Design, manufacturing and testing of Ti6Al4V prostheses printed by laser melting deposition

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3D printing - Introduction

3D printing → the process of making a physical object from a three-dimensional digital model

Commercial polymer printers from Symme 3D (Romania)

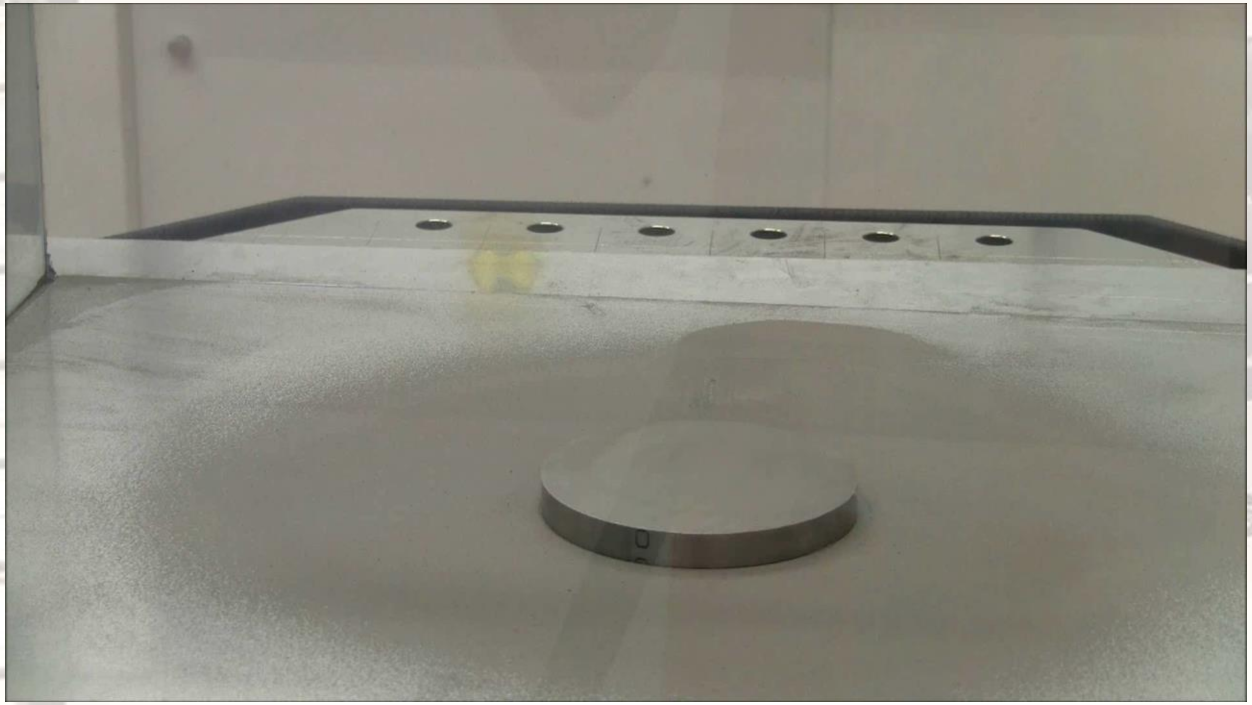
Commercial additive manufacturing machine from Trumpf (Germany)

For polymers → cheap technology, available for everyone

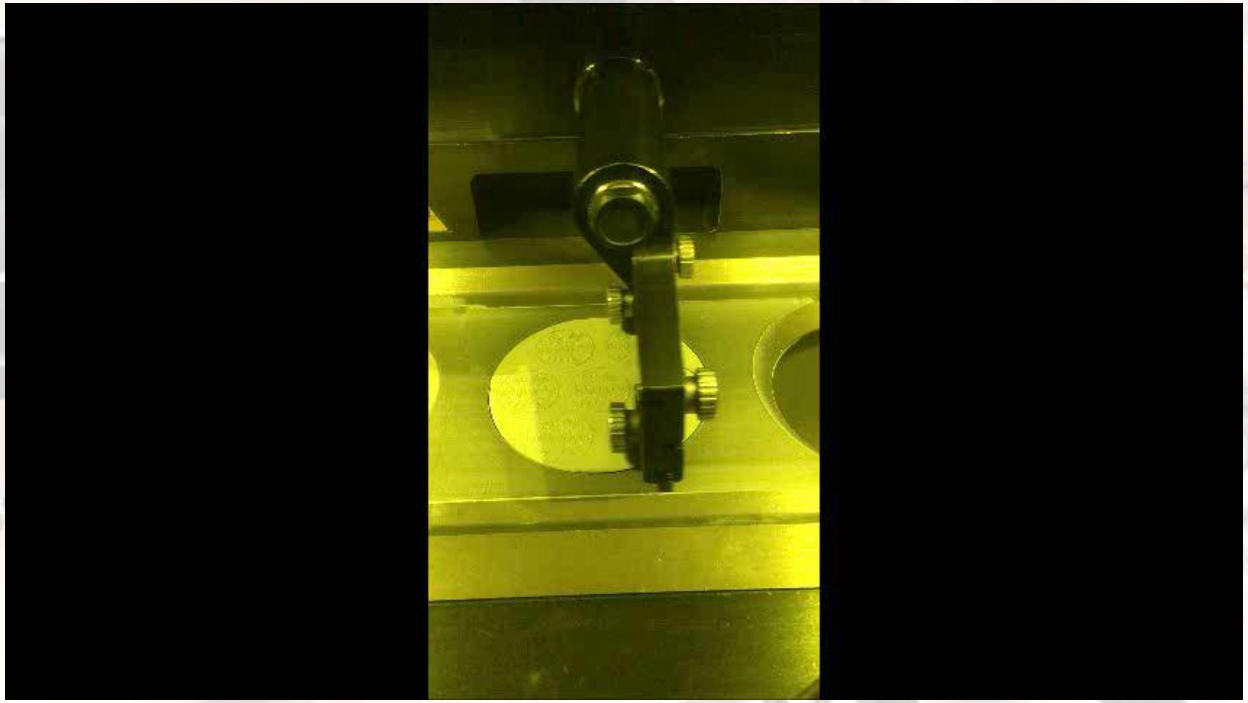
For metals → expensive technology, still restrictive

Printing of metal parts - Introduction

Laser Melting Deposition (**LMD**)



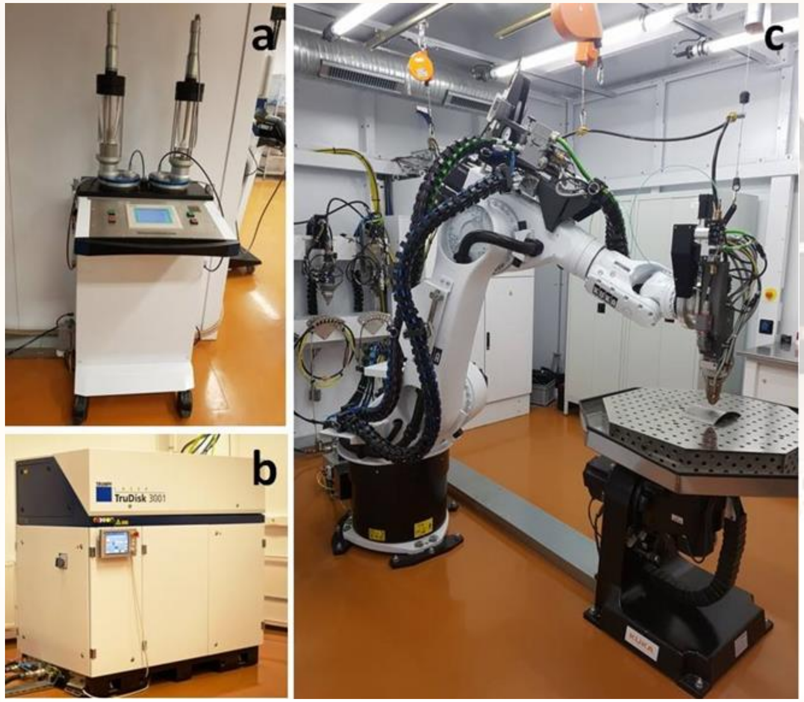
Selective Laser Melting (**SLM**)



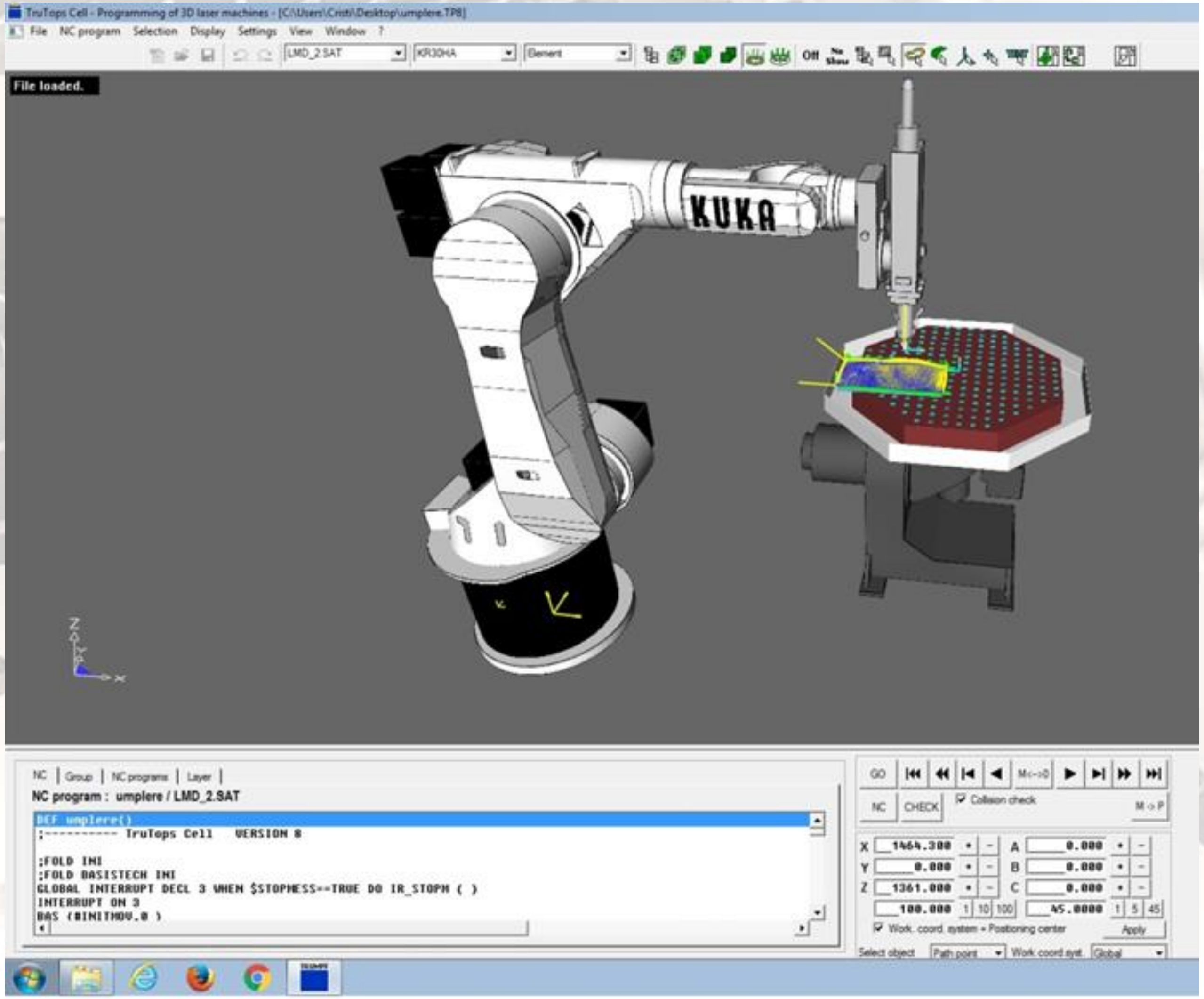
Complementary methods: LMD does not allow the print resolutions achieved by SLM, but it makes possible printing of large parts, in situ alloying, multilayer structures

The experimental setup

Metallic powder Ti6Al4V
Laser Power 1 kW
Powder flow 3 g/min
Processing speed 2.8 m/min



a. powder dispenser, b. laser source, c. robotic cluster equipped with powder nozzle

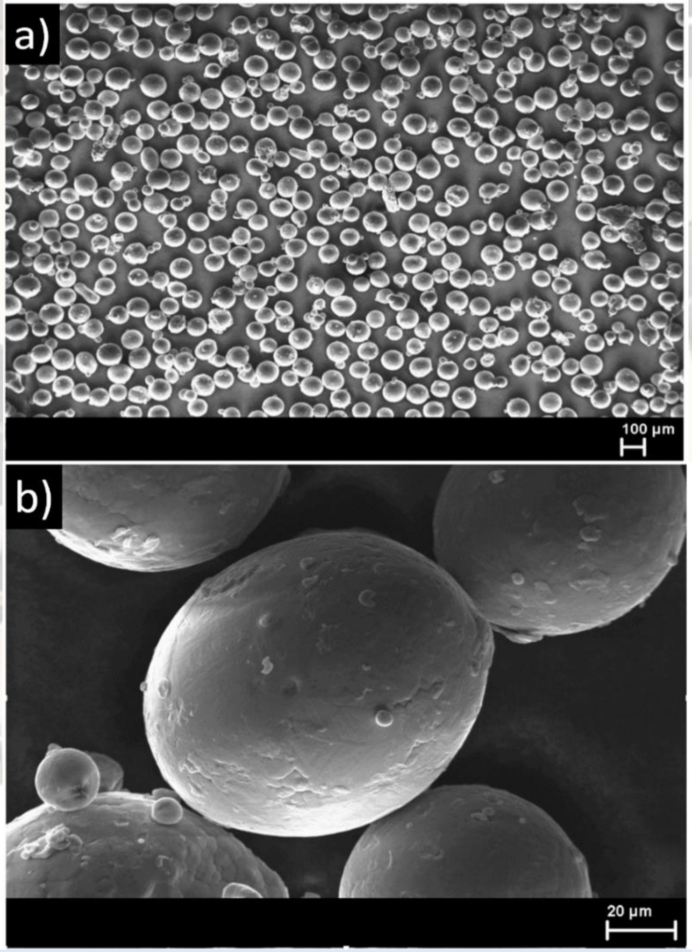


TruTops Cell Interface for programming TruLaser Robot 5020 robot movements

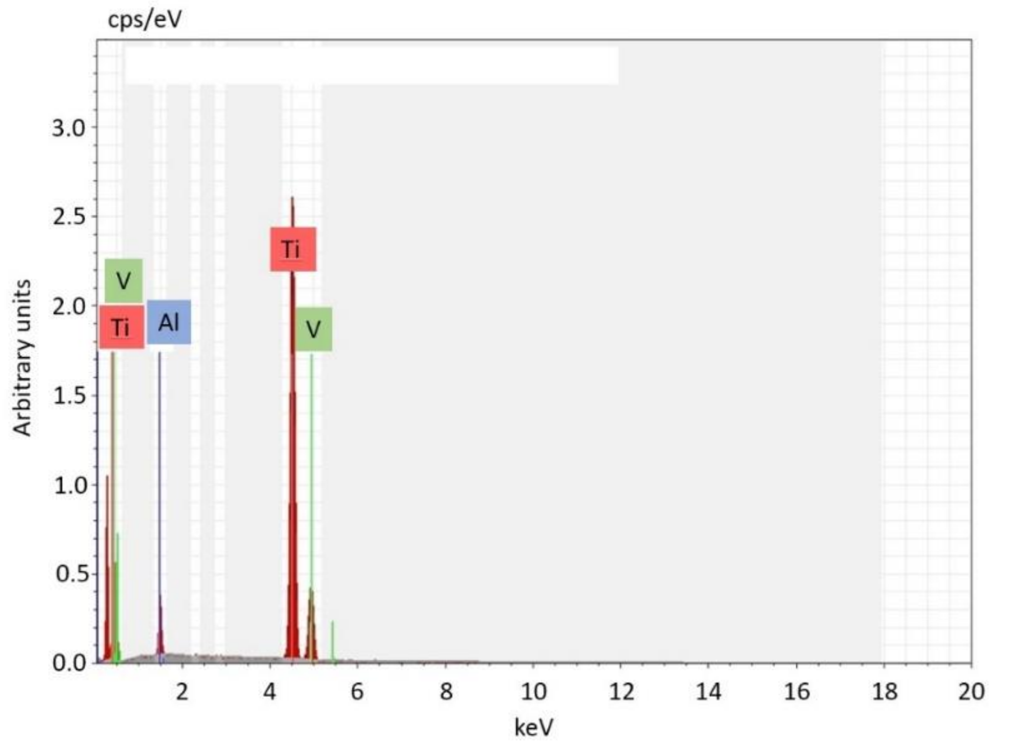
Characterization of Ti6Al4V powder

Conventional photo of a Ti6Al4V powder bed

Element	Composition [wt]
Ti	90%
Al	6%
V	4%

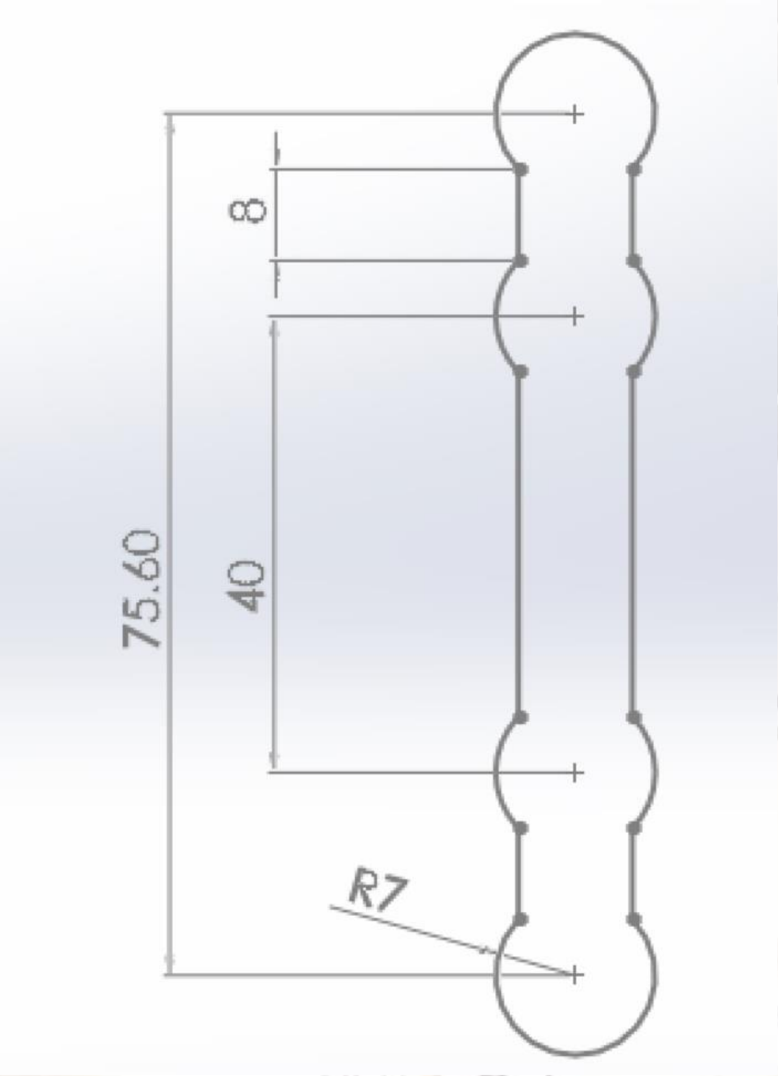


SEM images of the Ti6Al4V powder: a) overview and b) particles in detail



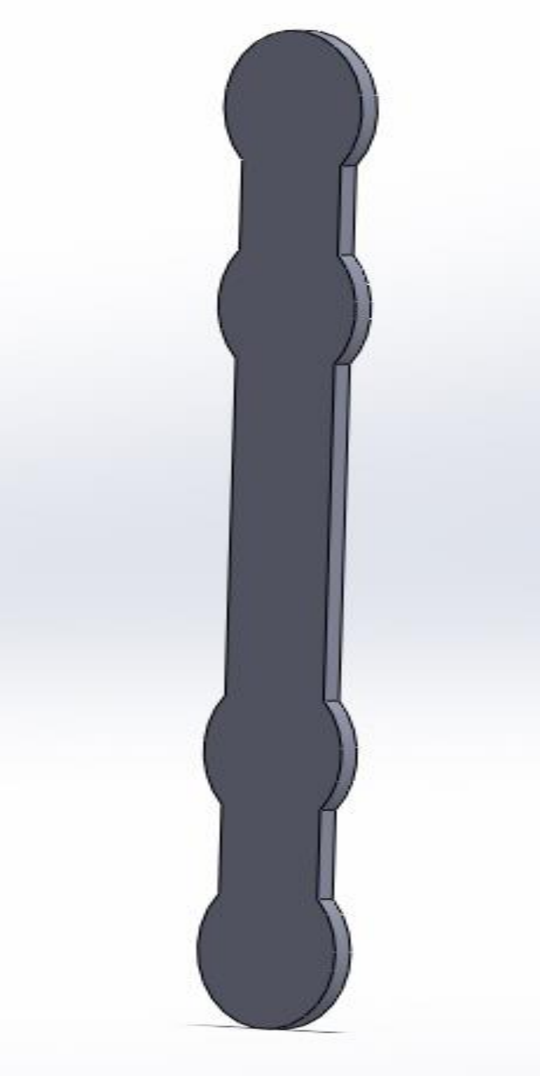
EDX spectrum characteristic to Ti6Al4V source powder

The first step - the execution drawing



2D Execution drawing

1 mm EXTRUDE

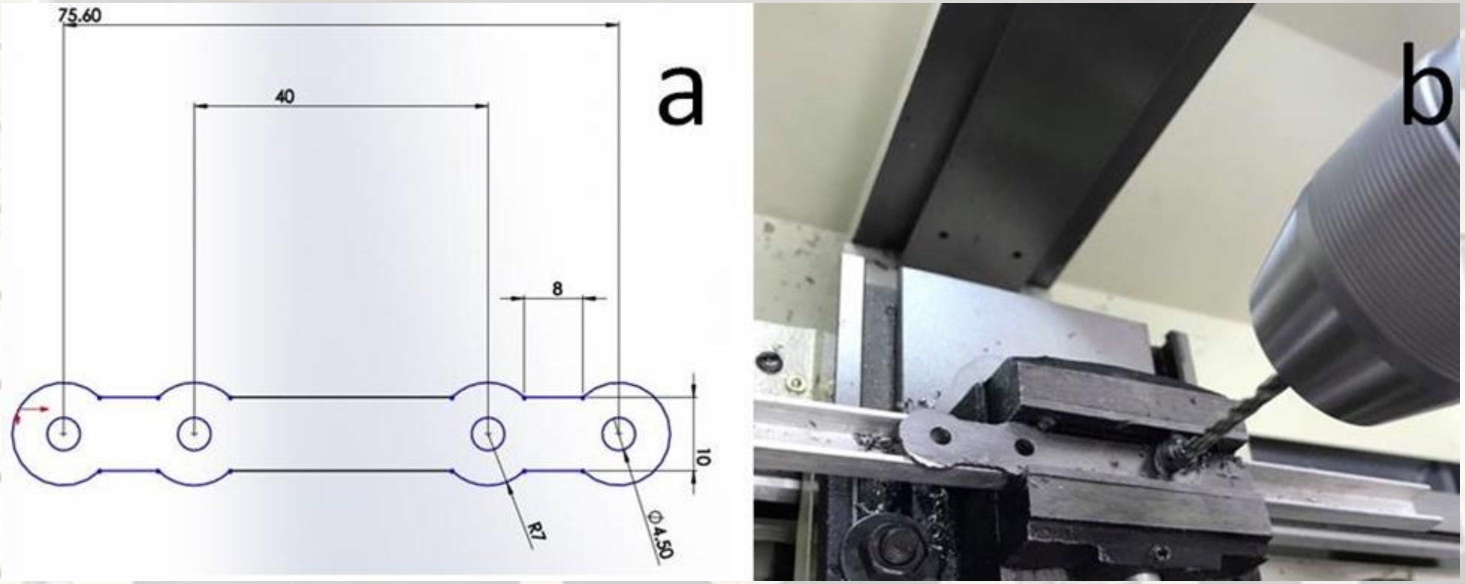

3D execution drawing

Optimizing trajectories

3D printing: a) cross-scanning, b) vertical scanning, and c) vertical contoured scanning

The cut shape obtained by LMD with a meandering vertical (a) and vertical with contur (b)

Machining and surface finishing



a) Technical drawing of the implant and b) Drilling of the intermediate form according to the technical drawing

Implant according to the technical drawing produced by LMD printing followed by cutting and drilling operations

Finished implants generated by LMD printing and mechanically processed to meet the roughness requirements

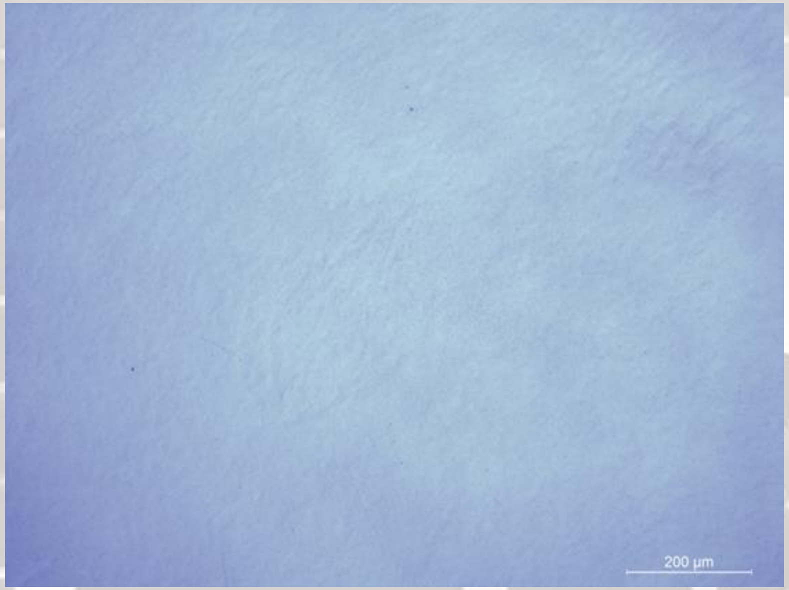
Samples preparation

Polishing machine

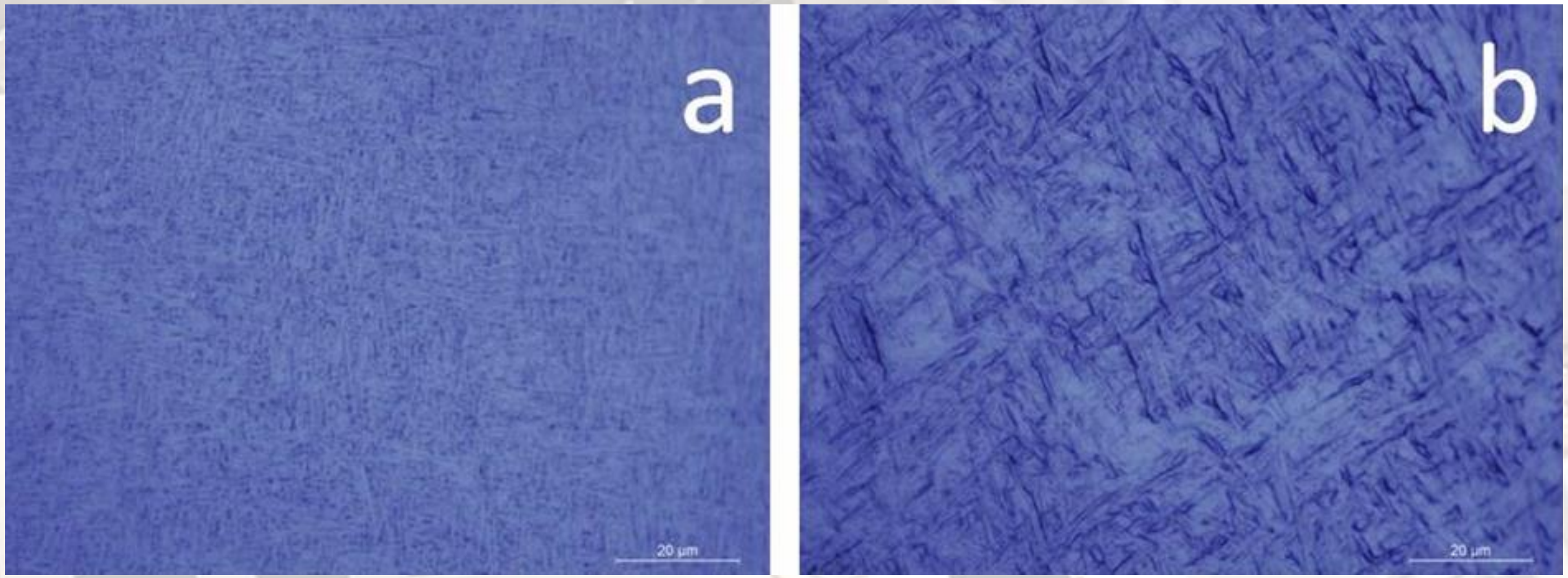
Hot pressing machine

Manual cutting machine

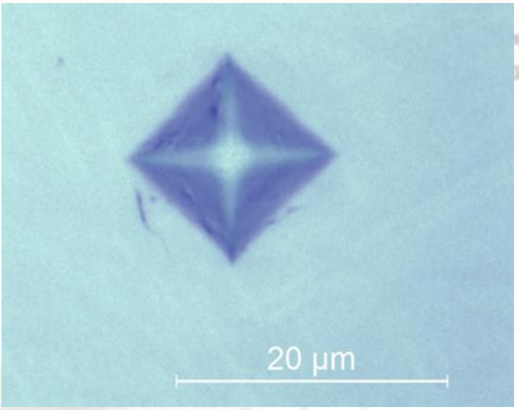
Metallographic characterizations



Optical microscopy image of a sample surface after polishing to mirror level



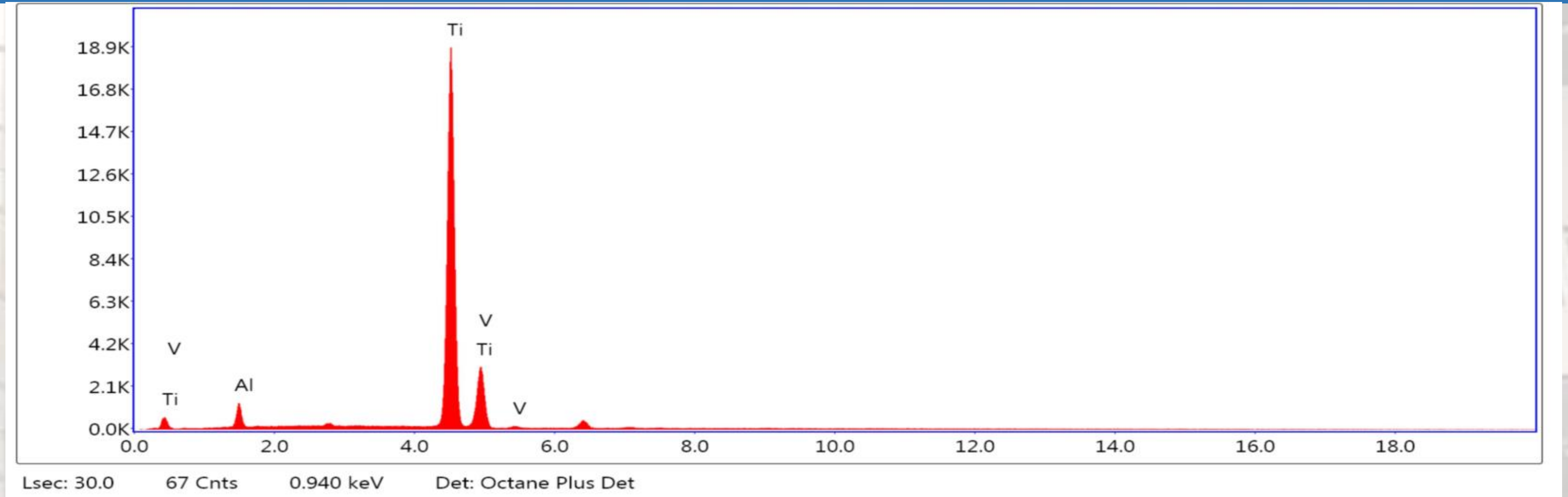
Optical microscopy images of a Ti6Al4V surface after etching: a) overview of the dendritic structure and b) detail with acicular grains β in a phase matrix



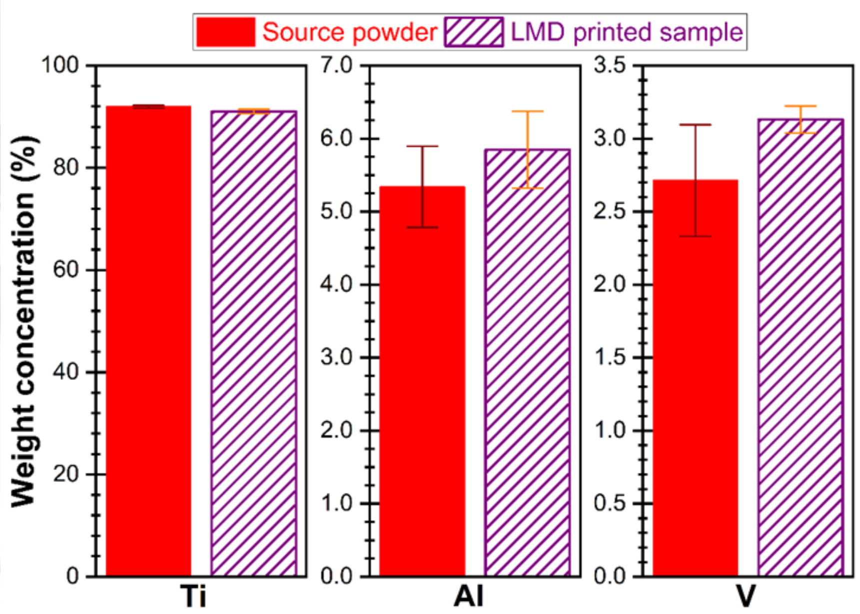
Microhardness → 392±7 HV

Hardness of the LMD sample > Hardness of the casted material (~349 HV)

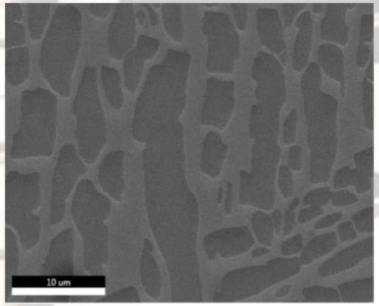
Physico-chemical analysis



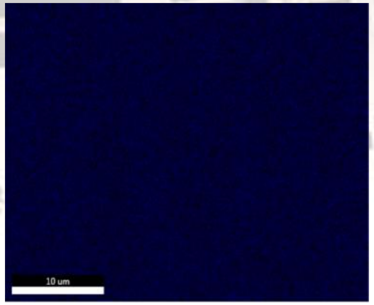
EDX spectrum of a LMD sample and local chemical composition



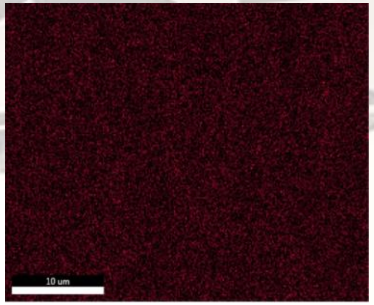
The comparative mass concentrations of Ti, Al and V estimated by EDX in the case of source powder and after LMD printing



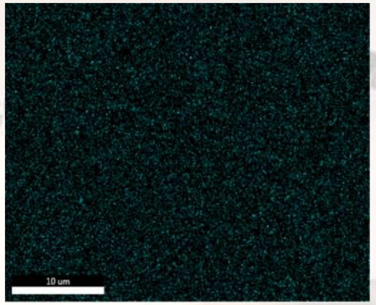
Analyzed area



Ti Distribution



V Distribution

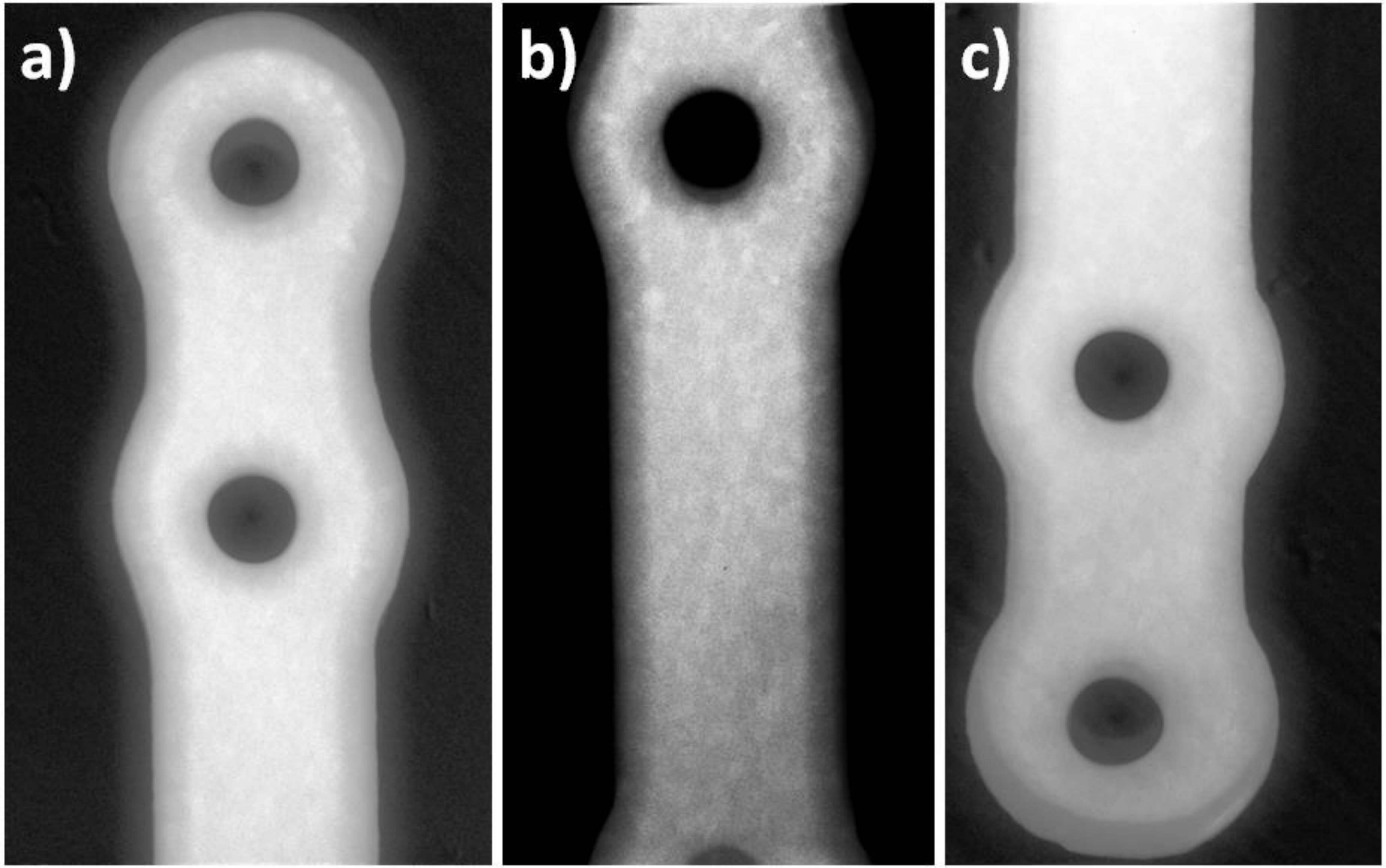


Al Distribution

Compositional map of the analyzed area on the surface of a LMD printed sample

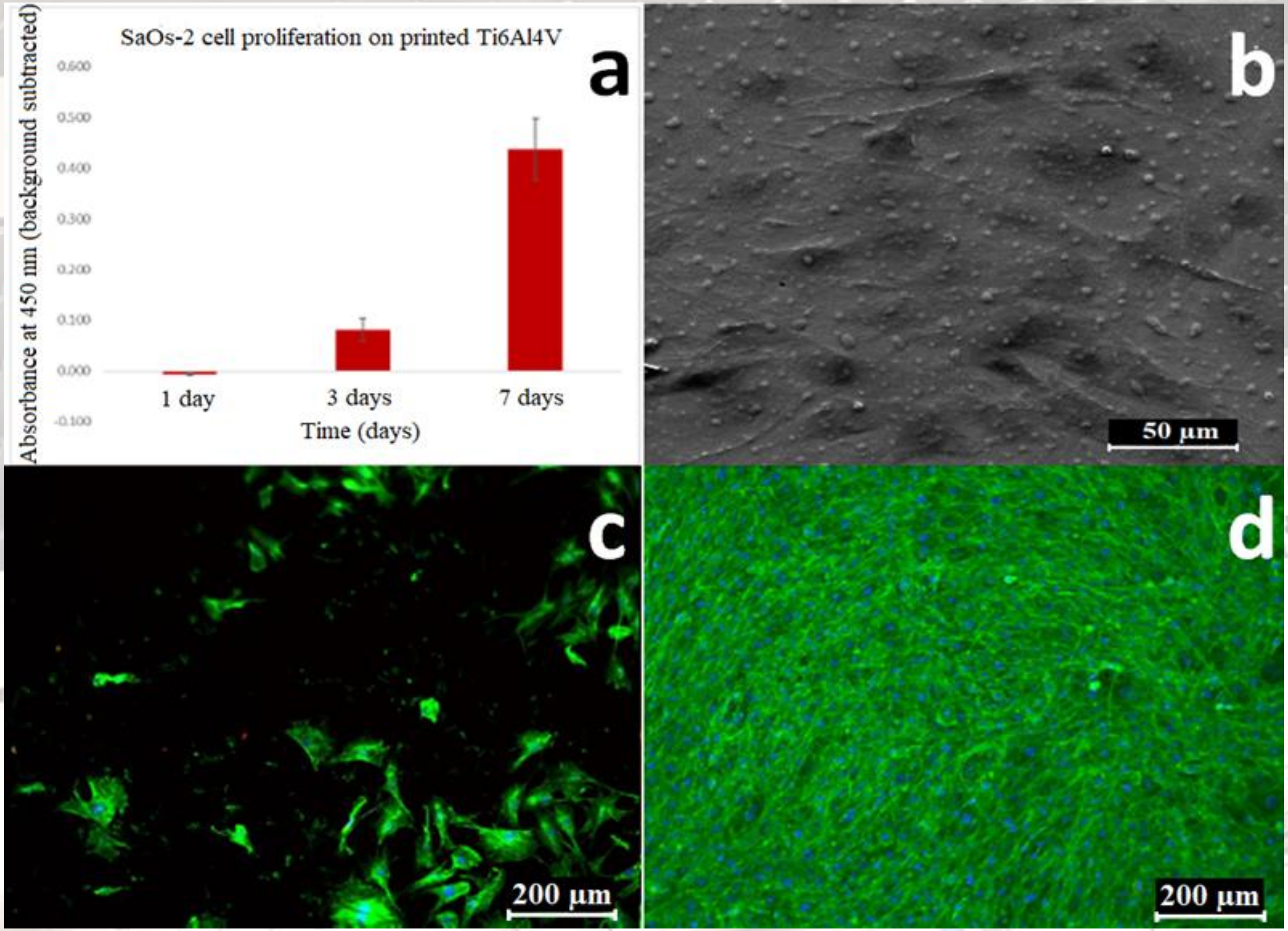
Element	Weight %	Atomic %
AlK	6.70	11.34
TiK	88.43	84.30
V K	4.87	4.36

X-ray Radiography



a) top
b) middle
c) bottom
of the
prosthesis

In vitro tests



(a) MTS results for SaOs2 cells grown on LMD printed Ti6Al4V;
(b) SEM micrograph of SaOs2 cells 3 days after seeding on LMD printed Ti6Al4V; fluorescence microscopy images of SaOs2 cells cultivated for
(c) 1 day and
(d) 3 days on the surface of LMD printed Ti6Al4V.

Conclusions

- ✓ Laser printing of orthopedic Ti6Al4V implants , starting from 50-90 µm granular powder.
- ✓ Optimized process parameters, dense deposits, no porosity or cracks.
- ✓ The design of the trajectory followed by the laser beam → essential for obtaining adequate shapes
- ✓ The incipient 3D prints were cut, drilled and polished to get the final implant.
- ✓ In vitro tests with osteosarcoma cells → MTS tests have shown that cells proliferate→ materials printed by LMD are biocompatible.
- ✓ This method of producing an implant opens new horizons for special applications, difficult to access by other techniques: implants of composite materials, implants with variable composition or implant thickness control.

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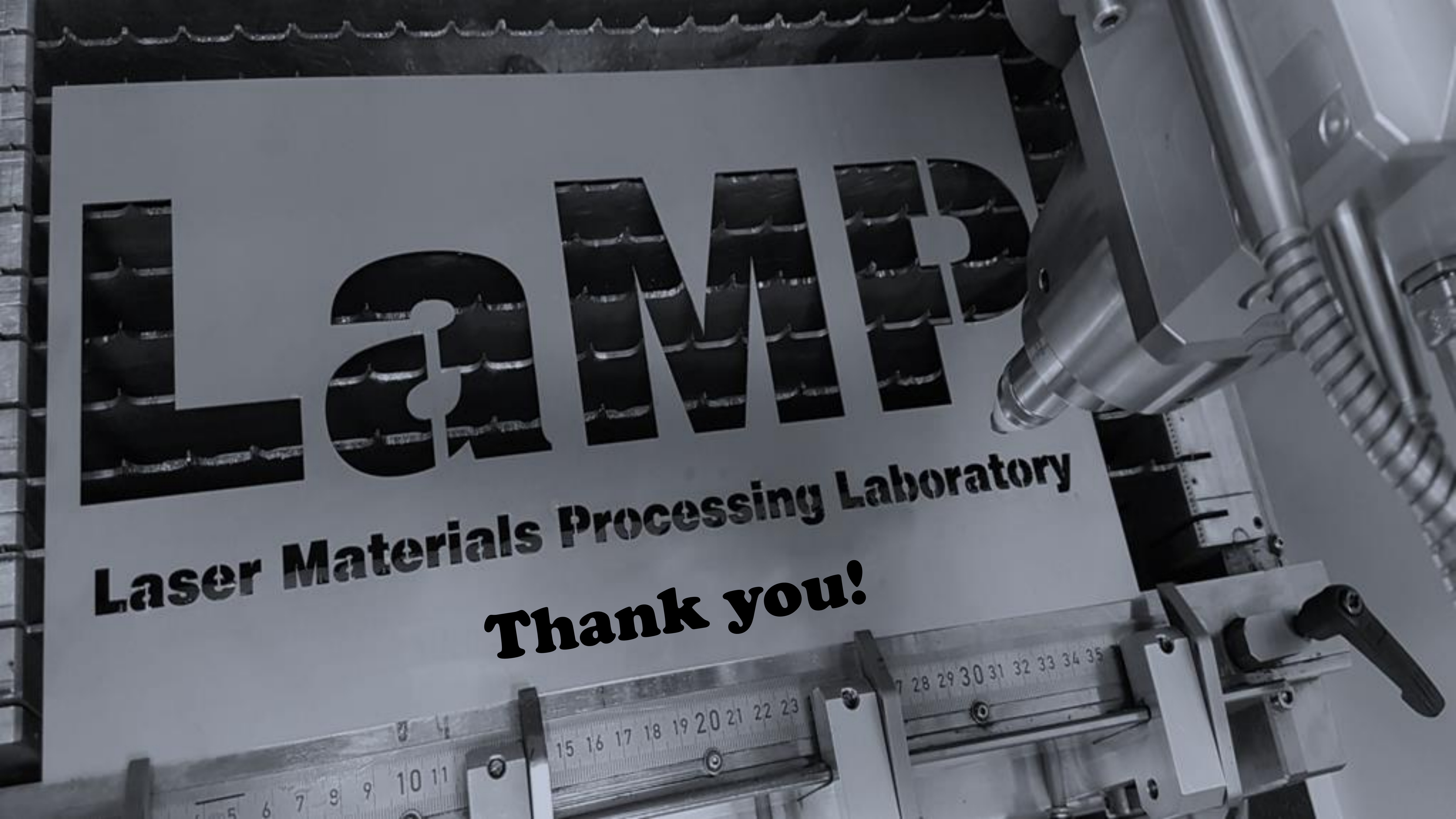
Stefana IOSUB – In vitro tests

Rösler Romania – surface finishing of the LMD printed bone plates.



Thank you!