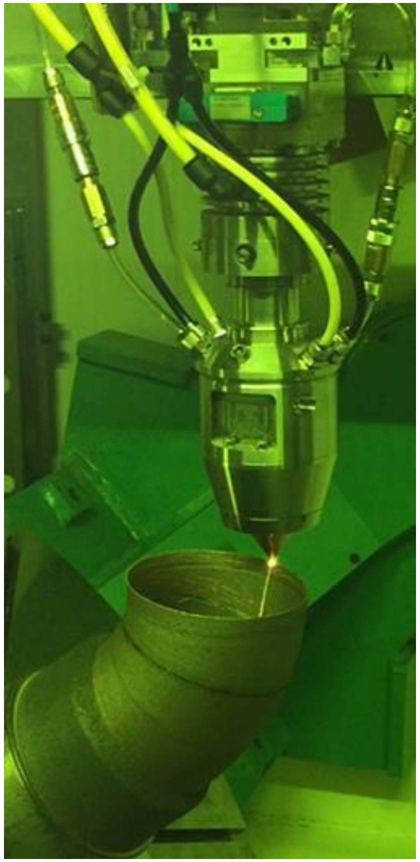
Metallic Glasses For High Performance Mechanism : Applications on Long Term Missions

Meeting-02/11/2021

DED Process (LMD)

Direct
Energy
Deposition



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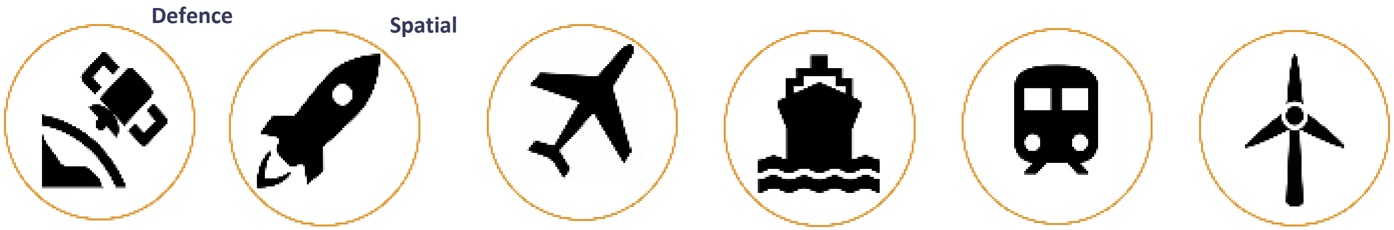
OPT'ALM manufactures and repairs mechanical metallic parts

Fields of :



Operational expert team of 6 peoples in :

- *Mechanical / Thermal engineering and Architectures, Material, Process analyses,*
- *Environmental test follow's up, Project management.*

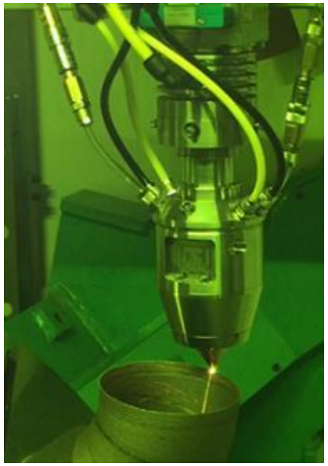
Industrial means of production : MODULO 400

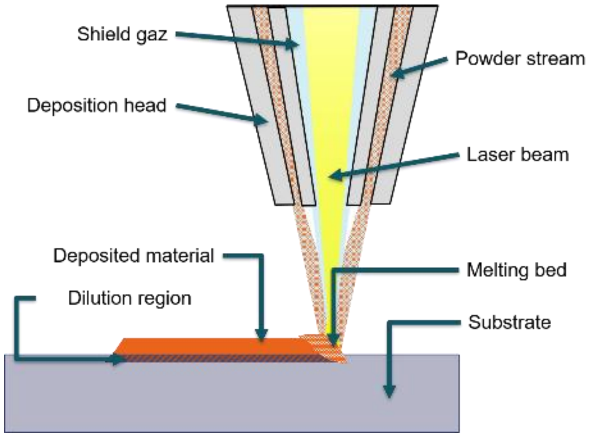
- *Secure ESH environments;*
- *5 continuous axis & 2 nozzles deposition systems, laser power source 2 x 1 kW;*
- *Atmosphere controlled;*
- *Deposition area : 650 mm x 500 mm x 500 mm under 5 continuous axis and near 1 m length by using positioning devices;*
- *Optical microscope, polishing machine, cutting machine;*

- *+ Post-processing CNC machines possibility.*

- DED -

Process





Materials employed at OPT'ALM

- TA6V Titanium alloy
- Nickel alloys (625, 718) & other Hight Performances
- Stainless steel 316L,
- Martensitic, Austenitic steels (AISI420, 17-4Ph, Maraging 300)
- Cobalt alloy (Stellite 21)

Applications

- 3D direct fabrications
- Design and function additions
- Repairs

Diameter 450 mm
height 470 mm

Diameter 80 mm
& 150 x 200 mm

Diameter 850 mm

➔ **Advantage of DED for manufacturing of metallic glass parts**

Fast cooling rate allowed & Huge flexibility on design of parts

- OPT'ALM contributions in the project -

First contact with RHP : Autumn 2018

Work packages where OPT'ALM was involved

- *WP 1.3* *Literature Review of metallic glasses – PROCESSES*
- *WP 1.4* *Trade off and application selection*
- *WP 2.3* *Metallic Glass development plan/manufacturing document*
- *WP 3.1* *Material manufacturing*
- *WP 4.1* *Production of samples*
- *WP 4.3* *Lessons learned*
- *WP 5.1* *Local management*

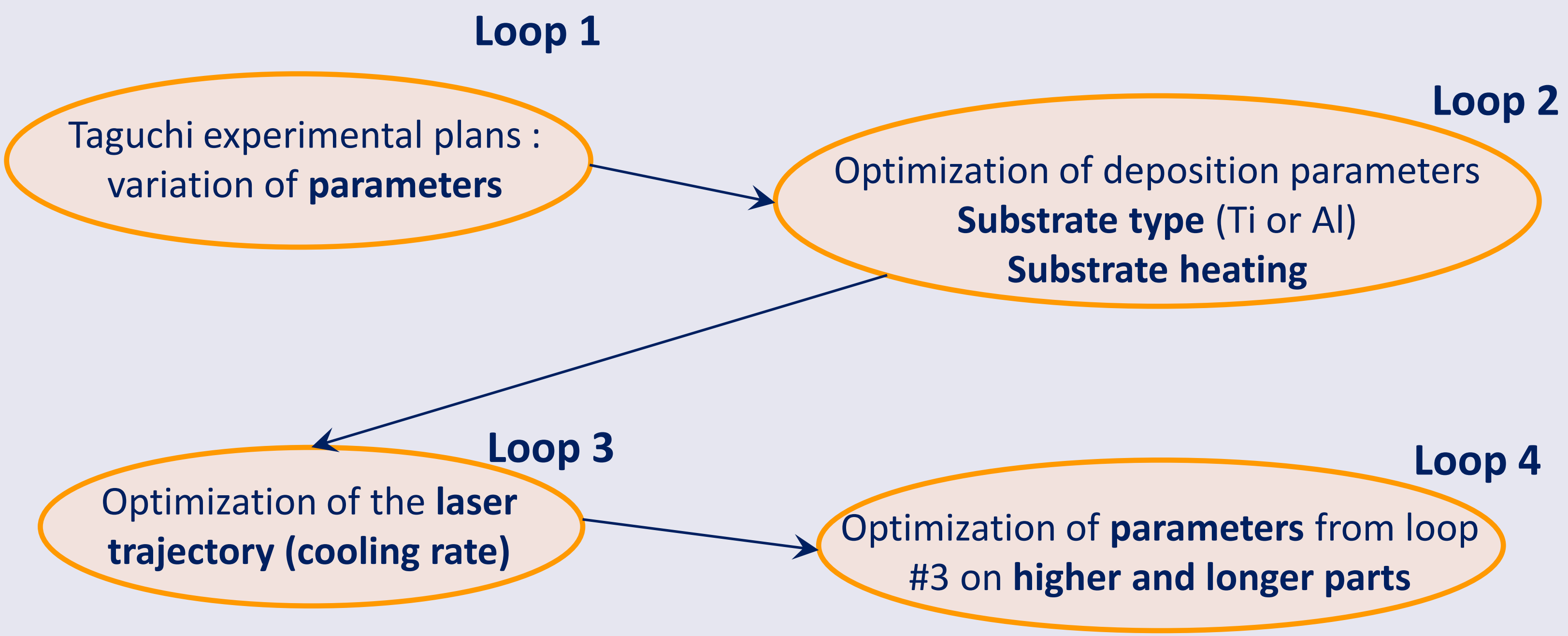
For DED, two materials chosen :

- **C1** : ZrCu(23-25)Al(3-5)Nb(1-3) → AMZ4
- **C3** : FeCrMoBWCMnSi

- Metallic glass development plan -

WP3

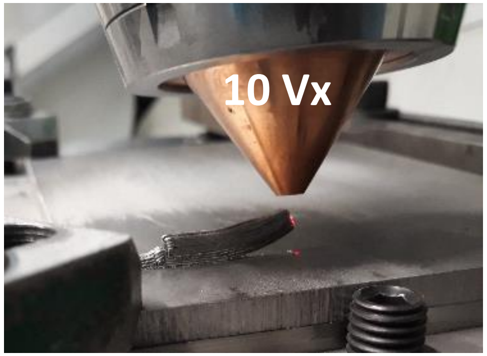
Material manufacturing :



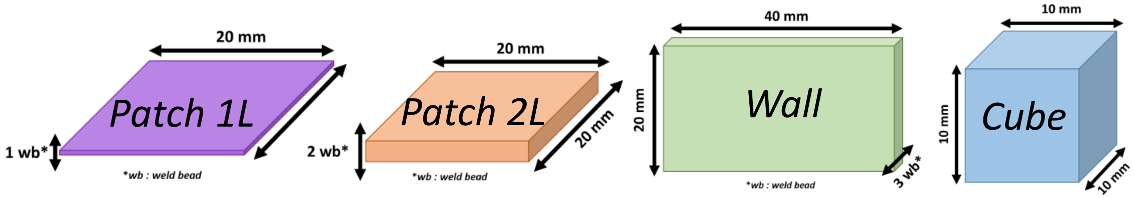
- Loop 1 development plan -

Objective : define parameters for each powder (C1 + C3)

- Parameters optimized : Laser Power,
  Deposition speed,
  Powder flow rate,
  Increment Z.



- Geometries tested :

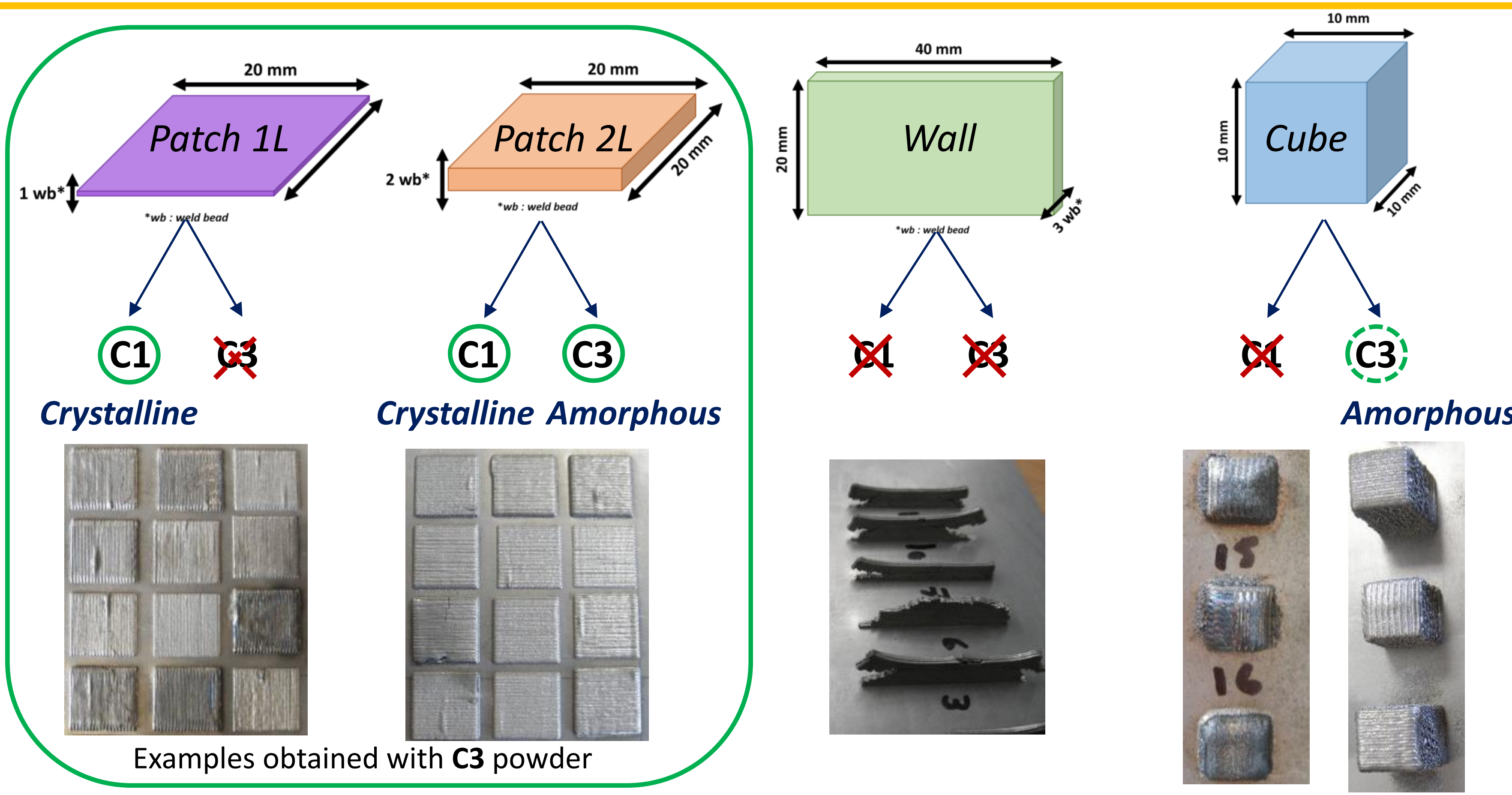


Validation of parameters :

- **OPT'ALM : Geometric observation (**length + height + thickness + grip of DED deposition on the substrate)

- **RHP : SEM and XRD analyses** to validate the best conditions.

- Loop 1 results -



Examples obtained with **C3** powder

- ➔ **Good geometrical results** obtained with **C1 and C3 patches**
- ➔ **Cracks** appeared on most of the samples with the **C3 powder**
- ➔ **C1 powder very sensitive** to the **energy input**

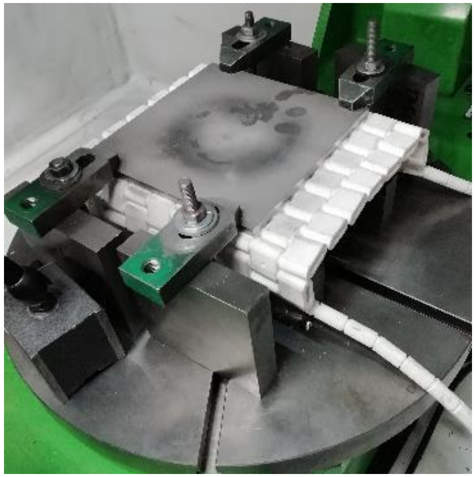
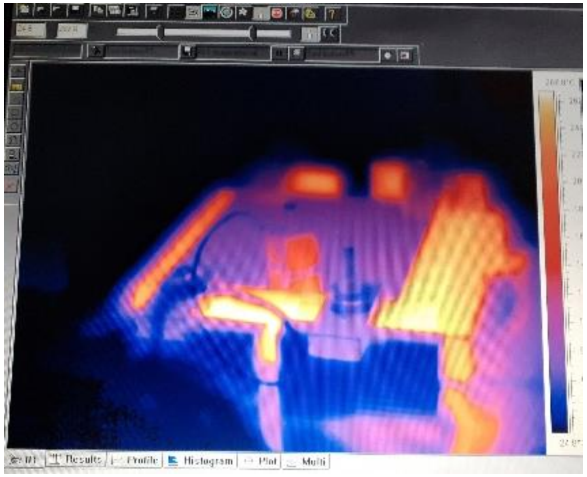
<u>Improvements</u> : ***heat the substrate*** (TA6V) to decrease temperature gap and prevent cracks
= Increase the grip at the substrate/DED interface

- Loop 2 development plan -

<u>Objective</u> : optimisation of deposition parameters

- **Less energy input** on a deposition volume
  (reduction of laser power, increase of the powder flow rate and deposition speed)

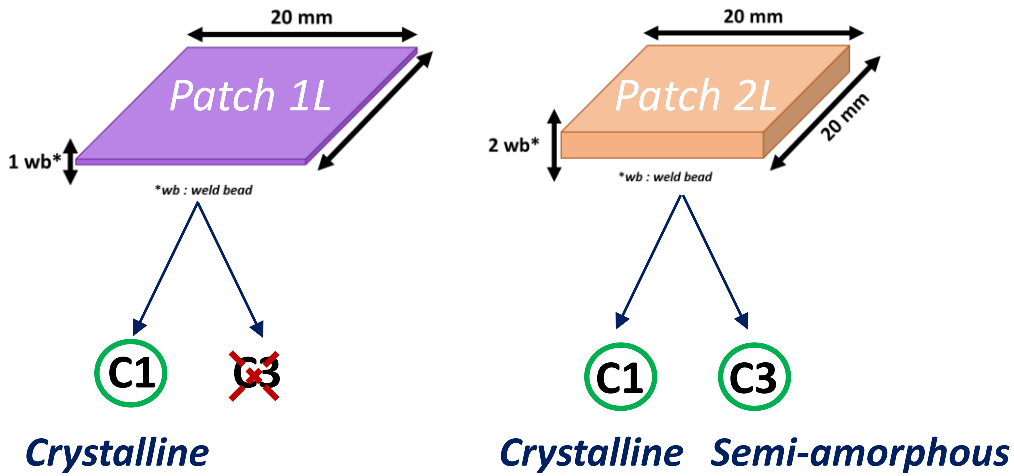
- ***Substrate heated up to 200°C by conduction (ceramic plate)***

View of the assembly used to heat the substrate

- ***Test of two different substrates :***
  - TA6V and Aluminium : **C3 powder**
  - TA6V : **C1 powder**

- Loop 2 results -



➔ **TA6V substrate** : Better results than 1st loop (**less cracks**, larger range of useable parameters)

- Heating the substrate helps to **improve the link between substrate/DED**

➔ **Al substrate with C3 powder : unsuccessful**

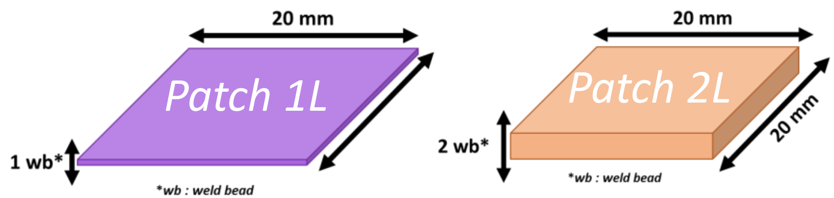
- Not enough laser power
- Compatibility between substrate/powder

➔ **However**, microstructure mostly **crystalline = need to improve the cooling rate (laser trajectory)**

- Loop 3 development plan -

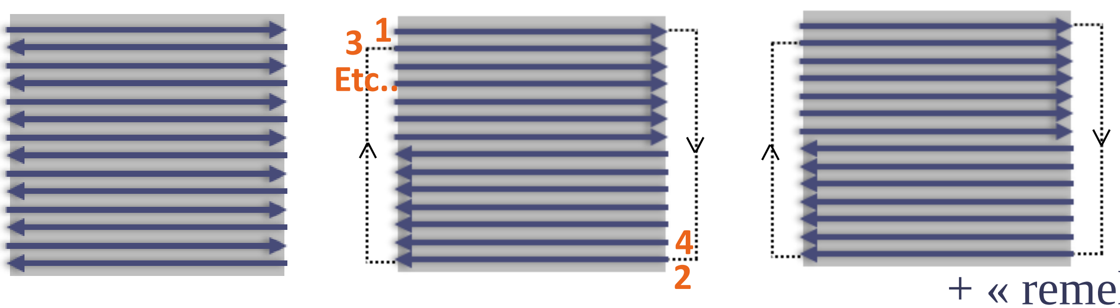
Objective : improvement of the laser trajectory

- ***Increase the time between each layer = optimize the crystallin structure***
- Geometries tested :



- Trajectories :

Choice 1 | Choice 2 | Choice 3

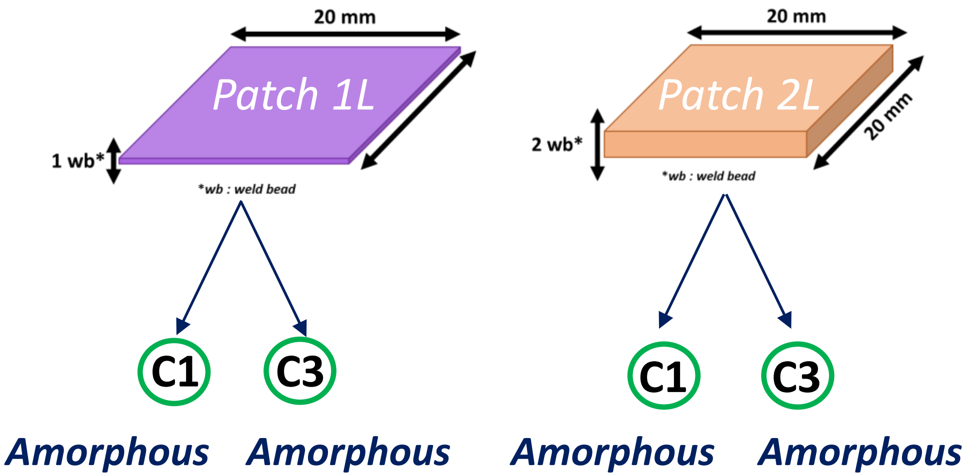


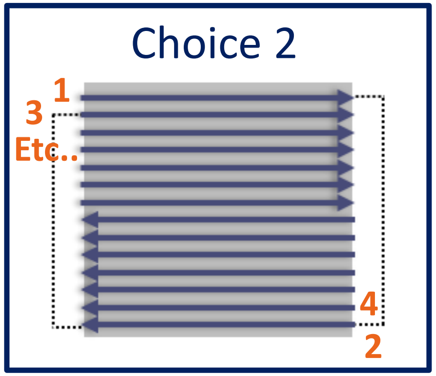
+ « remelting » layer

- Taguchi experimental plan

	Level 1		Level 2		Level 3	
	C1	C3	C1	C3	C1	C3
Flow rate (g/min)	4	3	5	4	6.5	5.5
Deposition speed (mm/min)	2000		2200		2500	
Laser power (W)	150		180		200	
Strategy	1		2		3	

- Loop 3 results -



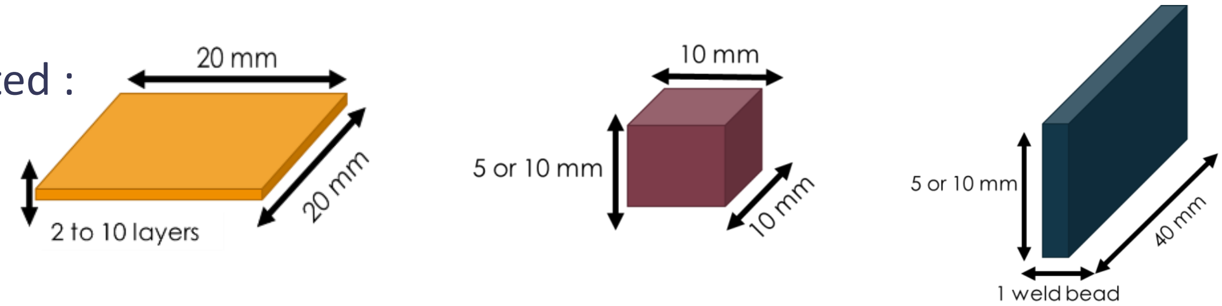


- ➔ Better results than for the 2nd loop
  - ➢ The trajectory "choice 2" **increase time between each layer = higher cooling rate**
- ➔ **Porosity** observed on **C3 powder** samples
- ➔ **OPT'ALM can produce metallic glasses patches** (1 or 2 layers) with C1 powder

- Loop 4 development plan -

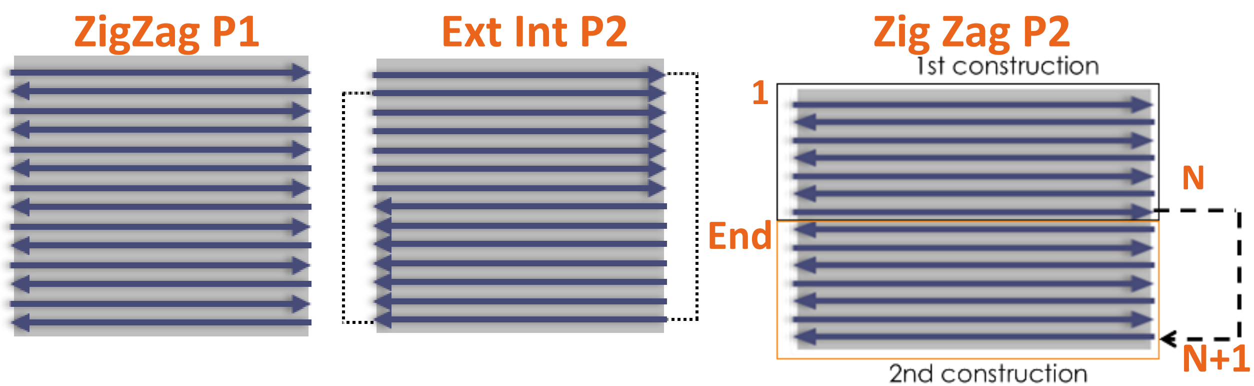
Objective : evaluate the capacity to produce new shapes (**higher and bigger**)

- Geometries tested :



- ***Heated*** substrates : ***TA6V→C1 powder and 17-4PH →C3 powder***

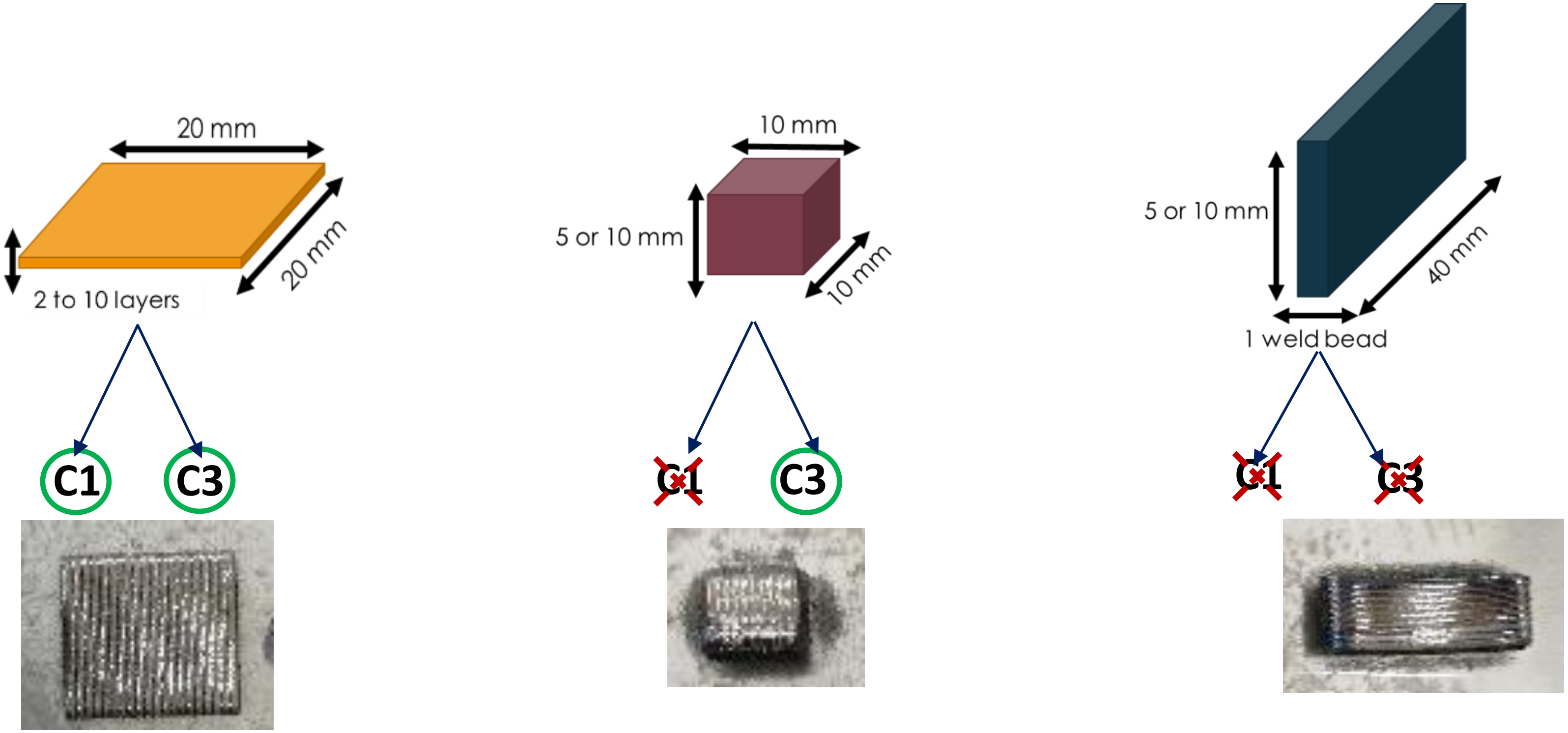
- Trajectory tested with C1 powder :



- Loop 3 parameters

	Zig zag P1	Ext int P2	Zig zag P2	Zig zag
Powder	C1	C1	C1	C3
Flow rate (g/min)	5	5	5	3
Deposition speed (mm/min)	2200	2500	2500	2500
Laser power (W)	150	200	200	180
Interlayer distance (mm)	0.1	0.1	0.1	0.1
Strategy	1	2	3	3

- Loop 4 results -



- ➔ Good results obtained only with **patches (1, 2 or 5 layers)**
- ➔ **Three trajectories** work with the **C1 powder**
- ➔ For **cubes** and **walls** :
  - ➢ Powder granulometries are thinner than the usually used in DED process
  - ➢ **Tests** with **bigger granulometry (45-90 µm)** could be done

- Metallic glass development plan -

WP3

Material manufacturing :

Loop 1

Taguchi experimental plans : variation of **parameters**

Loop 2

Optimization of deposition parameters
Substrate type (Ti or Al)
Substrate heating

Loop 3

Optimization of the **laser trajectory (cooling rate)**

Loop 4

Optimization of **parameters** from loop #3 on **higher and longer parts**

WP4

Demonstrators :

C1

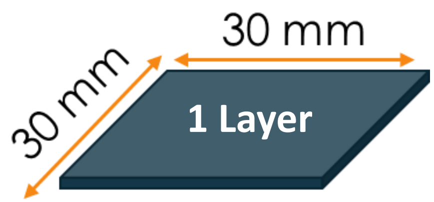
HDRM

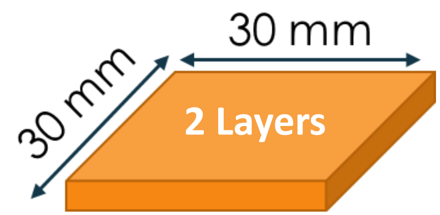
SPRING

- HDRM demonstrator results -

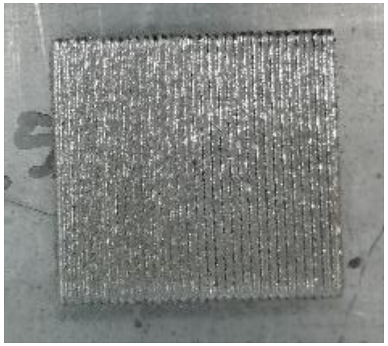
Objective : evaluate the capacity to produce amorphous patches (C1 powder)

- Design :





- Results :



Good results
(semi-amorphous + grip)

Oxidation

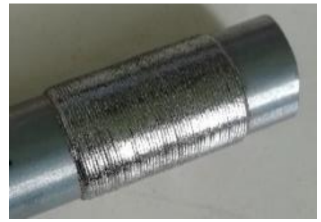
➔ Problems of flowability with the C1 powder

Improvement : ***flowability of the C1 powder***

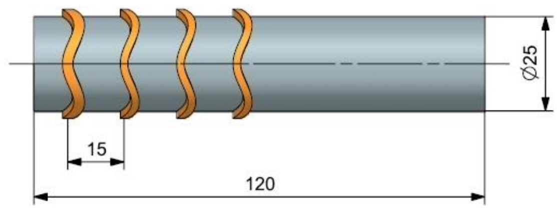
- Spring demonstrator results -

Objective : evaluate the capacity to produce amorphous springs (C1 powder)

- First design not successful:



- Near net shape approach :



- Results :

Thickness 0.5 mm	Thickness 1 mm	Thickness 2 mm
		

➔ **Good shape and grip but crystalline microstructure**

Improvement : ***increase the cooling rate*** (deposition strategy)

- Lessons learned -

Powder granulometry

- powder is thinner than required and usually used by OPT'ALM, causing issues on buildings

  ***Optimization** :* Having a granulometry between [45-90] µm

Geometry

- Best realizations with **patches** (C1 and C3) **and cubes** (only C3)

Substrates

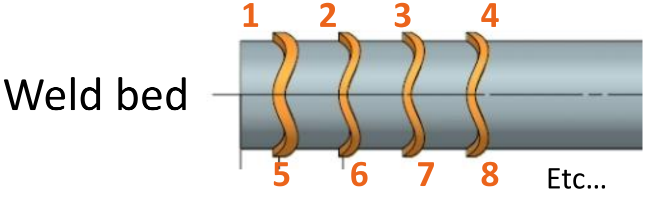
- **TA6V** : substrate heating (lower residual stresses, no cracking at interface)
- Aluminium : not successful
- **17-4PH with C3 powder** : successful with cube and patches

HDRM application

- **Successful**

Spring application

- Change the **deposition trajectory** = improve cooling rate to obtain an amorphous microstructure
- Use a **tube** instead of a rod = improve cooling rate and decrease substrate thermal expansion
- Printing trajectory suggested by OPT'ALM



- **Warning : post-processing machining parameters** of the springs need deeper special studies

OPT'ALM
Additive Manufacturing Options

Thank you

for your attention

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