ADDITIVE 4 BIOMEDICAL

UNIVERSITÀ DEGLI STUDI FIRENZE
DIEF DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

UNIVERSITÀ DEGLI STUDI DI BRESCIA

October 17th–18th, 2022

PRODUCTION PROCESS OPTIMIZATION AND CHARACTERIZATION OF 3D PRINTED METAL PRODUCTS

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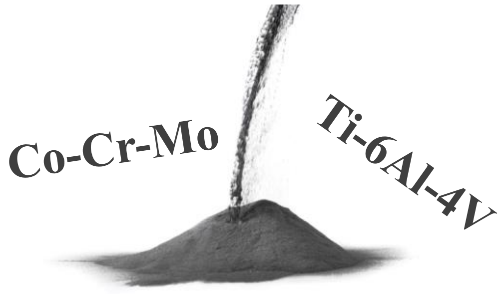
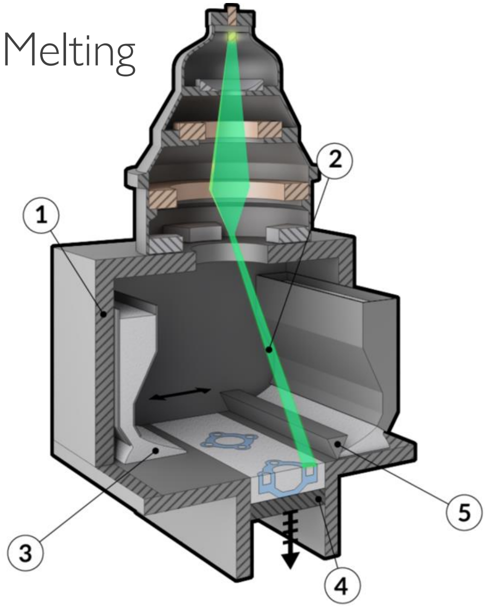
PhD Course

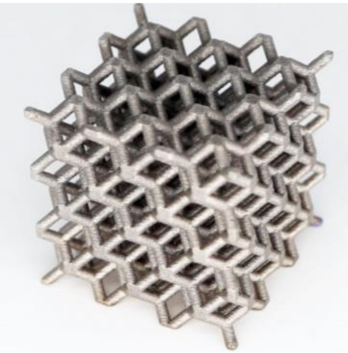
Introduction



Biomedical alloys

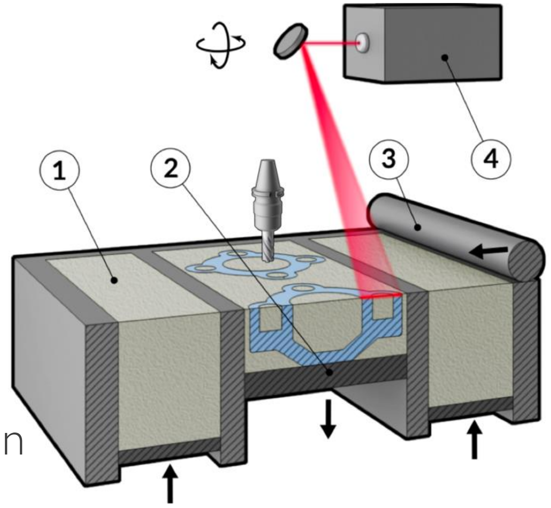
Elecrton Beam Melting
(EBM)





Lattice structure

Technologies

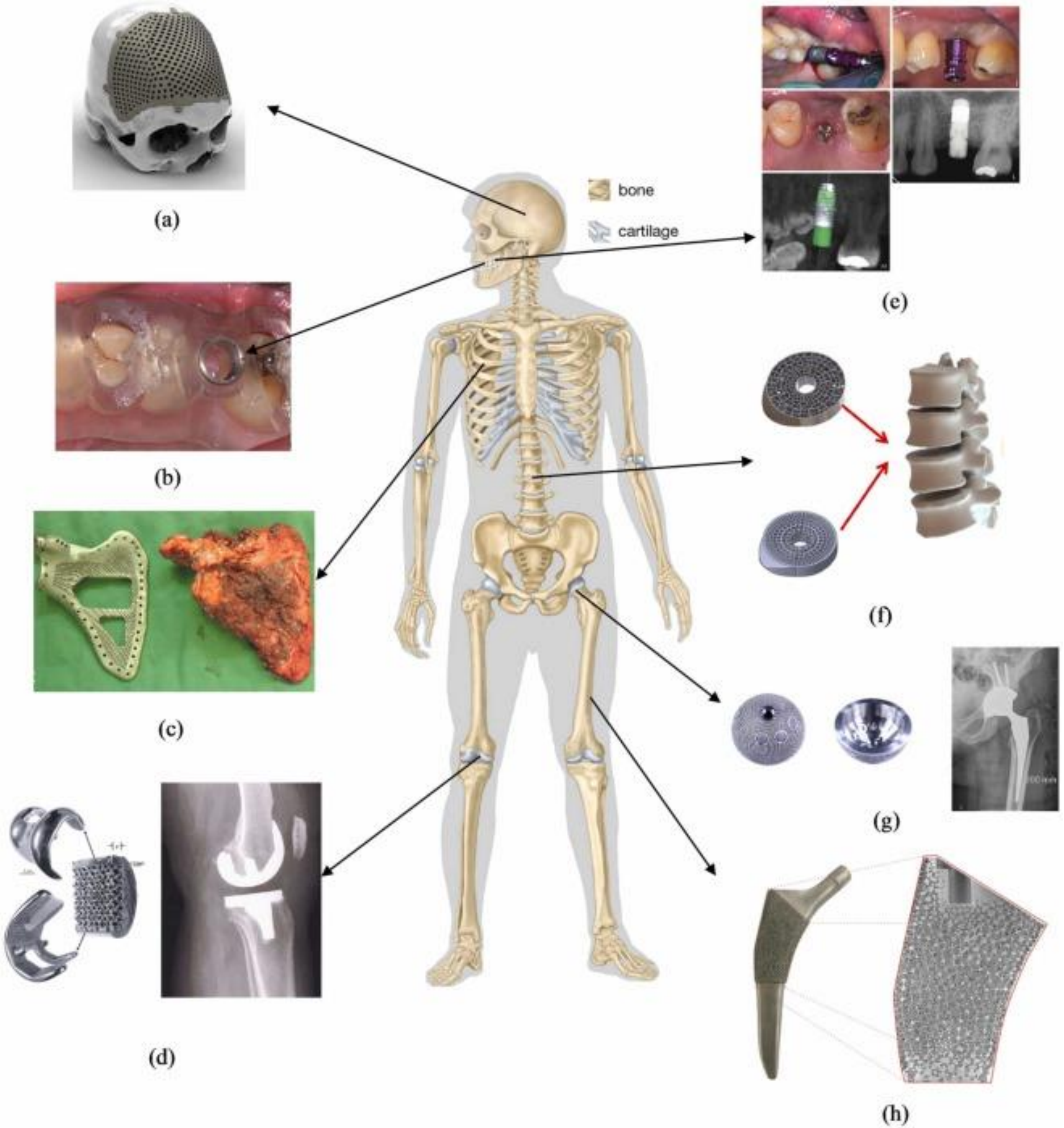


Laser-Powder Bed Fusion
(L-PBF)

The **lattice structure** can find interesting applications in many fields (biomedical, aerospace, mechanics, etc…) due to its excellent properties:

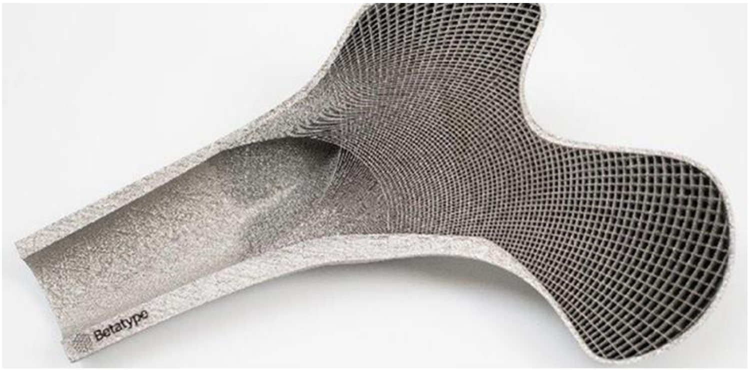
- Lightweight
- High resistance and hardness
- Osteointegratiom
- Heat transfer
- Shock absorption

Introduction



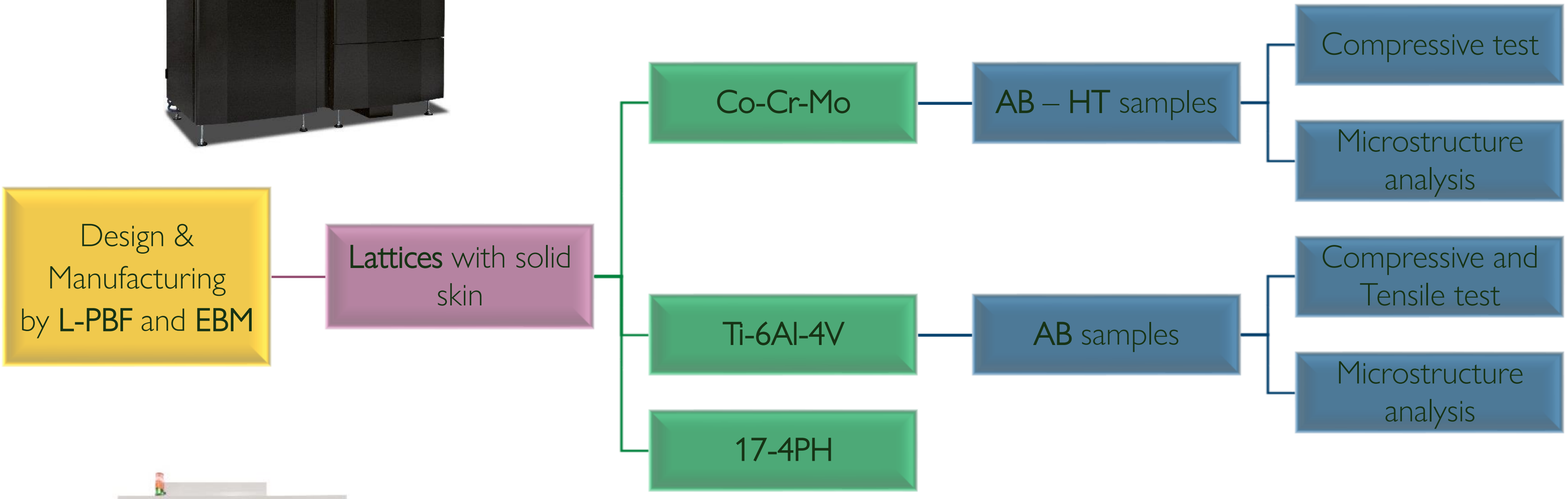
- Recent advances in **AM technology** have also provided opportunities for fabricating **biomedical parts** with complex geometries that can be easily **personalized**.

- A kind of **lattice structure** was **introduced into the implant design**, and L-PBF and EBM processes were used to build the part.



Methodology

Research Activity



Goals

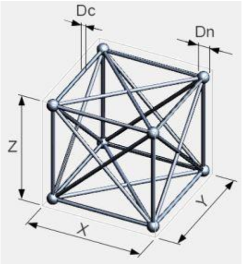
Research Activity

- **Mechanical characterization** - Compression test
- Study of **Co-Cr-Mo** alloy
- **Radial orientation** analysis
- **As-Built** vs **Heat treated** samples
- **Biomedical applications**

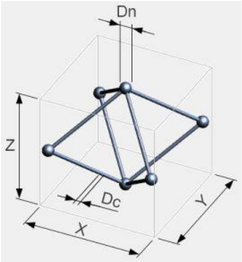
AB alloy

CoCr	Co	Cr	Mo	Ni	Fe	C	Si	Mn
Wt min (%)	Bal	28.00	5.00	0.00	0.00	0.00	0.00	0.00
Wt max (%)	.	30.00	6.00	0.10	0.50	0.02	1.00	1.00

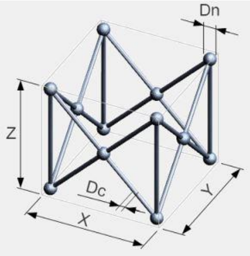
Unit cell design



FCC

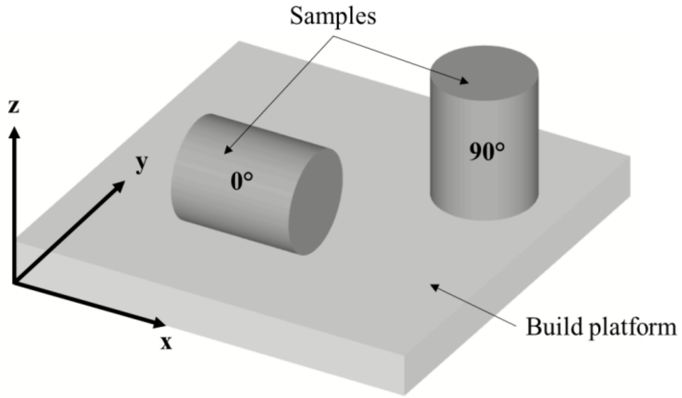


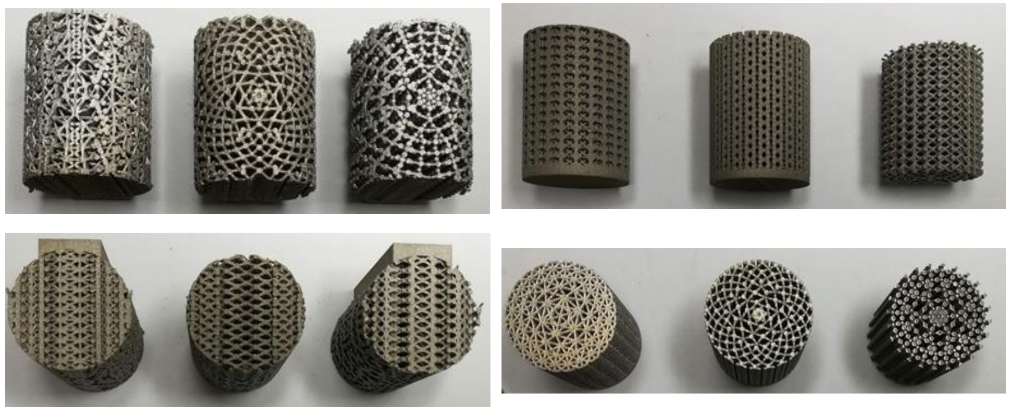
DM



DG

Samples building orientations in relation to the building plate





Radially oriented
CoCr samples
H = 24,0mm
D = 30,0mm

HT

*Vacuum heat treatment	
Heated	From room temperature to 1200°
Heating rate	13°C/min
Soaked	1200°C for 2h
Partial pressure was applied as the temperature reached 650°C and upwards, while vacuum cooling was carried out	

*Heat Treatment on Co-Cr-Mo samples was performed by the company TAV Vacuum Furnaces (Caravaggio (BG), Italy)

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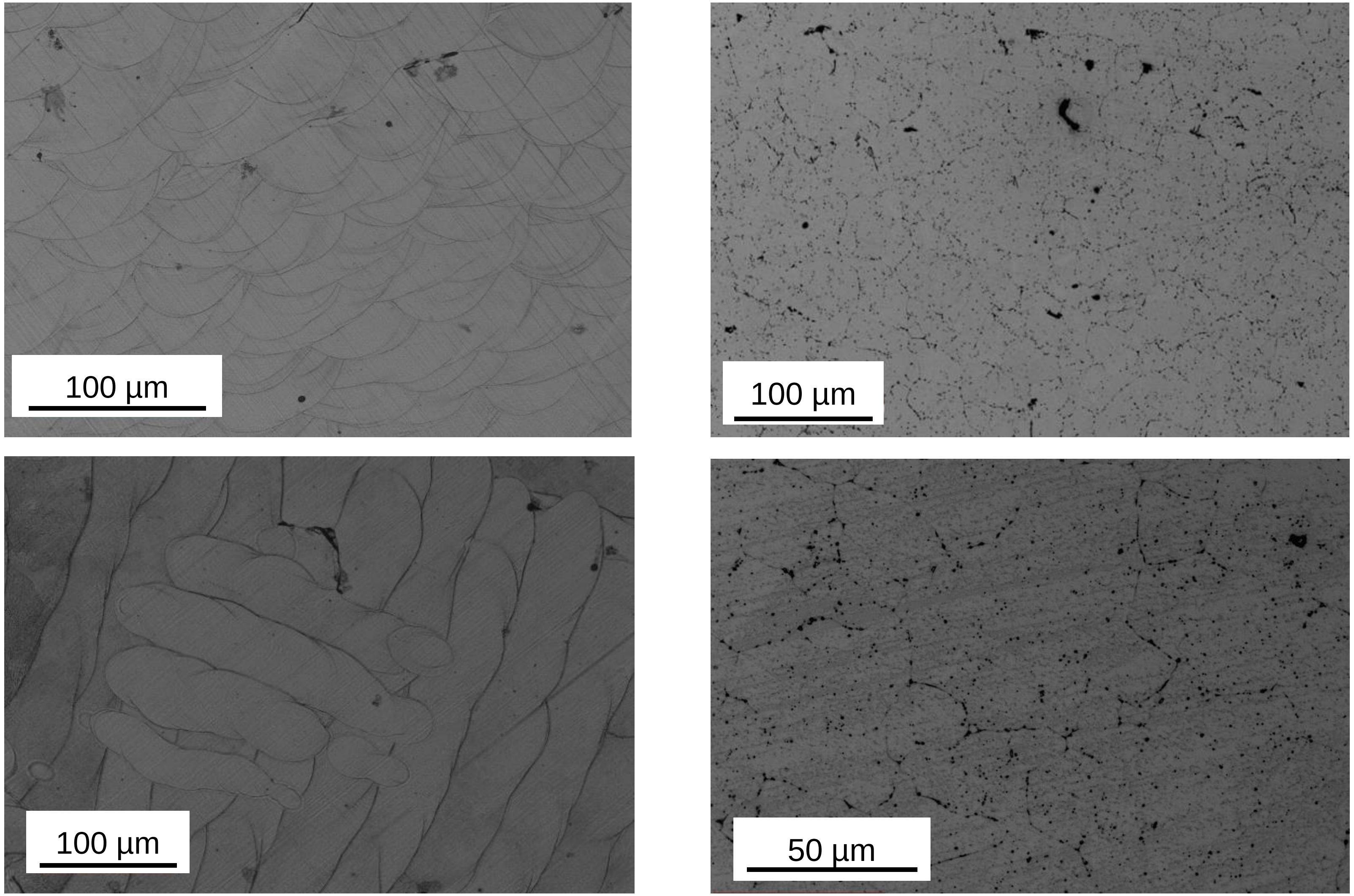
Microstructural analysis

Micrographs of the longitudinal (L) and transverse (T) cross-section of the studied specimens are studied to evaluate the dimensions of melt pools and the microstructure characteristic of Co-Cr-Mo alloy.

AB HT

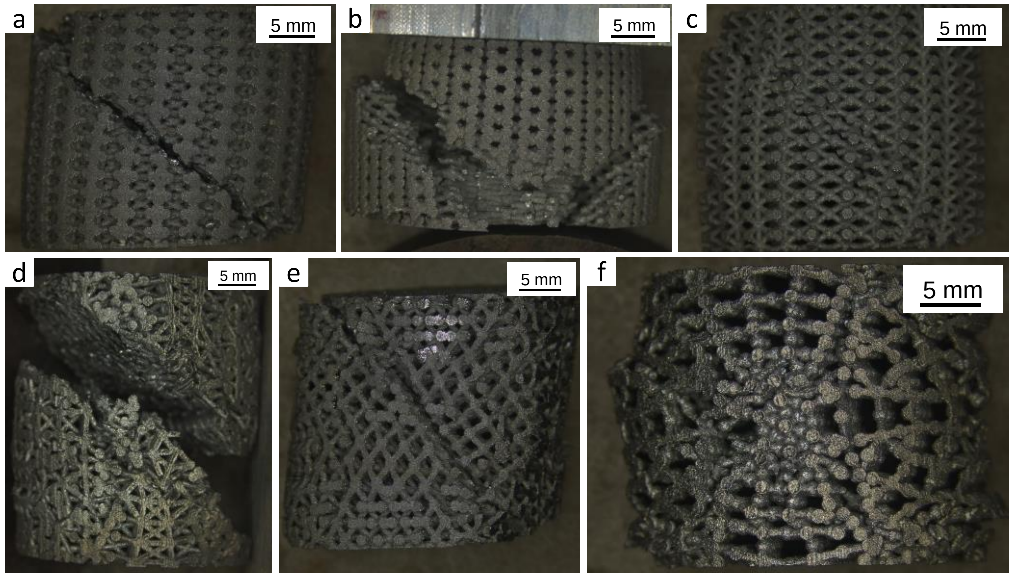


Mechanical characterization compression test

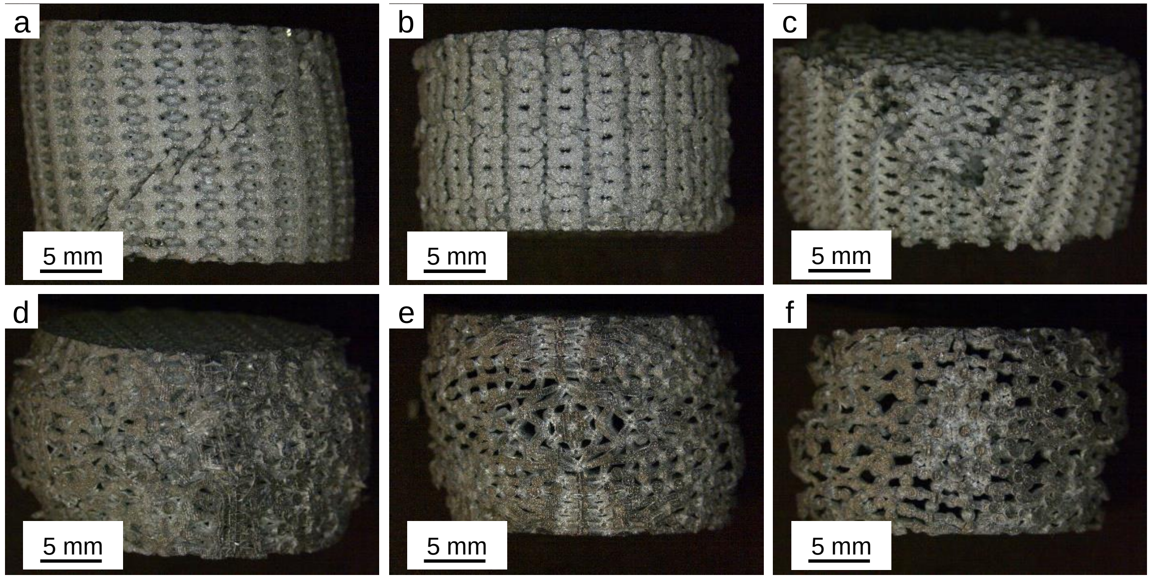
Instron 8501 – servo hydraulic machine	
Load cell	500 kN
Crosshead velocity	2 mm/min
the displacement was measured using the crosshead movement	

Load-displacement curves were generated from Instron output data.

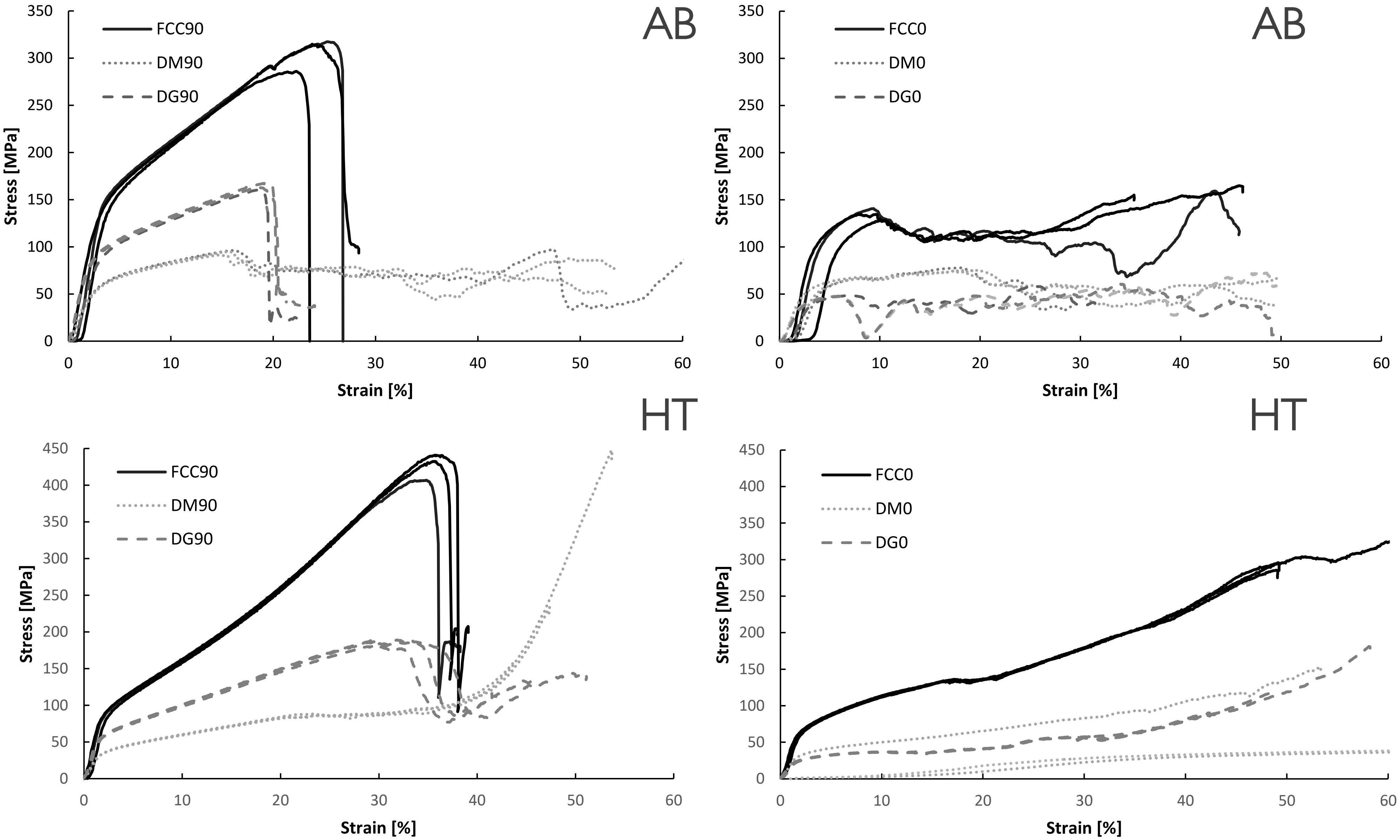
AB



HT



Mechanical characterization results



Methodology

Research Activity

- Design & Manufacturing by L-PBF and EBM
  - Lattices with solid skin
    - Co-Cr-Mo
      - AB – HT samples
        - Compressive test
        - Microstructure analysis
    - Ti6Al4V
      - AB samples
        - Compressive and Tensile test
        - Microstructure analysis
    - 17-4PH

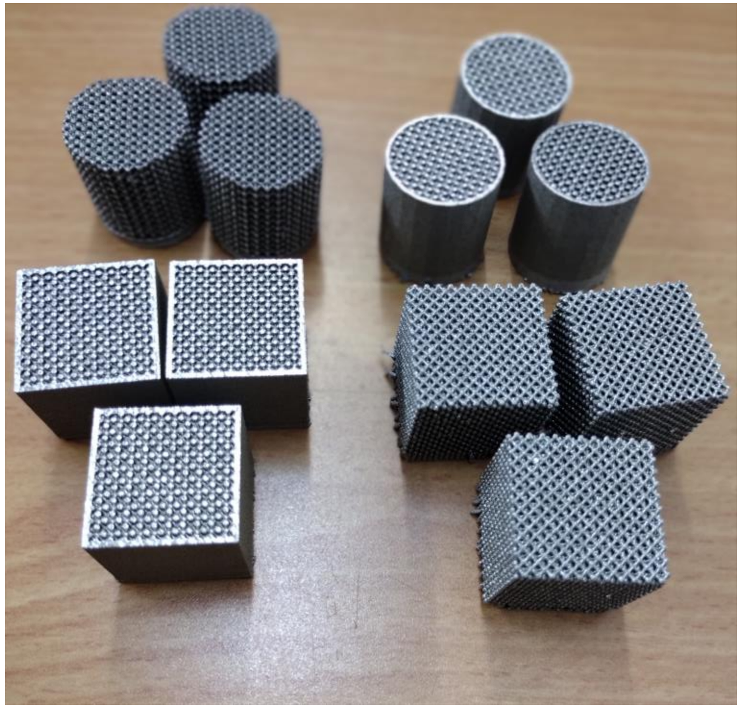
Goals

Research Activity

- Mechanical characterization – Compression and tensile test
- Study of **Ti-6Al-4V** alloy
- Lattice with and without skin
- Biomedical applications

Ti-6Al-4V chemical composition

Ti6Al4V	**Ti**	Al	V	Fe	C	O	N	H
Wt min (%)	Bal	5.50	3.50	0.00	0.00	0.00	0.00	0.00
Wt max (%)	.	6.75	4.50	0.30	0.08	0.20	0.05	0.02

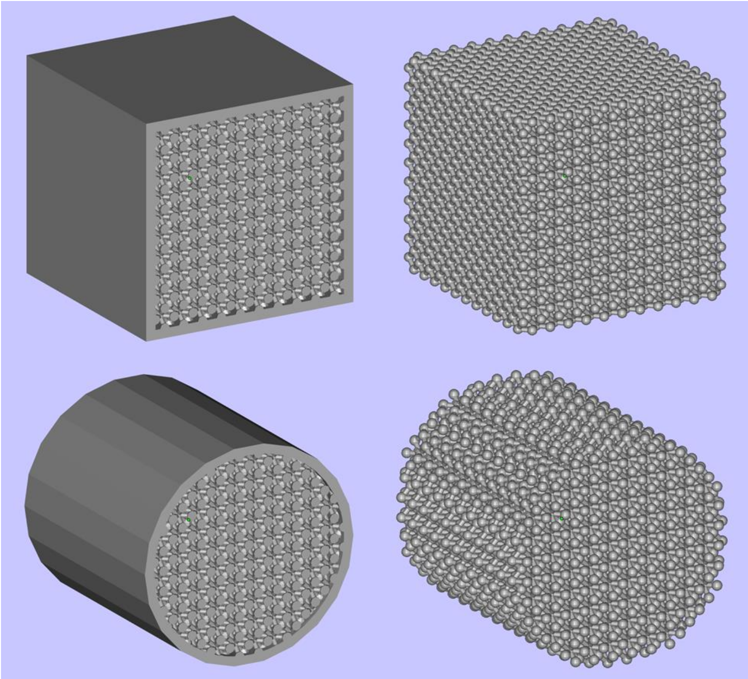


Design and Fabbrication

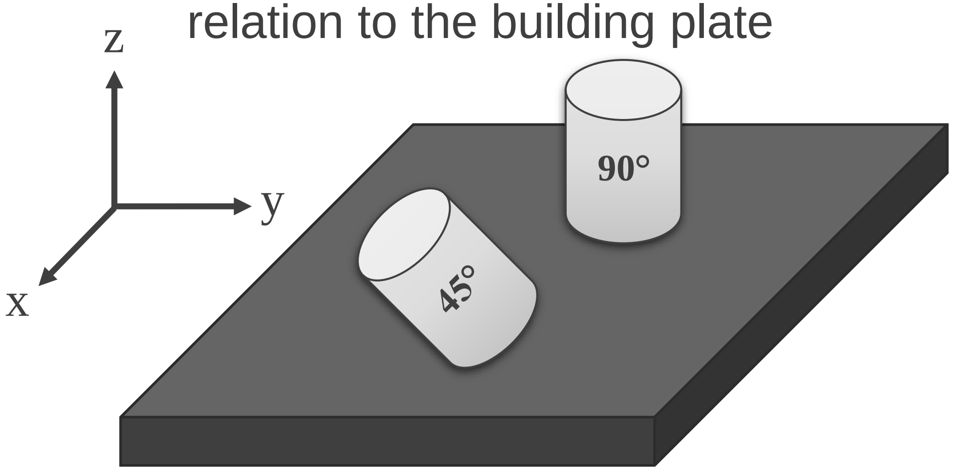
Ti-6Al-4V

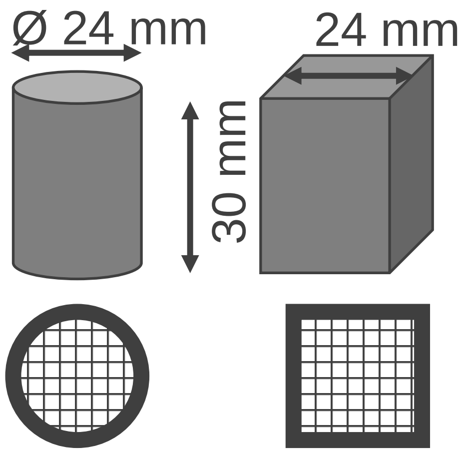
Research Activity

Unit cell design
compressive samples



Samples building orientations in relation to the building plate





Three different unit cells were used:

FCC+CP
FCC
BCC

Thickness 1 mm

Design and Fabbrication

Ti-6Al-4V

Research Activity

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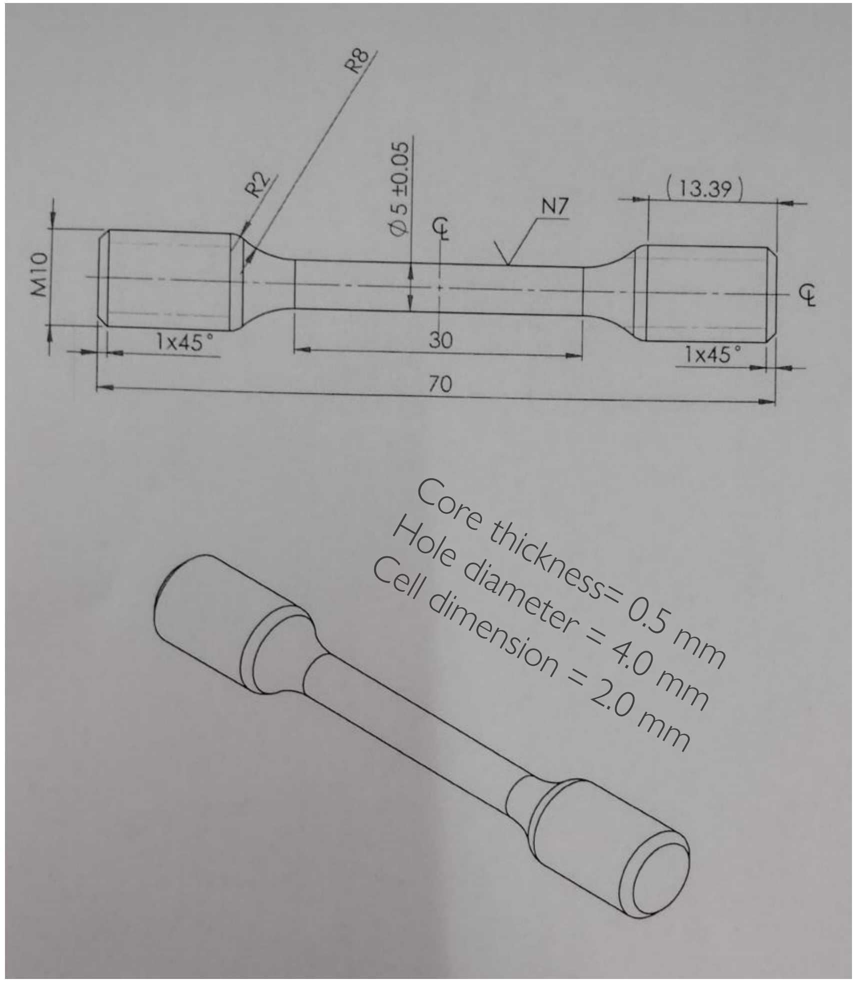
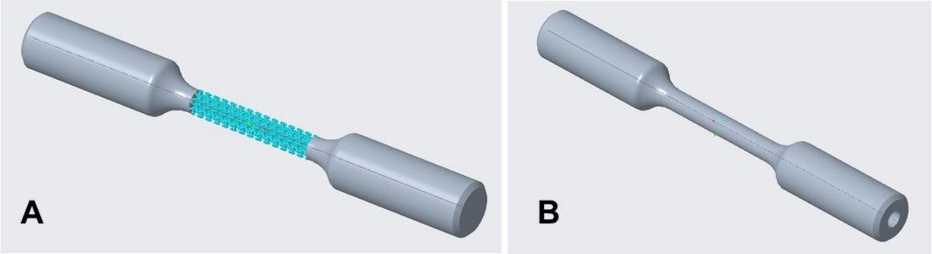
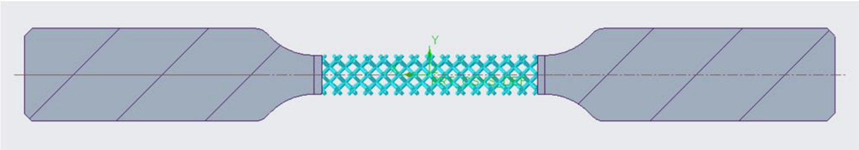
Dimensions



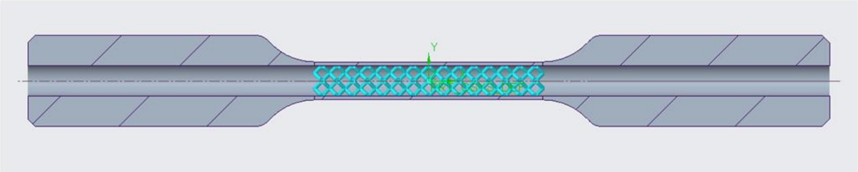
BCC unit cell was used



A

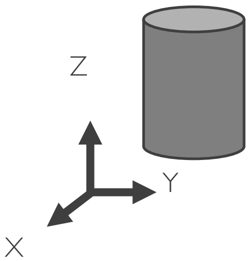


B



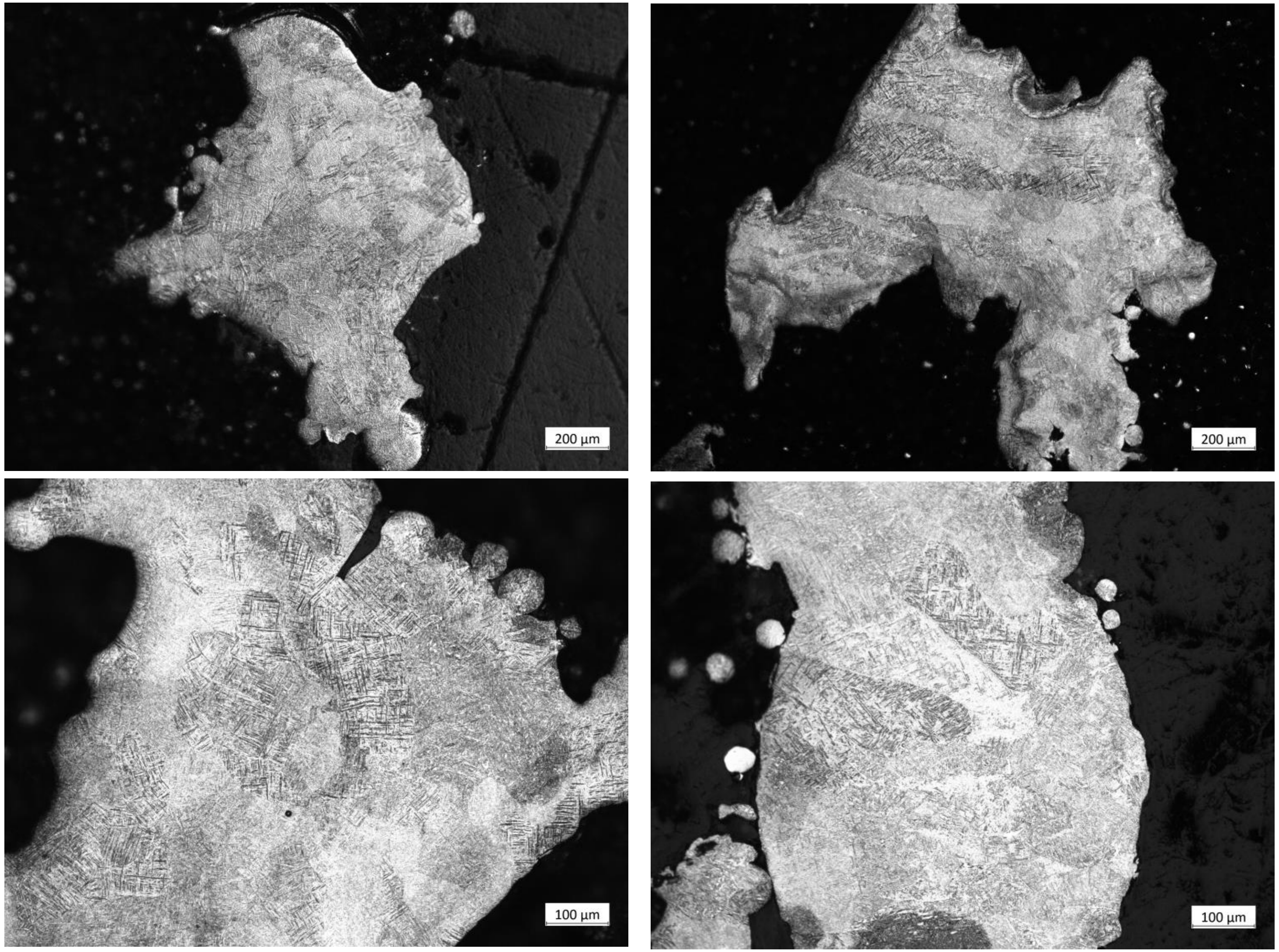
Microstructural analysis

Ti-6Al-4V



MICROSTRUTTURA - **XY**

MICROSTRUTTURA - **YZ**



Mechanical characterization
Compression and tensile test

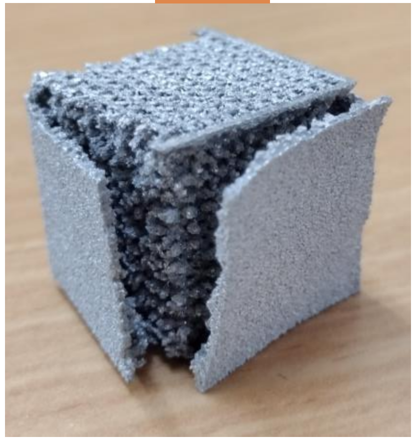
Ti-6Al-4V

Research Activity

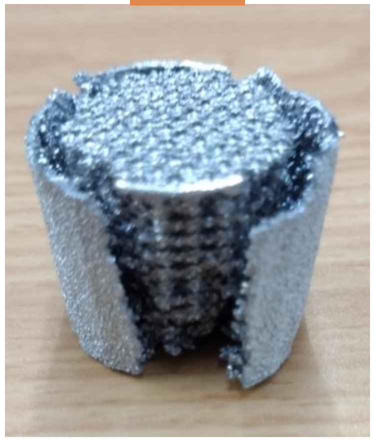
Instron 8501
Load 250 kN
v = 2 mm/min

A few examples of Compressive samples

FCC



FCC



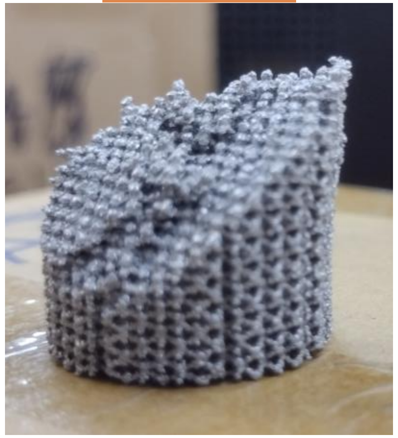
Vertical samples

BCC

FCC+CP

45° samples

BCC NG



Samples without skin

Mechanical characterization Results

Ti-6Al-4V

Research Activity

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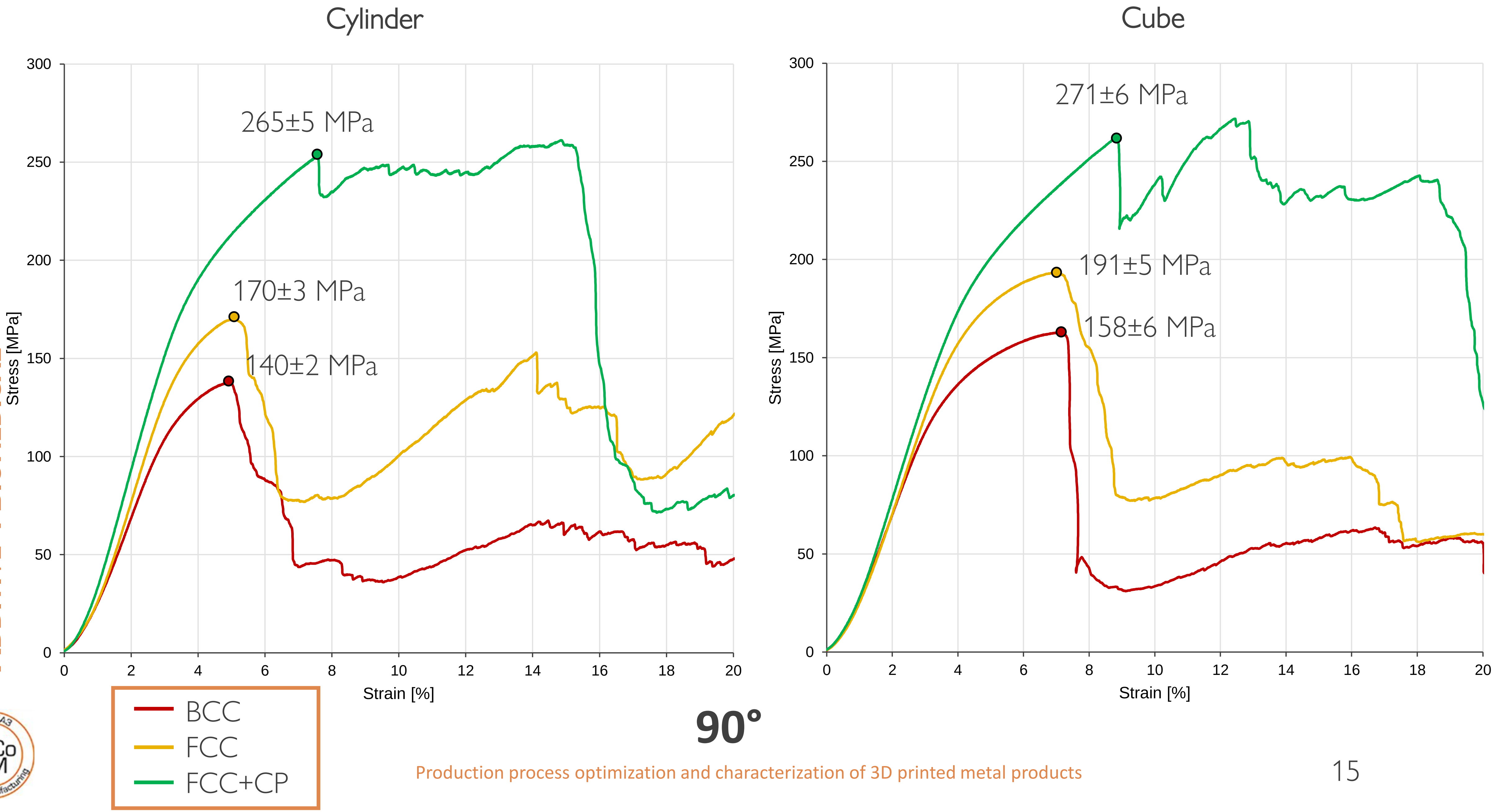

90°

Mechanical characterization Results

Ti-6Al-4V

Research Activity

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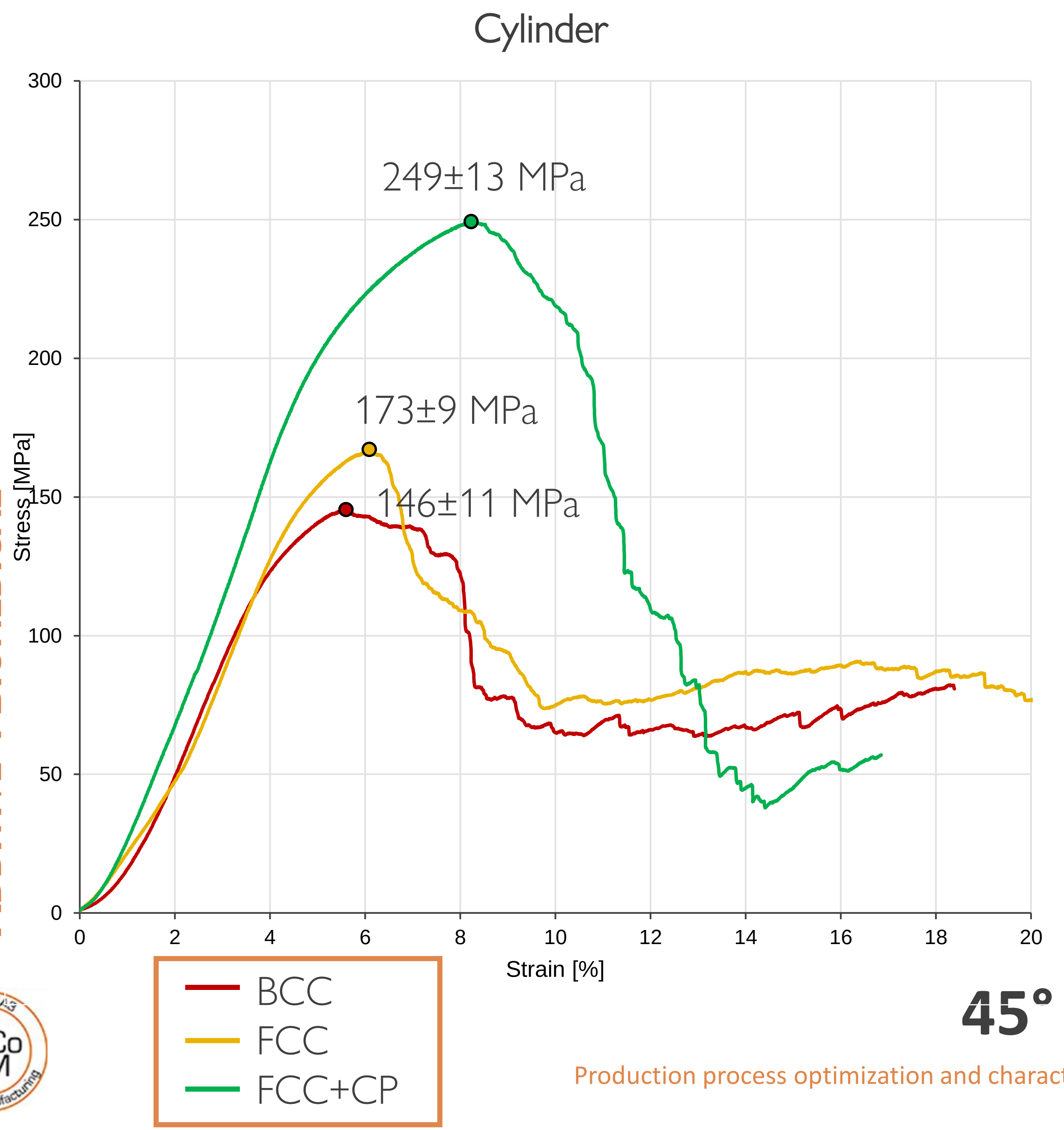
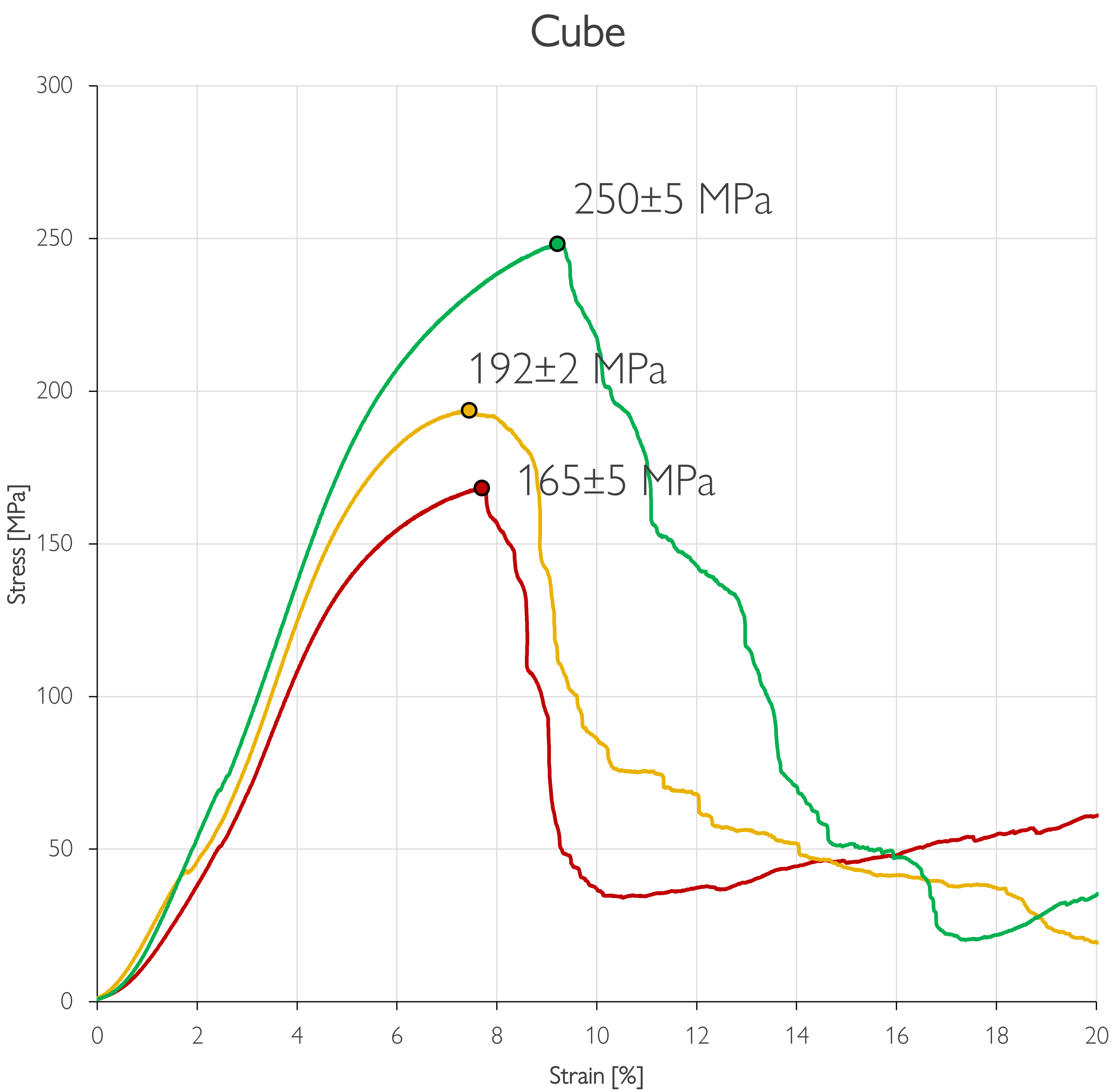
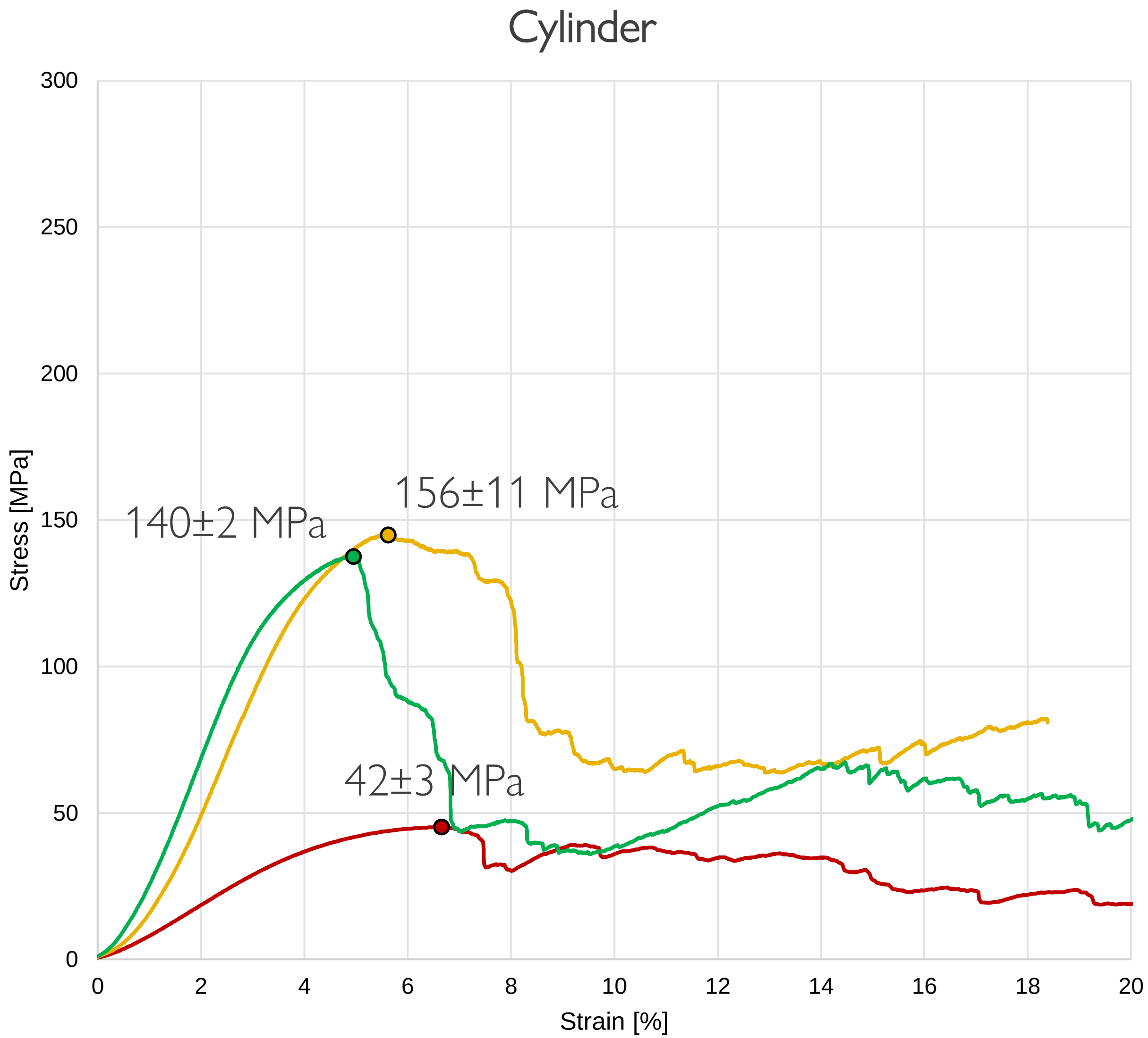
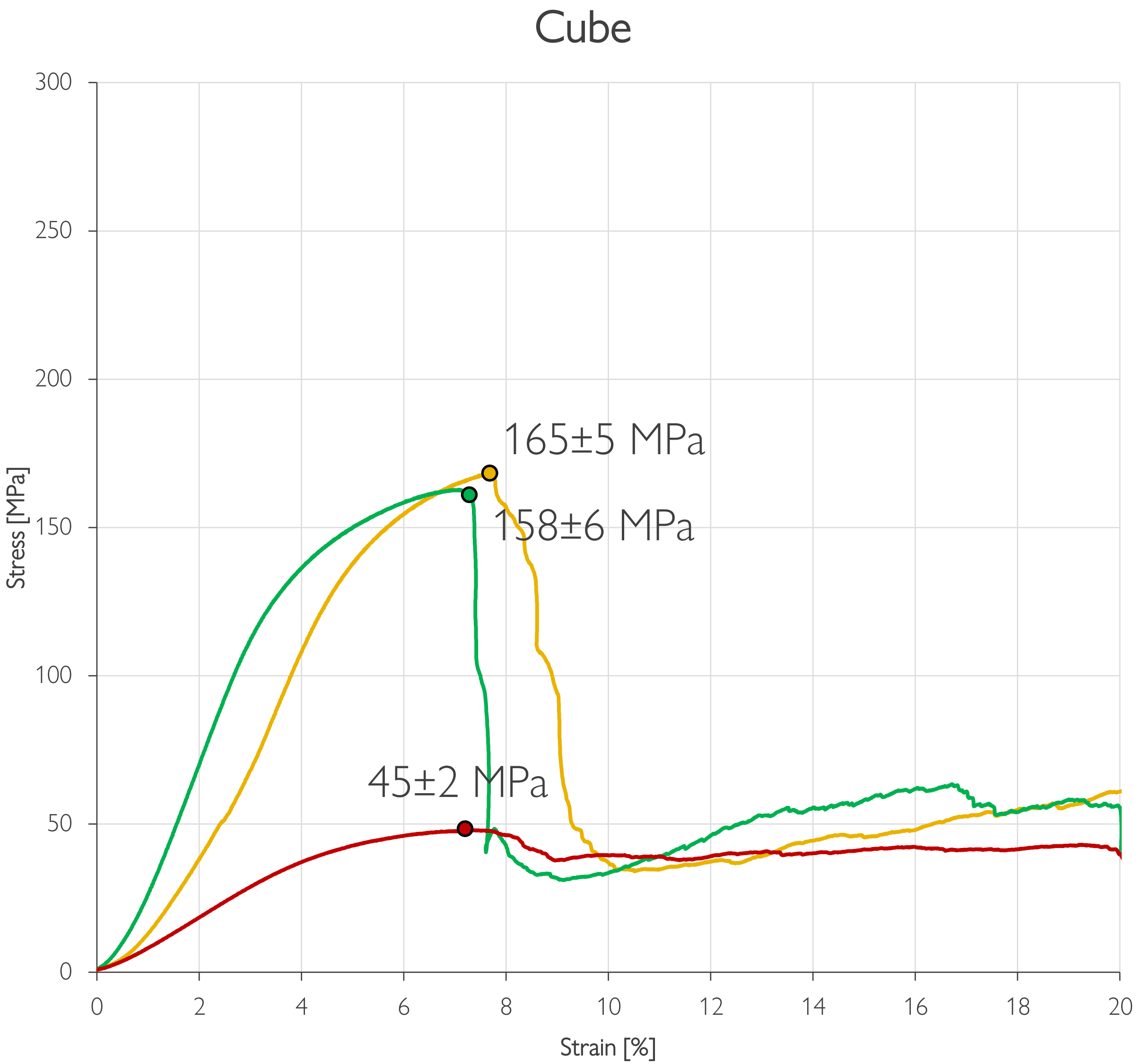




45°

Mechanical characterization Results Ti-6Al-4V





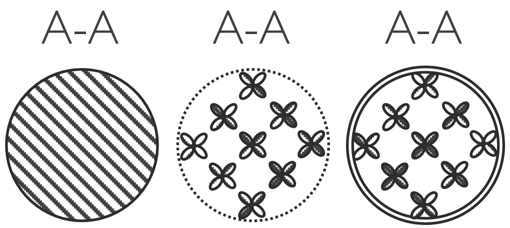
- 90° BCC without skin
- 45° BCC with skin
- 90° BCC with skin

BCC skin-no skin

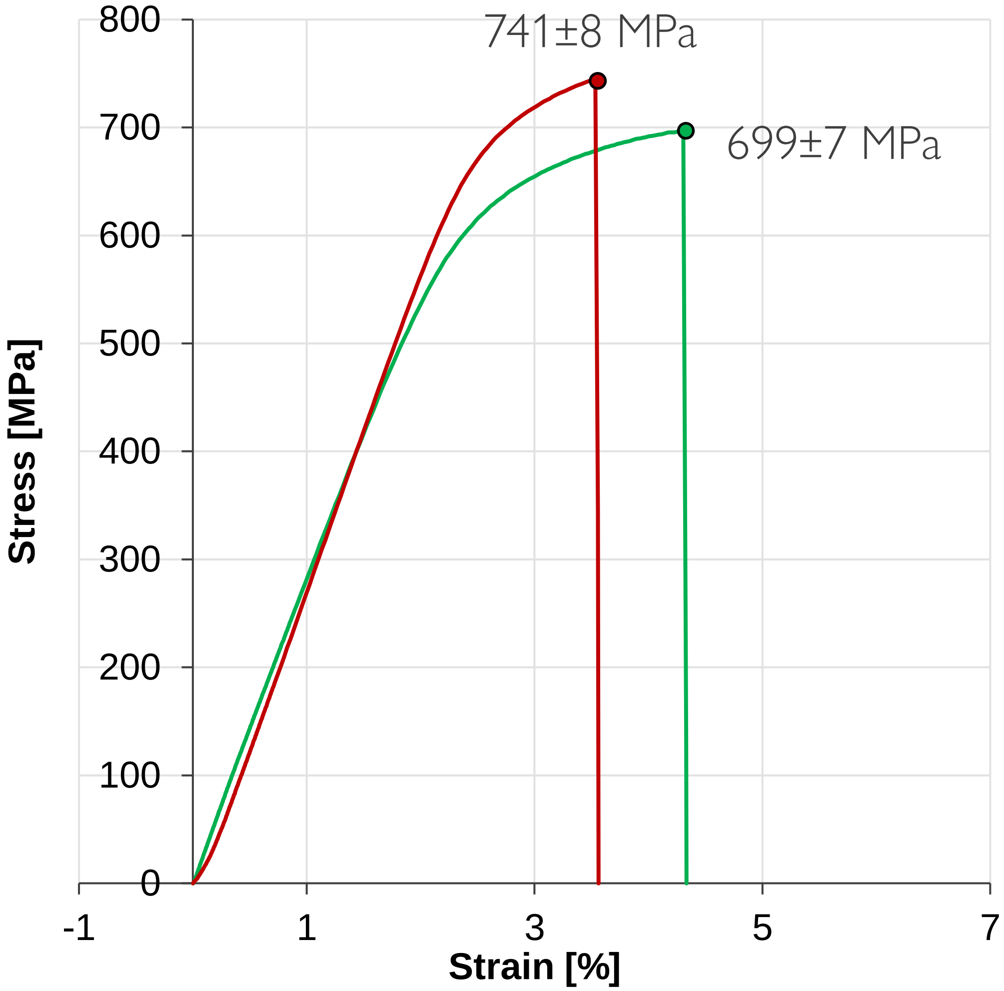
Mechanical characterization Results

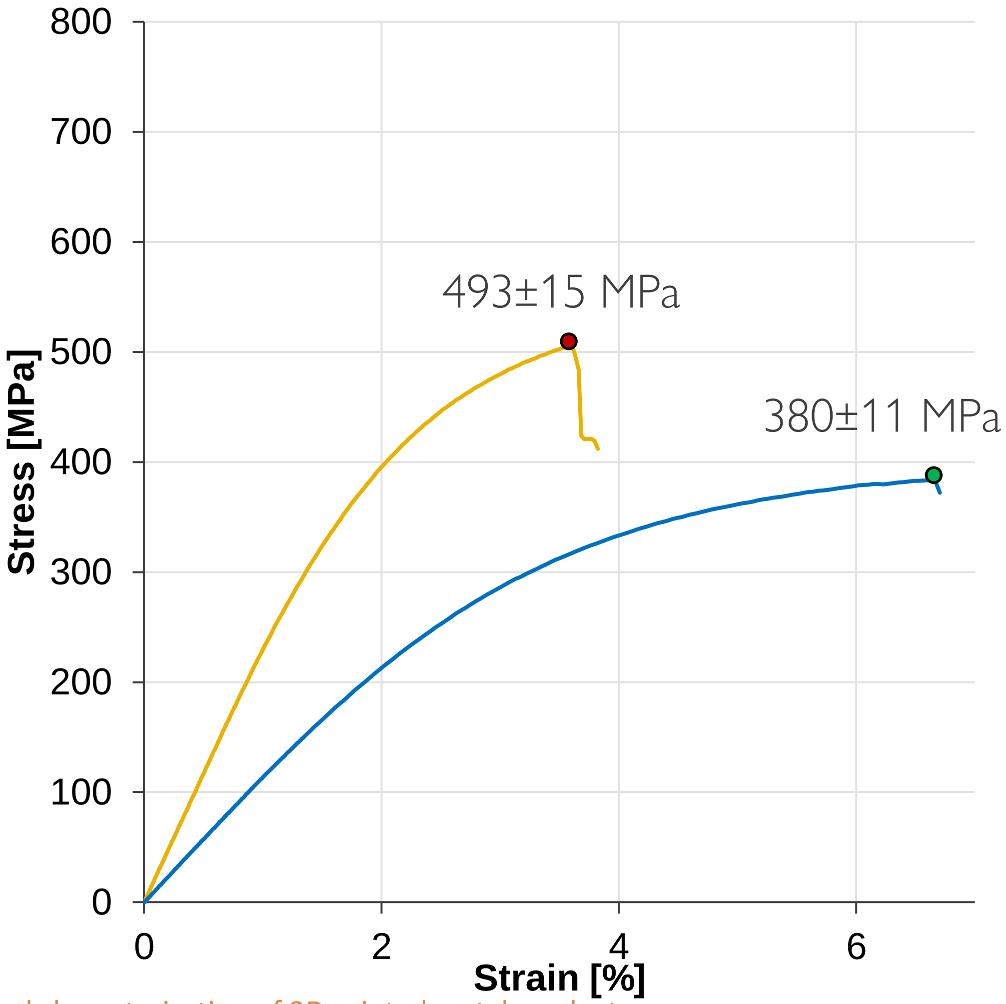
Ti-6Al-4V

Research Activity



- Tensile lattice BCC with skin Amin
- Tensile lattice BCC with skin Amax
- Tensile lattice BCC without skin Amin
- Tensile lattice BCC without skin Amax





Without skin

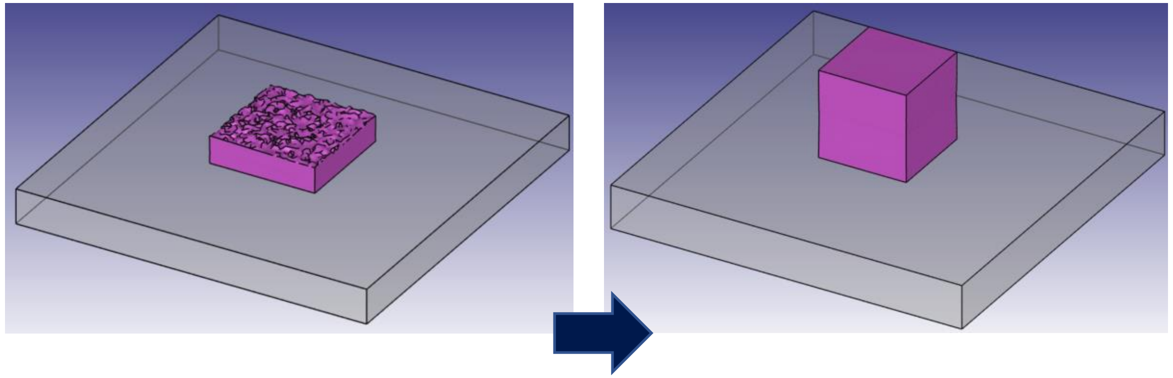
Skin

FEM Analysis by DEFORM

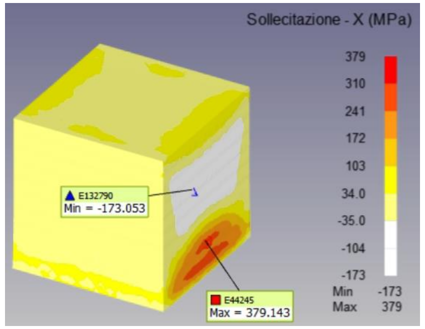
Research Activity

The goal of this work is to obtain:

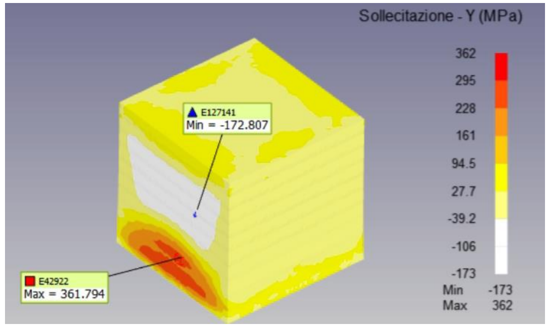
- macro **simulation** of 3D printing of **complex geometry**
- **Prediction** of the distribution of stress, temperature, to optimize process parameters before producing samples or components.



SAMPLES ATTACHED AND CUTTED FROM THE PRINTING PLATE

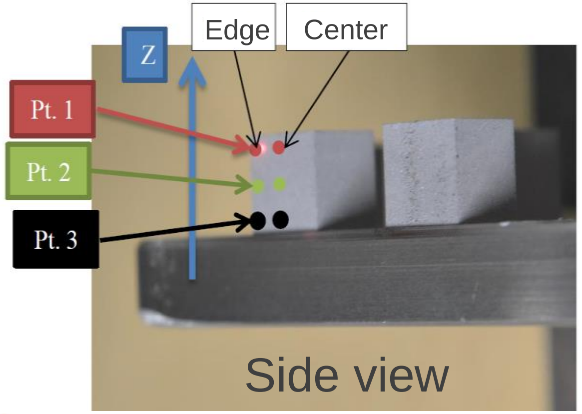


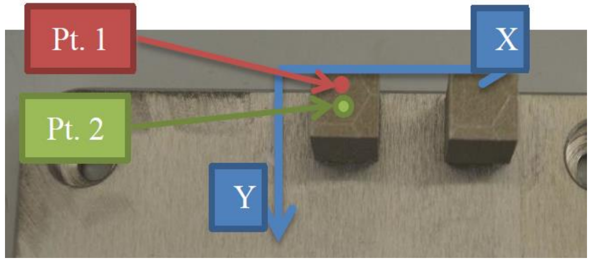
X direction



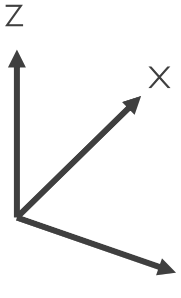
Y direction

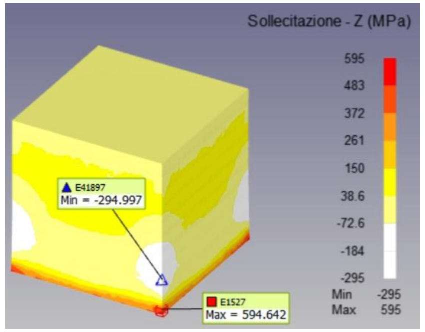
Experimental analysis - XRD



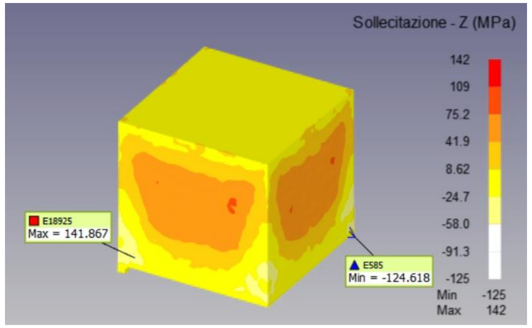


Top view





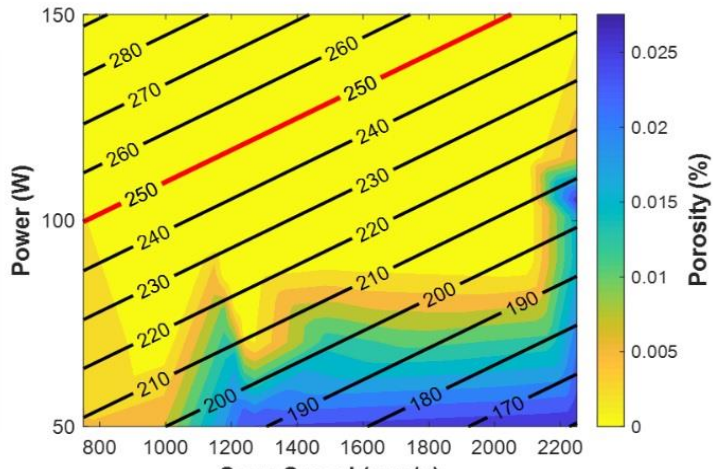
Z direction



Z direction

(DETACHED FROM THE PRINTING PLATE)

Conclusions



In conclusion:

- Proceed with **new experimental tests**.
- **Metallurgical characterization** (pores, microstructure and hardness investigation), especially into the interface between solid and lattice structure.
- Development of a **customized prosthesis** implemented with optimal mechanical and microstructural characteristics.
- Further study of the mechanical behavior of lattice structure with and without **external shell**

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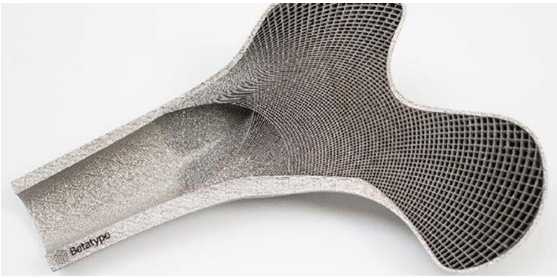

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Thank you for your attention!

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