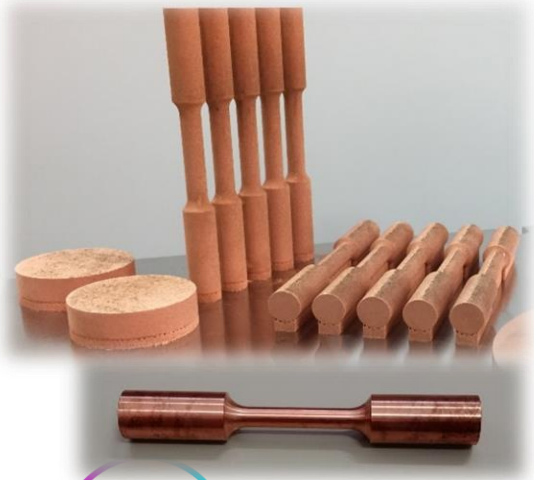




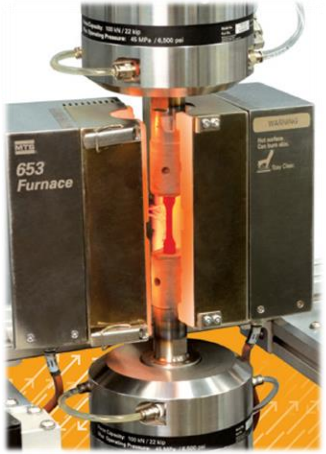
Thermal conductivity and emissivity at high temperature

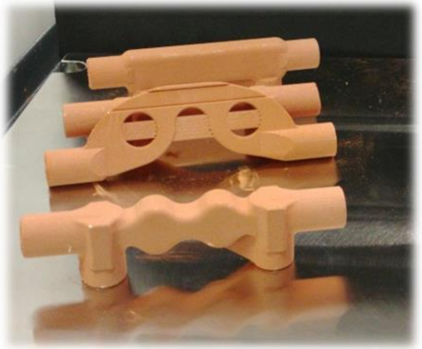
Tensile tests at high temperature

Study of AM Process to reduce surface roughness



MTS 858 Mini Bionix II, Department of Industrial Engineering (DII) University of Padova

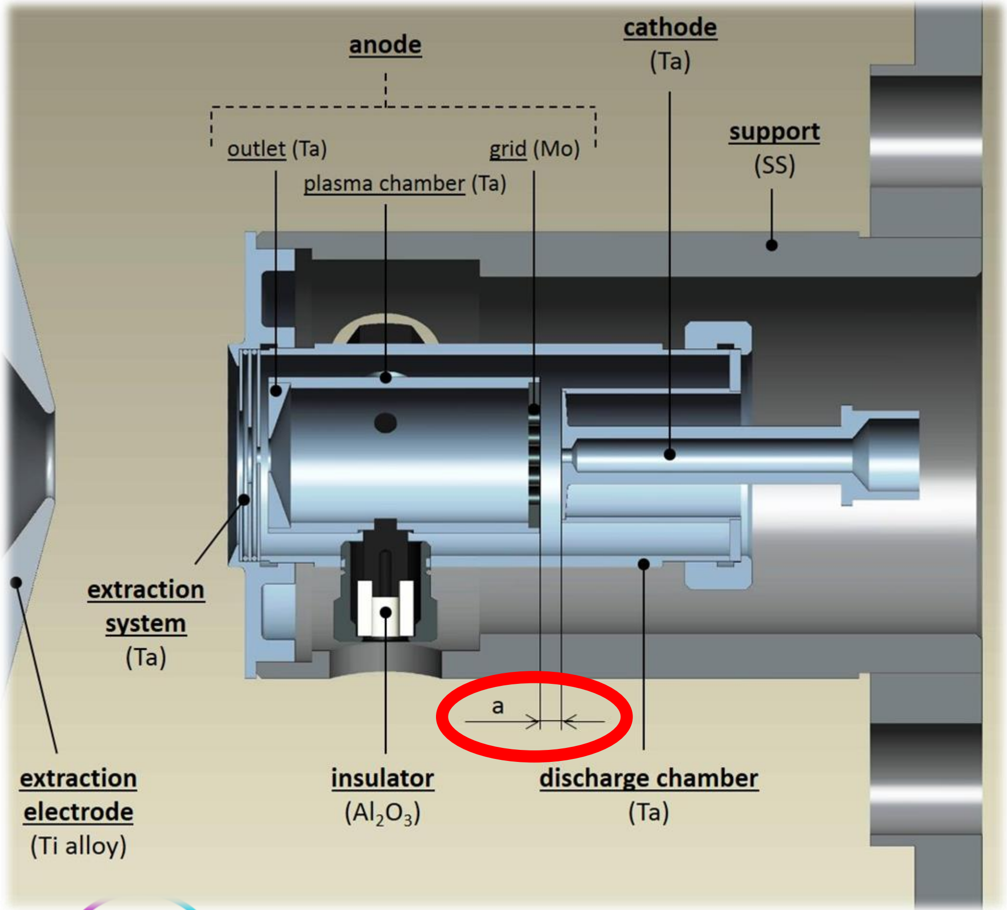




Dept. of Management and Engineering
University of Padova

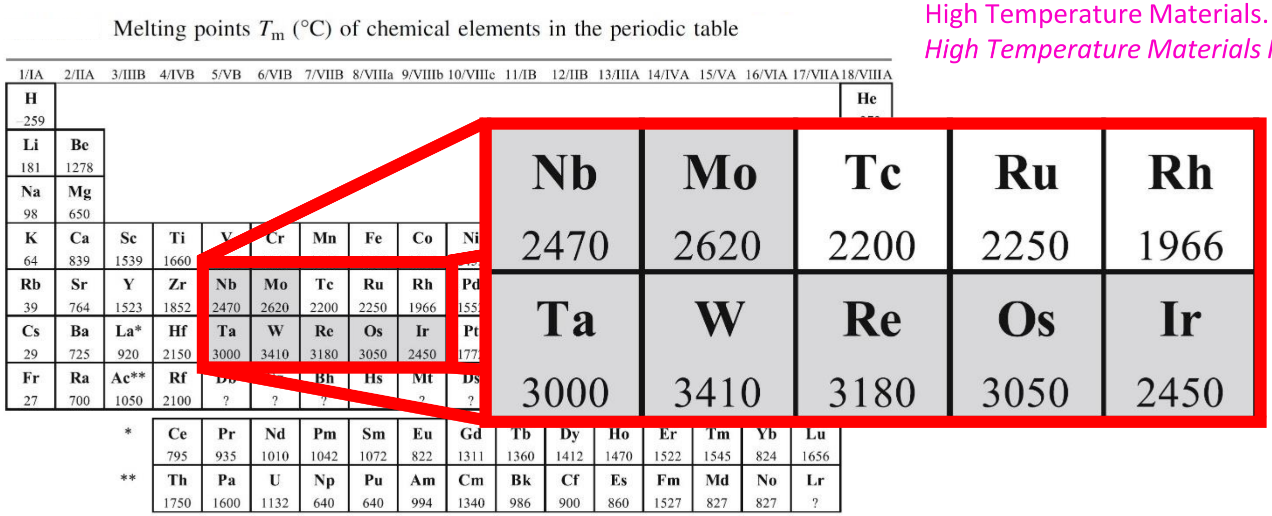
Refractory materials Development for High Temperature Applications

1st FEBIAD ion source prototype used at SPES



Courtesy of the SPES Target Group

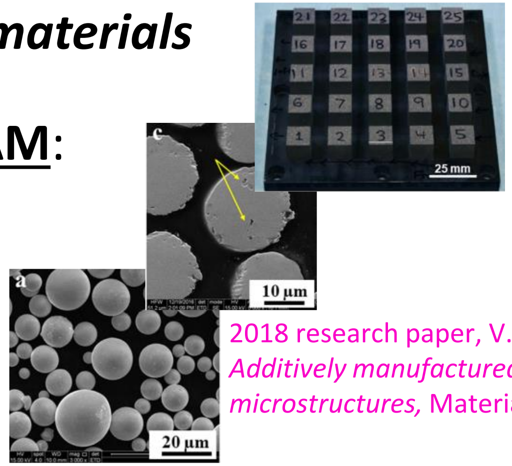
Shabalin, I. L. (2014). Introduction to Ultra High Temperature Materials. In *Ultra-High Temperature Materials I* (Vol. 2).



Ultra-High temperature materials

Refractory Metals Powder @ DIAM:

- Ta Powder → 1550 EUR/Kg → 7,5 Kg
- Mo Powder → 275 EUR/Kg → 10 Kg
- W Powder → 275 EUR/Kg → 20 Kg



2018 research paper, V. Livescu et al. *Additively manufactured tantalum microstructures,* Materialia 1, 15–24

DESIGN GUIDELINES AND CRITICAL ISSUES.

- **PRINT THE ENTIRE CAVITY IN A SINGLE COMPONENT.**
- **RESPECT OF THE GEOMETRICAL TOLERANCES (AS BUILT)**
- **MATERIAL HIGH PURITY REQUIREMENTS**
- **SURFACE FINISHING - ROUGHNESS**

First prints.

Printer: EOS M280
Laser: 400 W Yb fiber laser λ=1060-1100 nm

6 GHz SRF cavities, preliminary samples:

Verify the printability of the cavities…

- with different orientations (vertical and horizontal);
- without internal supports;
- with different down-skin parameters.

➢ Surface finishing processes @ Rösler S.r.l. and Legnaro National Laboratories (LNL-INFN).

Flanged SRF 6 GHz cavities: printed with a single job

A B C

3 wall thicknesses:

A: 3 mm

B: 2.5 mm

C: 2 mm

Leak tests and cryogenic tests @ INFN-LNL.

Pure copper – mechanical surface treatments

~~treatment~~	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10
No beneficial effect on roughness	Abrasive paste RSP 587 *(commercial Rösler product)*					Corundum abrasive powder			Synthetic diamond powder	

1

Rough sample

Step 5

Step 8

Step 10

~~treatment~~	Step 1	Step 2	Step 3	Step 4	Step 5	Step 6	Step 7	Step 8	Step 9	Step 10
No beneficial effect on roughness	Abrasive paste RSP 587 *(commercial Rösler product)*					Corundum abrasive powder			Synthetic diamond powder	

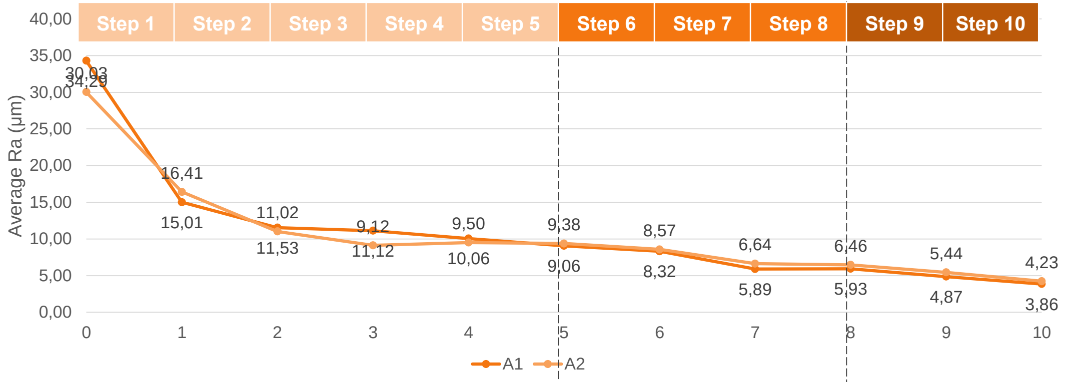
2

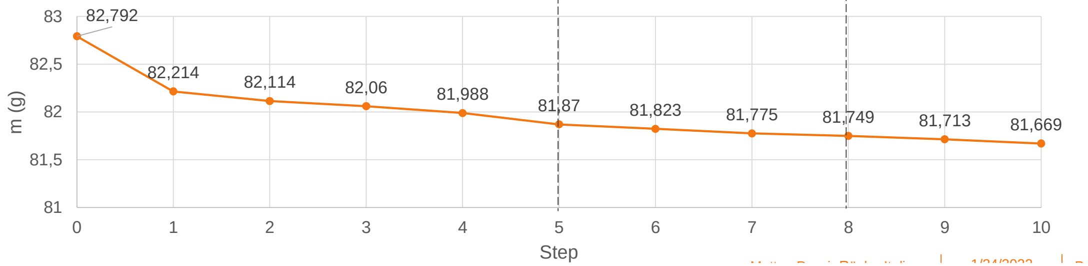
Rough sample

Step 5

Step 8

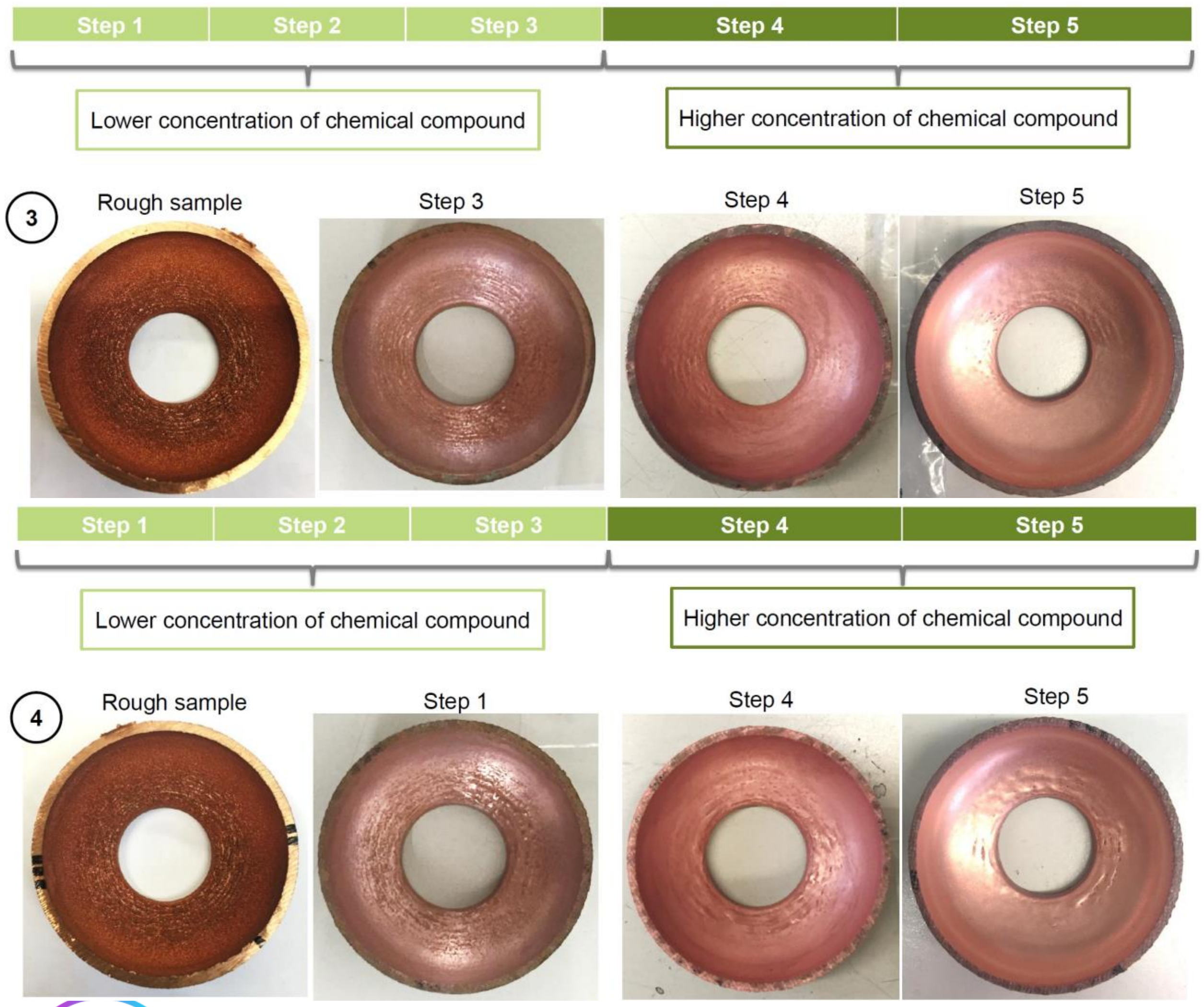
Step 10

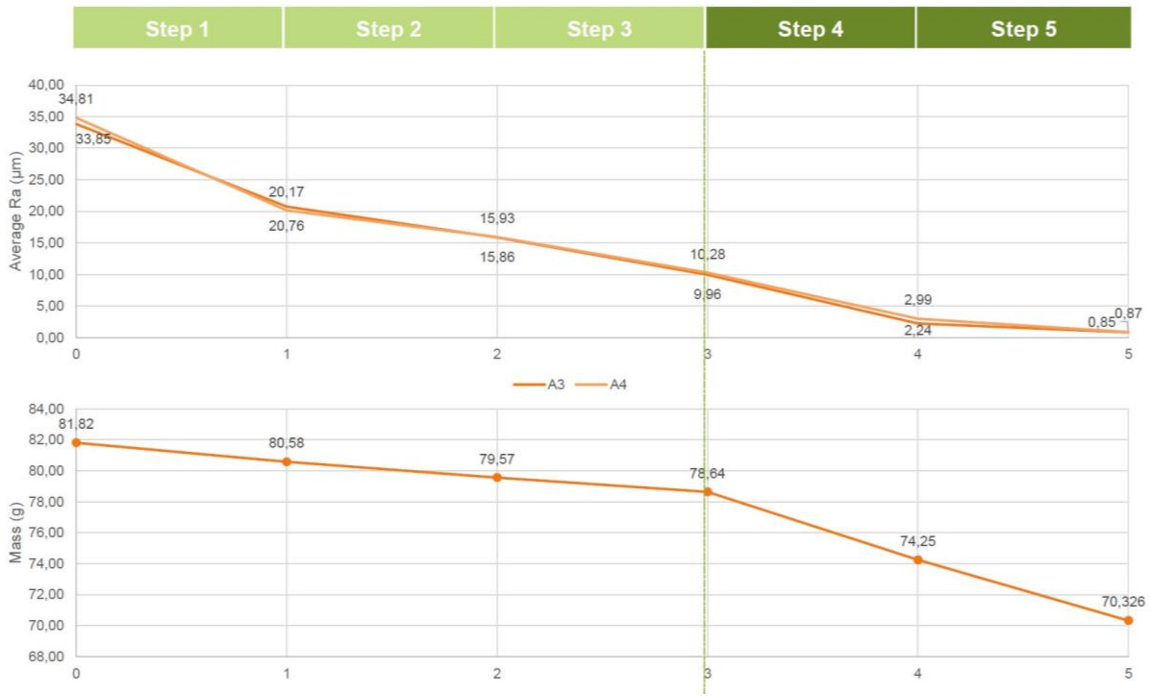




Roughness measurements on samples 1 and 2 and mass loss

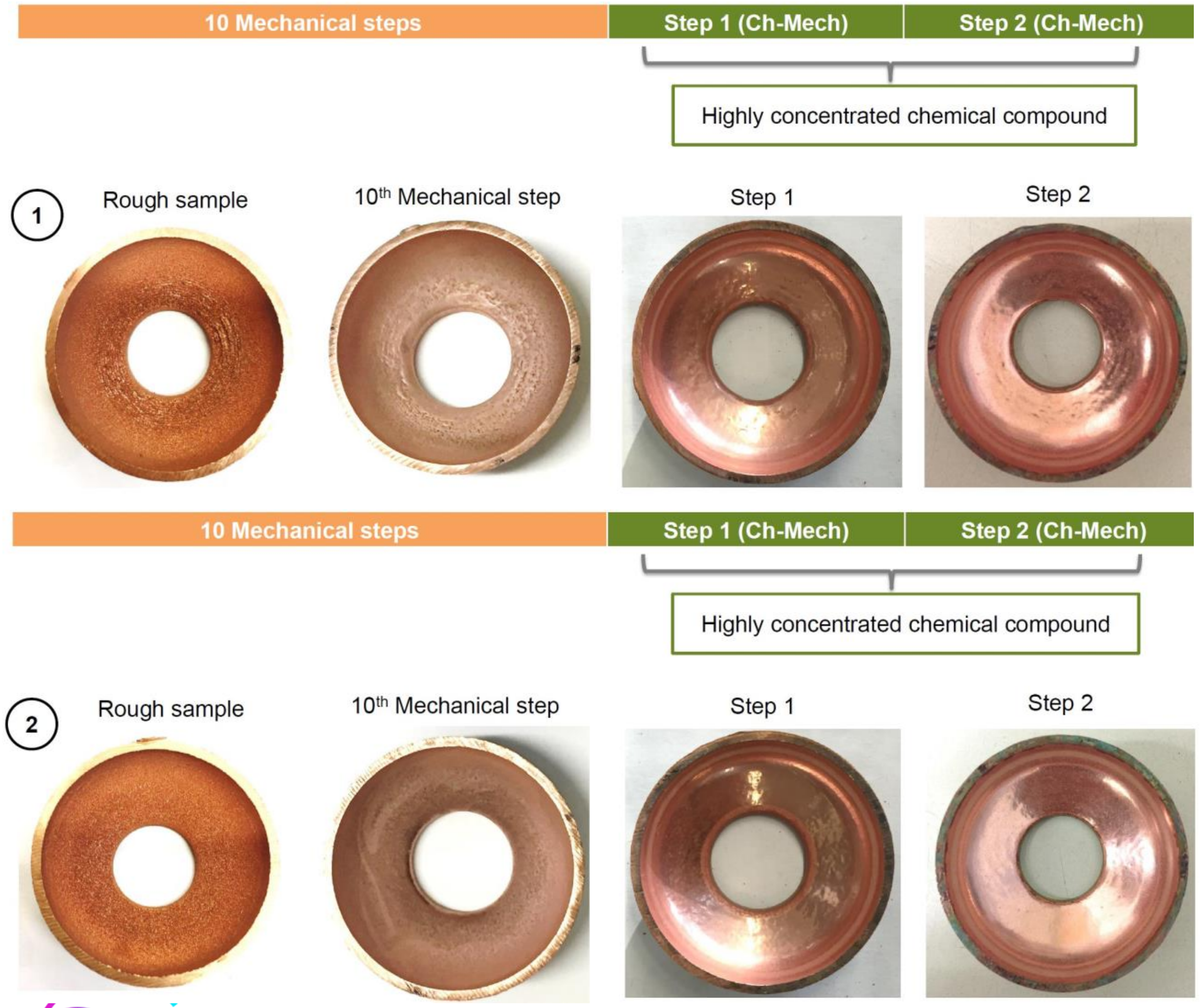
Pure copper –chemical-mechanical surface treatments

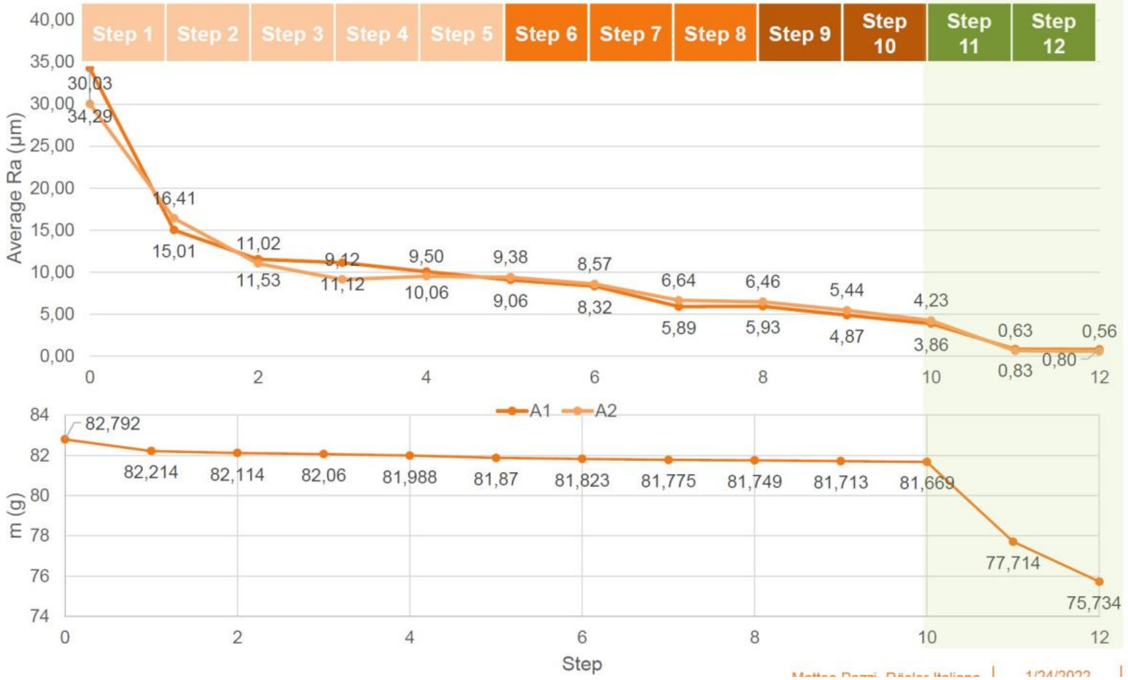




Roughness measurements on samples 3 and 4 and mass loss

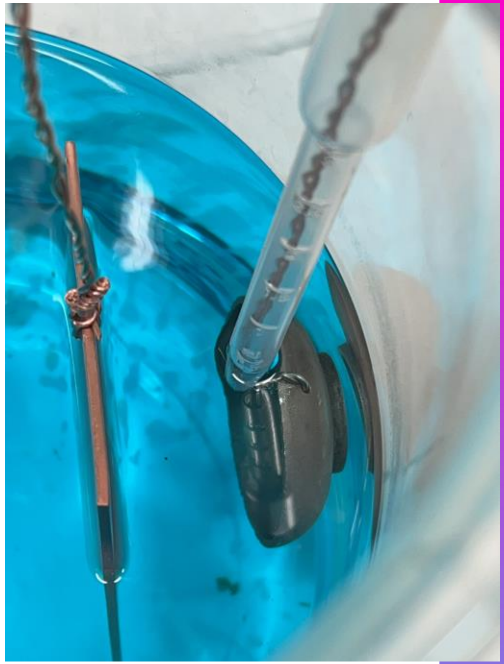
Pure copper mechanical and chemical-mechanical surface treatments





Roughness measurements on samples 1 and 2 and mass loss

Surface treatment LA of INFN LNL

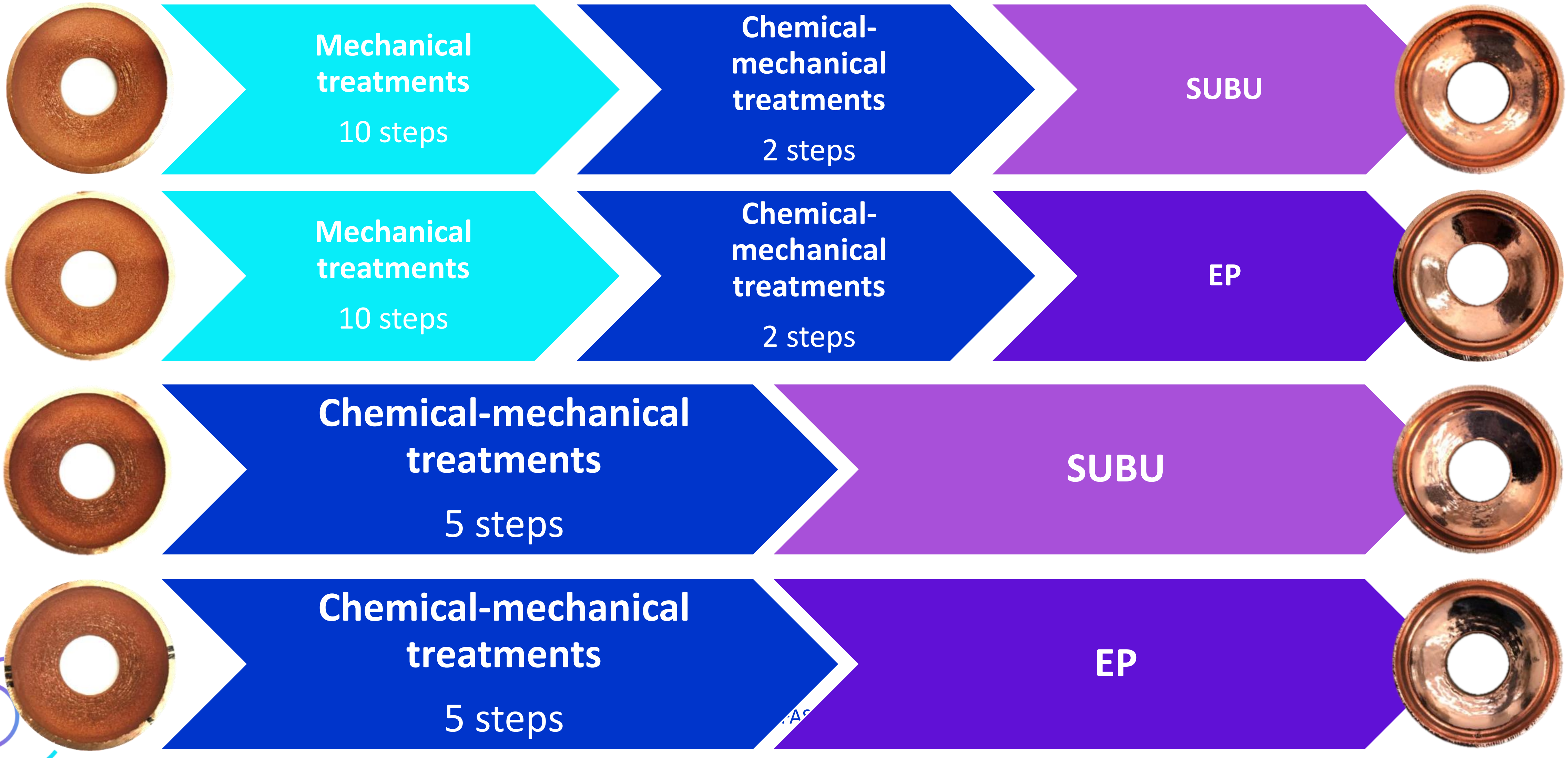


Other two samples to arrive.

EP, 1 h, < 40 um removed,

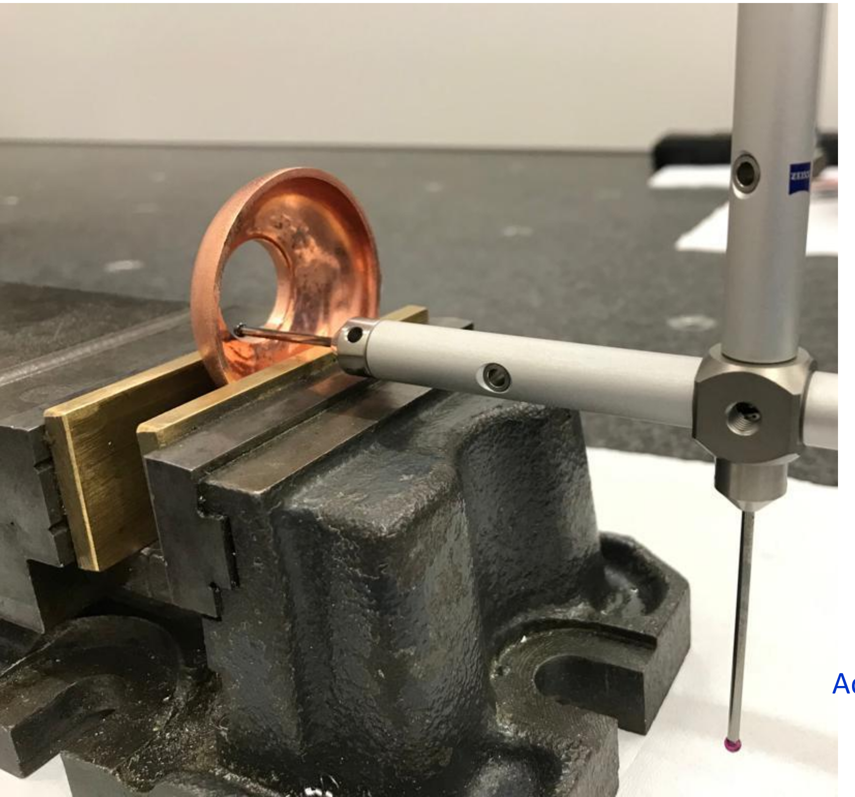
SUBU, 13 min, <10 um removed

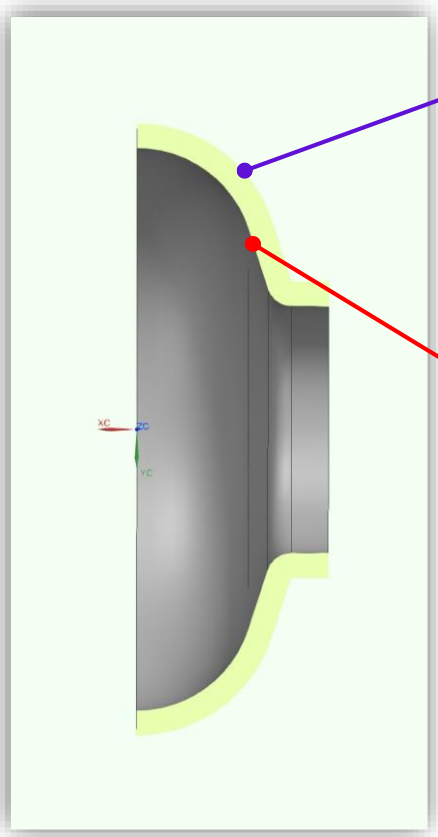
Surface treatments on half cavities



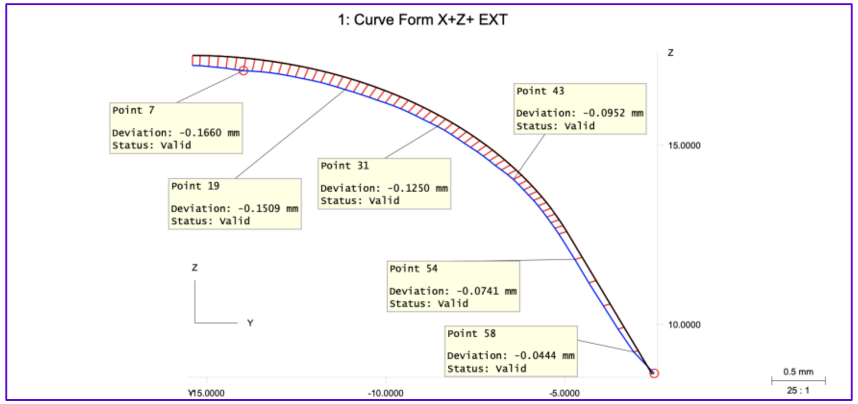
CMM SURVEY

From the measurements, it was found that the treatments removed 0.2 - 0.4 mm of material from the internal surface.
The removal is non homogeneous along the profile.

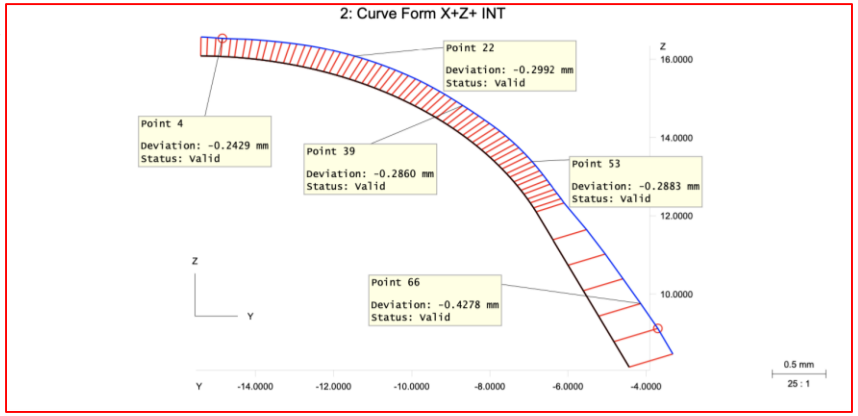




External profile



Internal profile



Internal supports

As demonstrated, copper cavities can be succesfully printed in one step without any support.

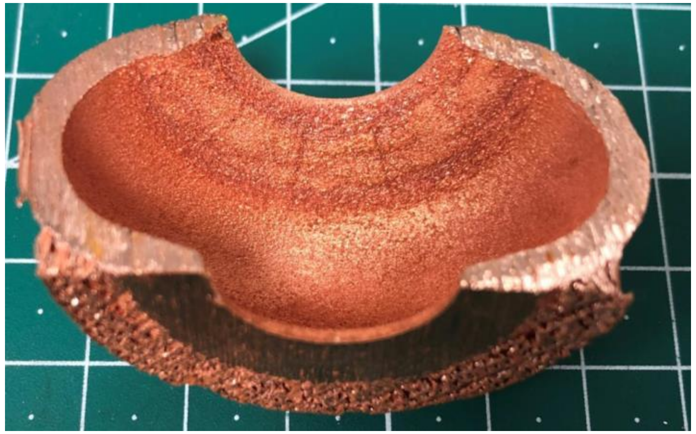
But internal supports could help improving the surface quality.

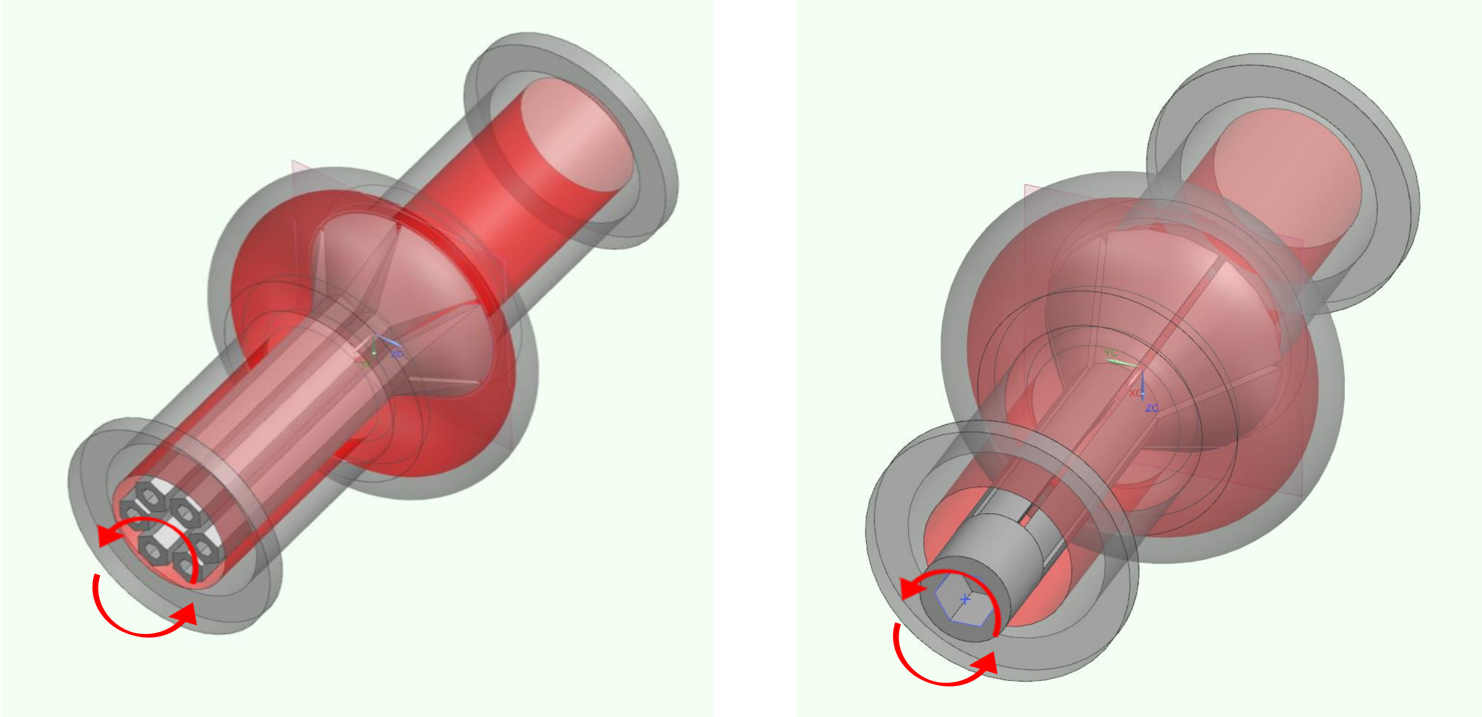
Several solutions are under development.

It is mandatory to satisfy the following requirements:

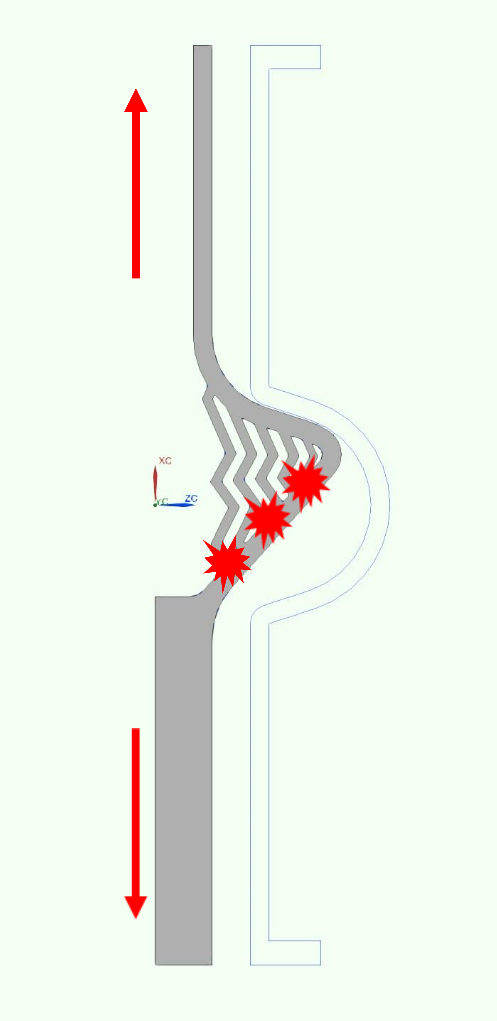
- Internal supports should not be difficult to remove;
- Supports should not compromise the quality of the internal surface;
- Mechanical methods for removing supports should be avoided.

Internal supports



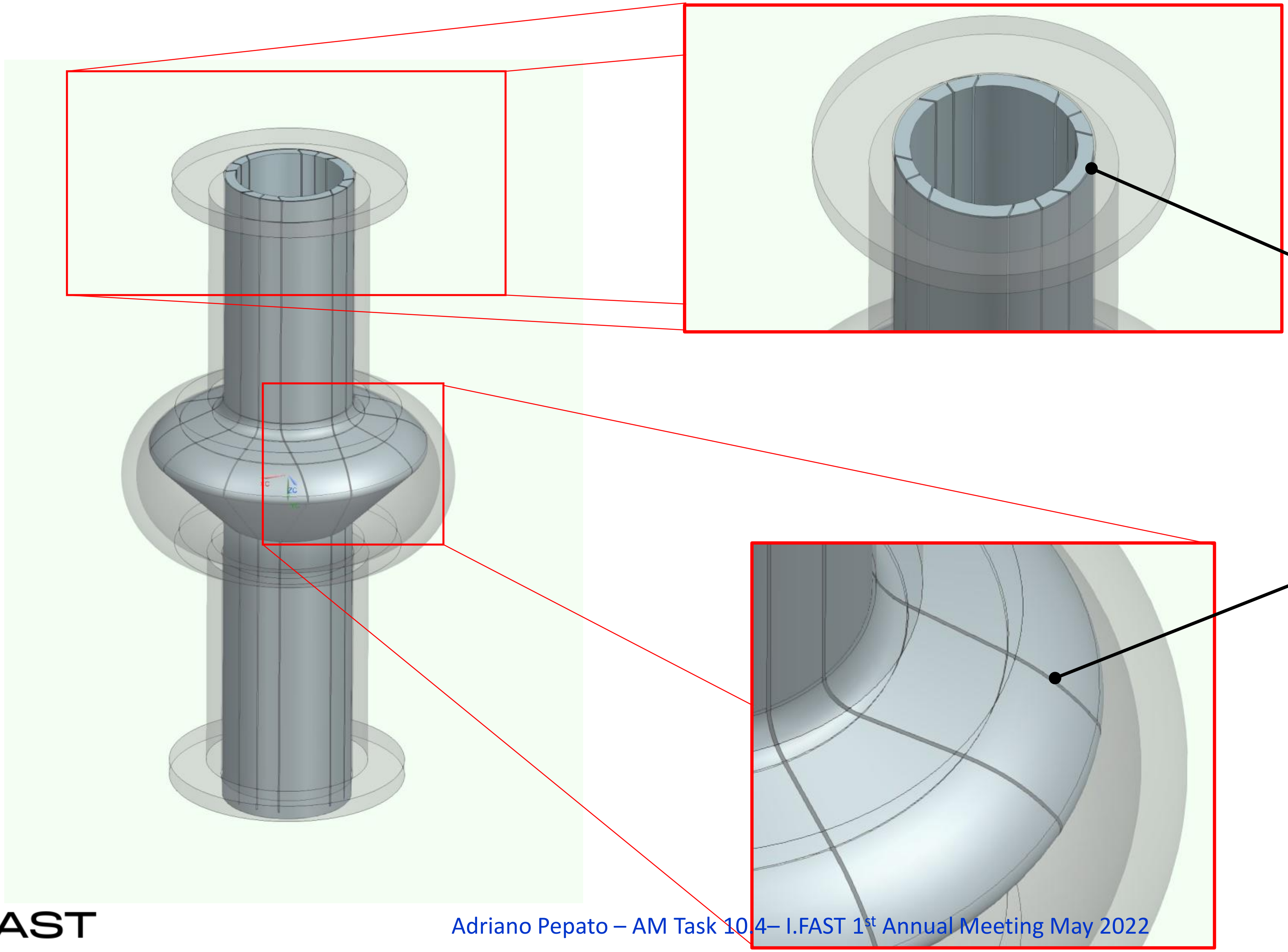


Example: supports removable by torsion



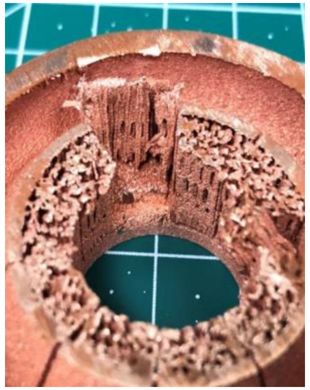
Example: no-contact extendable supports

Internal supports

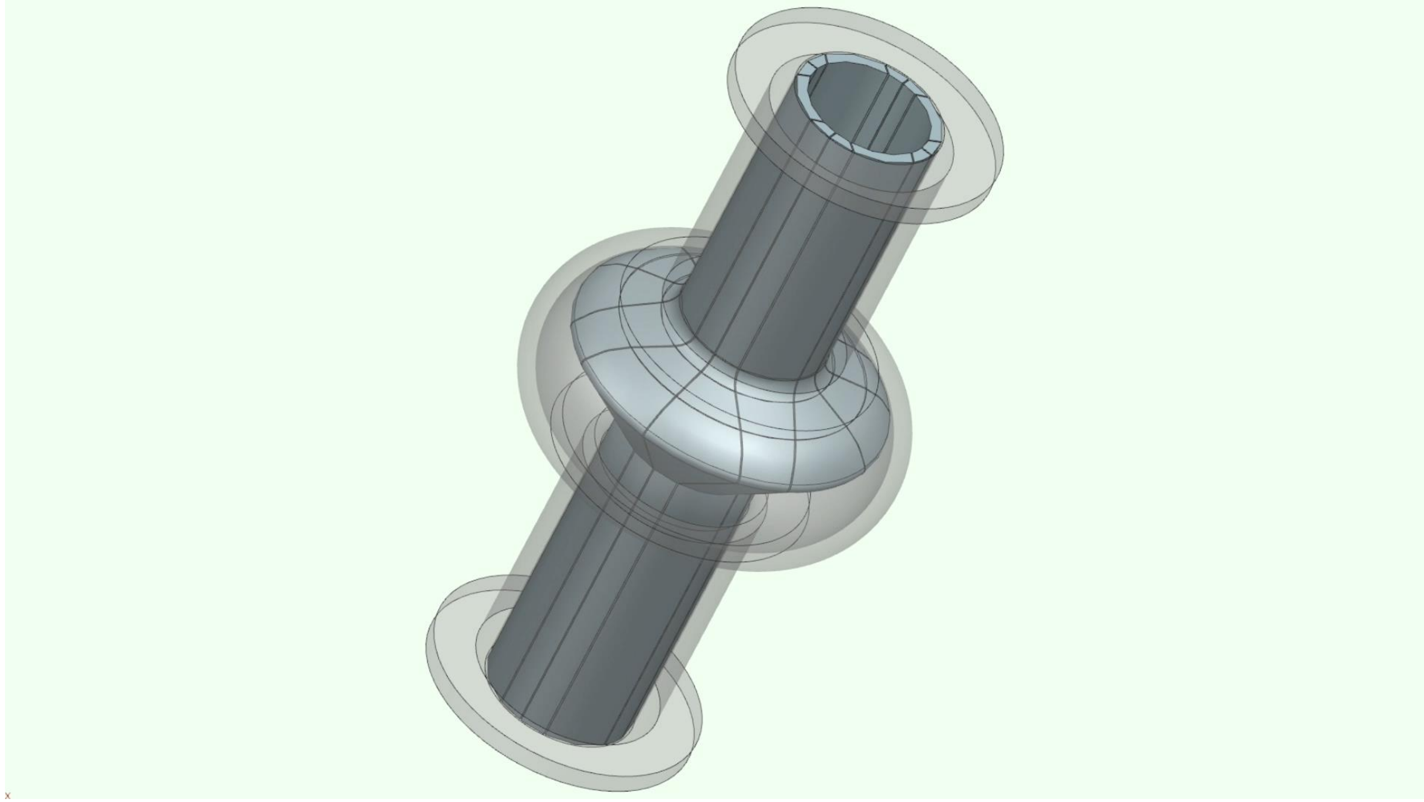


Gap between the supporting structure and the cavity

Gap between the parts



Internal supports



Pure Copper

PSD: 12-28 µm

Layer thickness: 20 µm

Same core parameters, different downskin contour parameters

Different gaps between part and contactless supporting structure

Internal supports

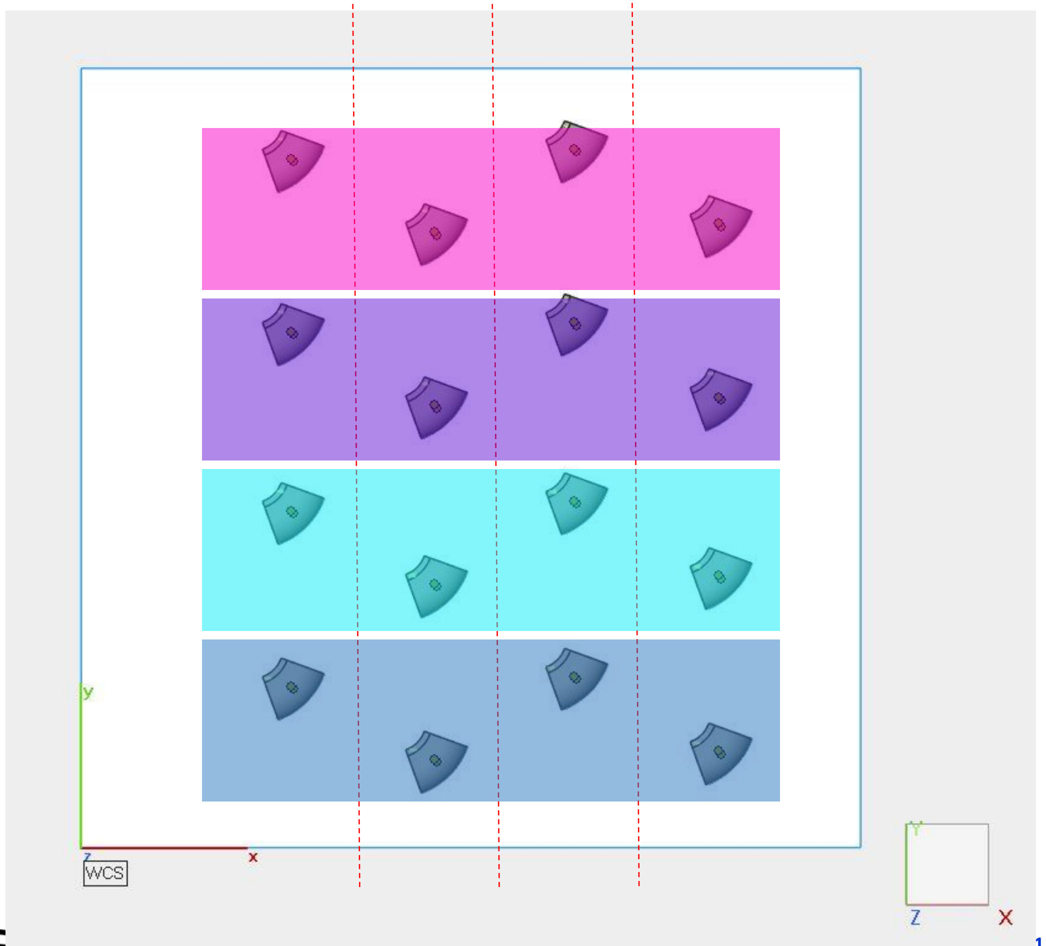
Gap [mm]: 0.08 0.160 0.320 0.500

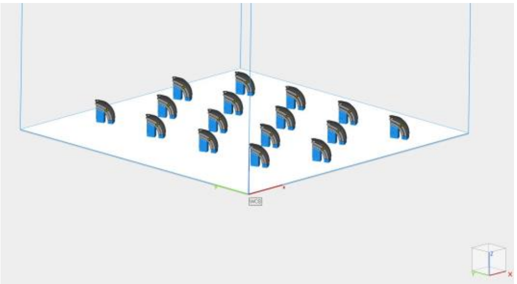
Contour/post contour 1 + edge/post edge 1

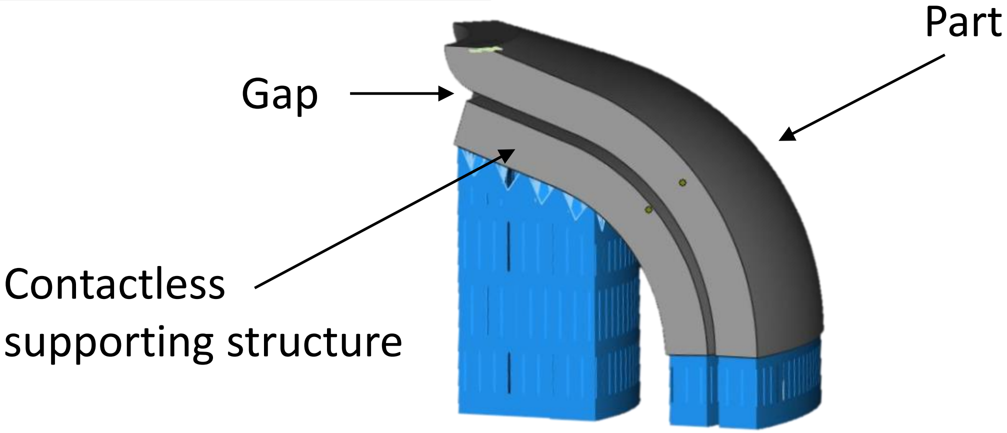
Contour 2 + edge/post edge 1

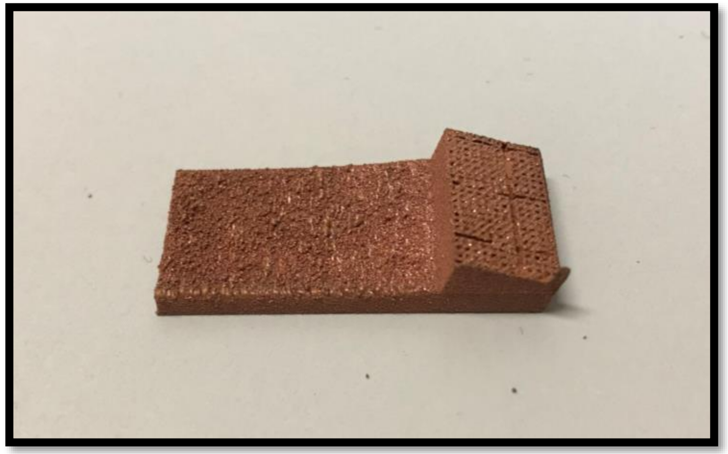
Contour/post contour 2 + edge/post edge 1

Contour 2 + edge/post edge 2







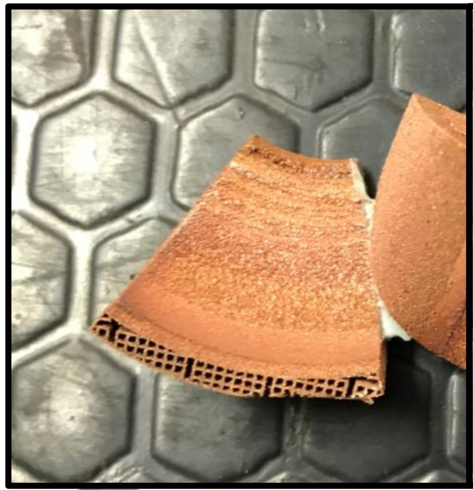


Inclined wall (18°)

Internal supports

Half cavity printed without any kind of supporting structure

Gap: 0.08 mm



Gap: 0.16 mm

Gap: 0.16 mm

Gap: 0.32 mm

Gap: 0.50 mm

Pure niobium

TANIOBIS AMtrinsic® Spherical Nb Powder (PSD: 15-60μm)

Elements	Quantity
Nb	99.9 %
C	<50 ppm
H	<50 ppm
N	<100 ppm
O	<600 ppm
Ta	<100 ppm
Cr	<50 ppm
Fe	<50 ppm
Ni	<50 ppm
Hf	<50 ppm
Mo	<50 ppm
Zr	<50 ppm
W	<50 ppm

Samples were manufactured using different building parameters on a building platform made of pure copper.

The relative density of each sample was estimated by Archimedes method.

Densities of the cubes produced

ranged from 98.44% to 99.56%

EOS M100
Yb fiber laser
Spot diameter: 40 μm
λ = 1064 nm
Nominal power: 200 W

Pure niobium

TANIOBIS AMtrinsic® Spherical Nb Powder

Elements	Quantity
Nb	99.9 %
C	<50 ppm
H	<50 ppm
N	<100 ppm
O	<600 ppm
Ta	<100 ppm
Cr	<50 ppm
Fe	<50 ppm
Ni	<50 ppm
Hf	<50 ppm
Mo	<50 ppm
Zr	<50 ppm
W	<50 ppm

Inclined walls:

Angles investigated: 18° 20°, 22°, 25°, 30°, 35°, 40°, 45°, 50°

Acceptable results only for angles higher that 35°.

EOS M100

Yb fiber laser

Spot diameter: 40 µm

λ = 1064 nm

Nominal power: 200 W

NEED TO APPLY THE NO CONTACT SUPPORT APPROACH

LPBF of pure niobium – further steps

- Increase the relative density of the parts
- Improve the surface quality of the as-built parts
- Characterization of Nb:
  - mechanical/thermal properties, microstructural analysis
  - superconductive properties
- Treatments (purification treatments, surface treatments)

Final step: 6 GHz superconductive cavity made of pure Nb

What next:

Ultra pure Cu cavities production (max. density up to 99.98%):

- **We'll receive a couple of cavities printed with EOS M290 (fibre infrared laser, 1 kW)**
- **We'll receive a couple of two cavities printed with TRUMPF 5000 TruPrint (solid state green laser 1 kW)**
- **Chemical-mechanical surface finishing (Rösler) and final finishing from 1 mm up to the optimized roughness for the Nb sputtering (INFN LNL)**
- **Test at Room and cryogenic temperature (INFN LNL and CNRS).**

Ultra pure Nb:

- **We hope to receive the proper Nb powders (PSD and composition) by the end of April 2022**
- **Printing of cavities at DIAM (Development and Innovation on Additive Manufacturing for metals, INFN PD)**
- **Chemical-mechanical surface finishing (Rösler) and final finishing from 1 mm up to the optimized roughness (INFN LNL)**
- **Test at room and cryogenic temperature (INFN LNL and CNRS).**

iFAST

Thanks for your attention

This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.