# Understanding the microstructure evolution during Laser Metal Deposition of HSS M4 obtained from various building strategies, through thermal modelling, and both microstructural and mechanical characterizations

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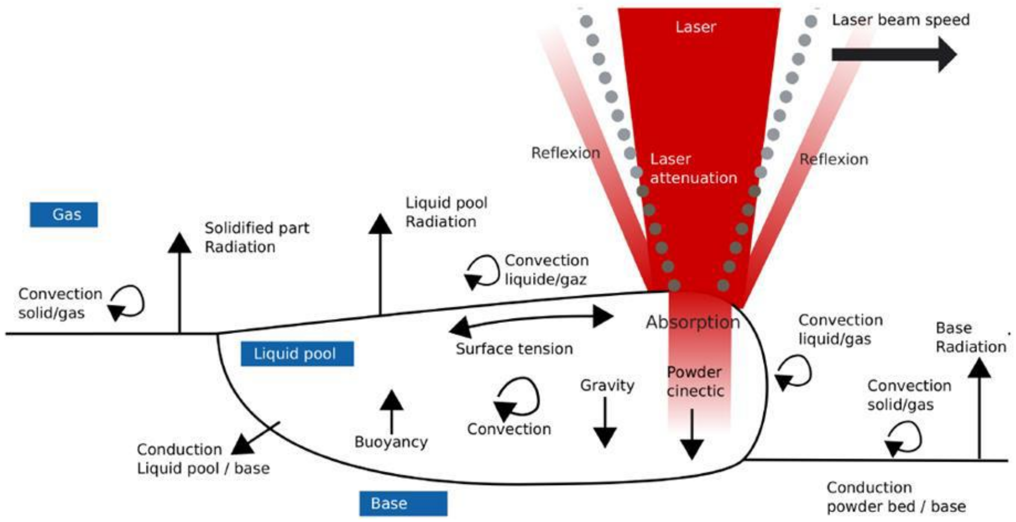
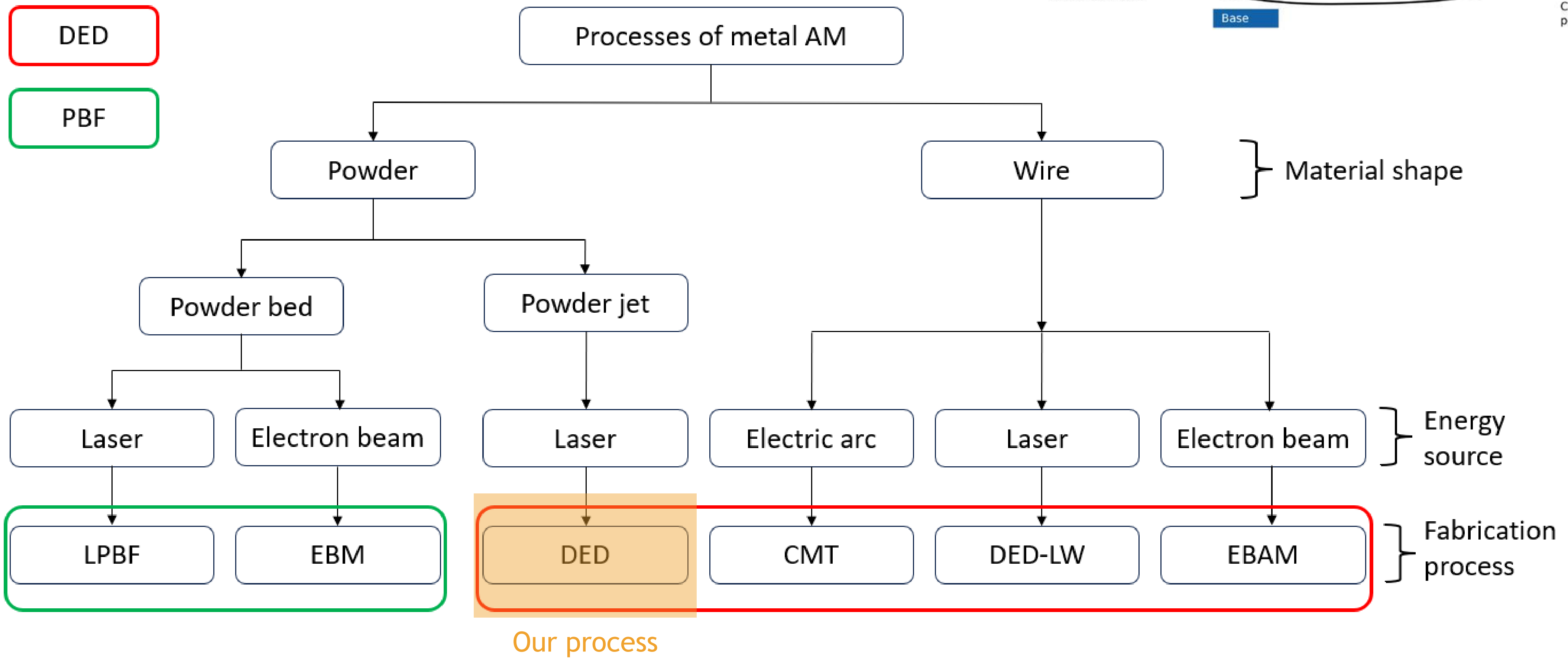
# Content

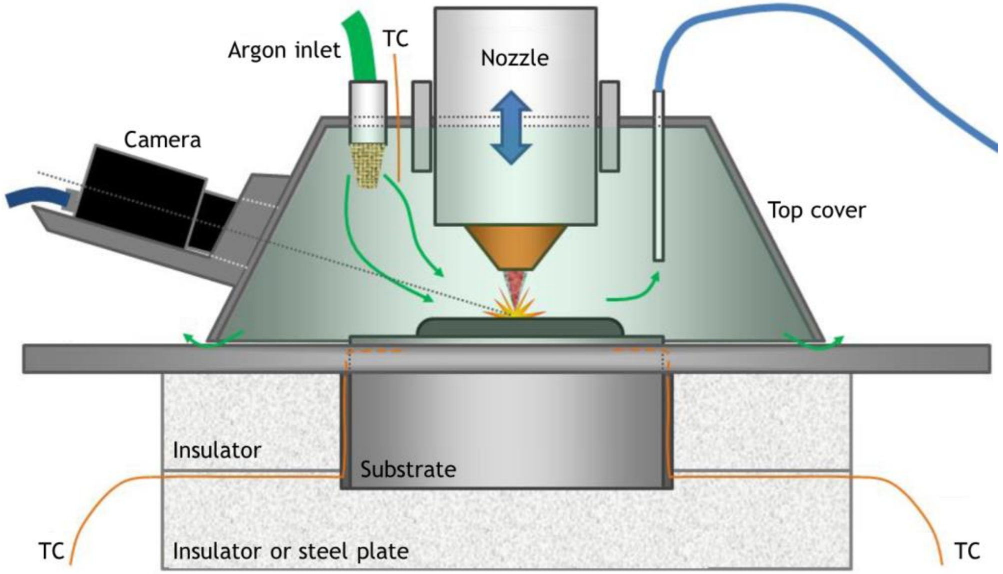
- Laser Metal Deposition (LMD) or Direct Energy Deposition (DED) process
- High Speed Steel (HSS) M4 material
  - Microstructure
  - Wear properties
- Thermal modelling
  - Thin wall
  - Large deposits:
    - Improvement of the deposit's homogeneity
    - → Laser power optimization process strategy
    - Remelting, hardness and nanohardness
- Influence of the DED process on the microstructure
- Conclusions

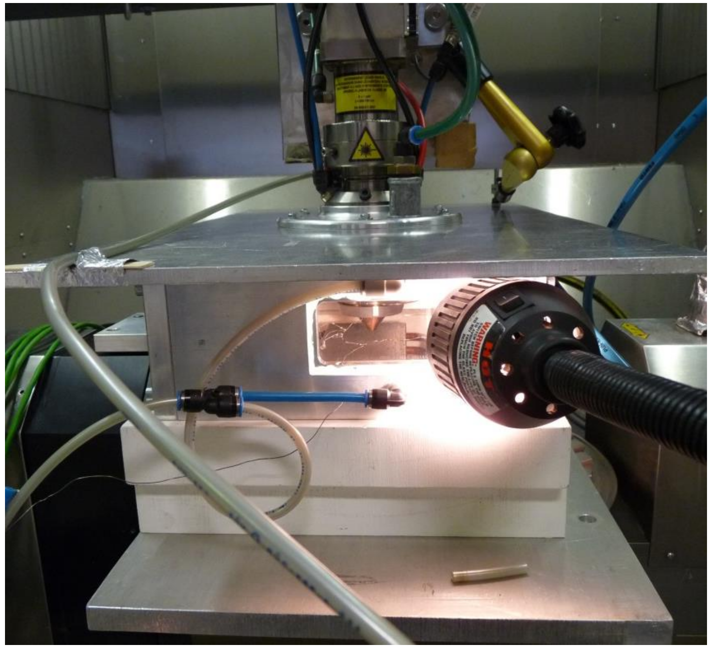
# LMD or DED process



# LMD or DED process



- Parameters:
  - Nozzle scanning speed: 6,87 mm/s
  - Powder feed rate: 76 mg/s
  - Preheating temperature: 300°C
  - 42CrMo4 substrate (diameter 100 mm, height: 40 mm)

# HSS M4 material

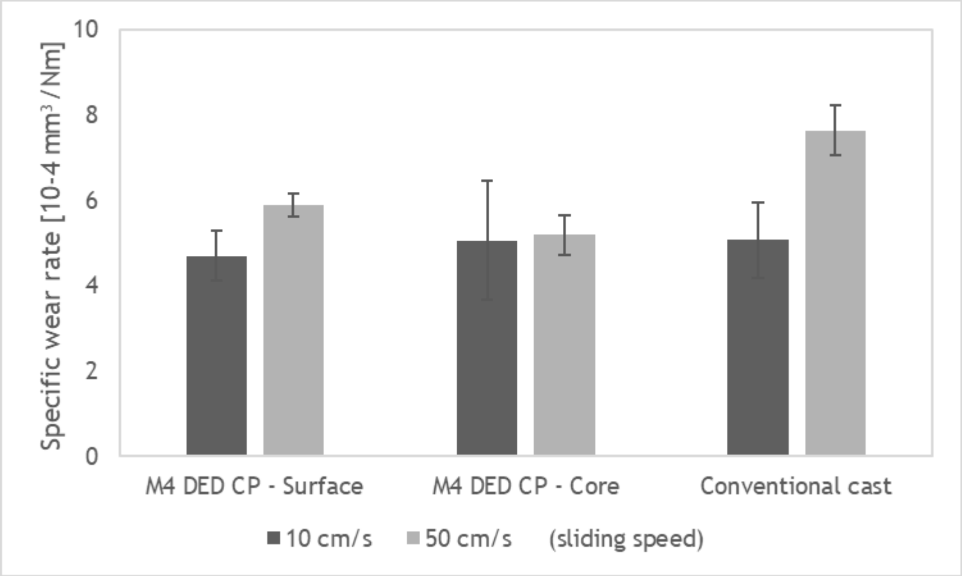
- Fe-Cr-C-X alloys with X: carbide-forming element (i.e., V, Nb, Mo or W)
- Hard carbides to increase hardness and improve wear resistance
- Applications: cutting tools, rolls for hot rolling mills, etc.
- HSS M4 powder composition (in wt%)

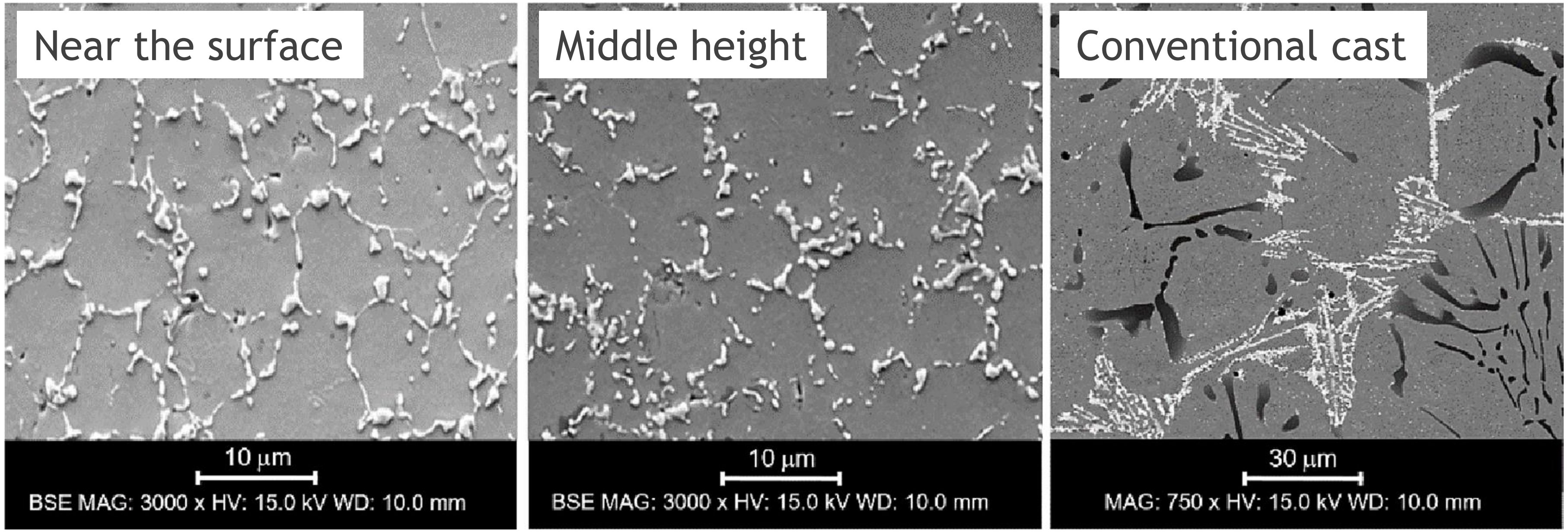
| C | Mn | Cr | Mo | V | W | Ni | Si | Fe |
|---|---|---|---|---|---|---|---|---|
| 1.35 | 0.34 | 4.30 | 4.64 | 4.10 | 5.60 | 0.90 | 0.33 | Bal. |

- Particle size [50-150] µm

# HSS M4 material

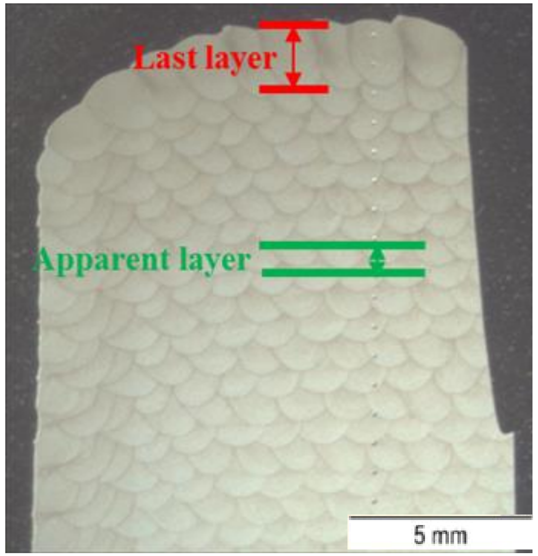
- Microstructure:
  - Near the surface: Continuous $M_2C$ network at grain boundaries
  - Middle height: Discontinuous network of $M_2C$
  - Conventional cast: coarser microstructure with large MC carbides inside grains and acicular $M_2C$ carbides at grain boundaries



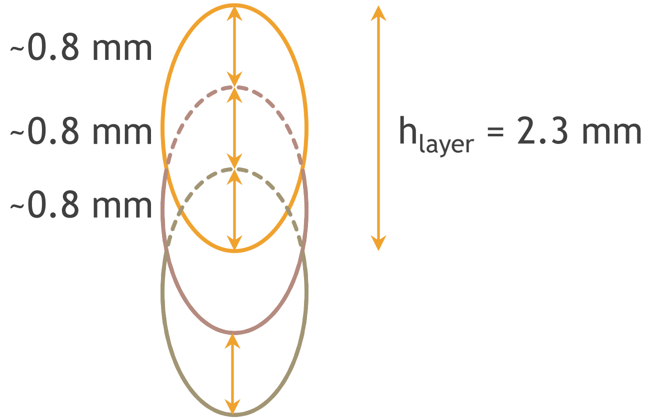




→ Process modelling to predict microstructure evolution

# HSS M4 material: layer height – Case of constant laser power

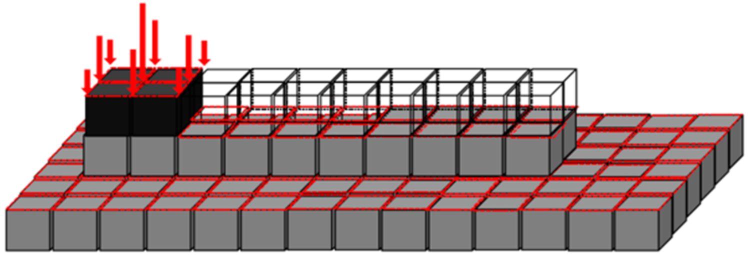



- Average height of the last clad layer ($h_{layer}$) (top of the deposit): 2300 µm = 2.3 mm = real clad layer height at that point
- Average height of apparent clad layer (h): 836 µm = 0.836 mm
- Number of apparent clad layers in the last track: ~3



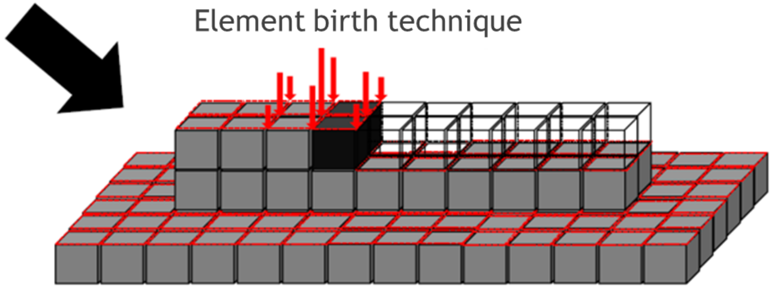
# Thermal modelling

- All the thermal models were developed using a FE homemade code called Lagamine, an ULiège software developed since 1984 by the MSM team
- The Fourier's law of heat conduction, and the surface energy balance considering convection and radiation heat transfer equations are taken into account
- The addition of material during the additive process is simulated using the element birth technique



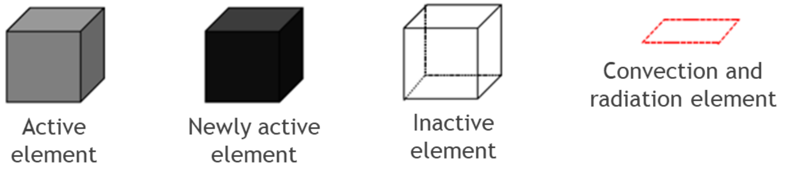
Variable number of elements, nodes, DOF
Heat flow and new material simulated by 2 to 9 elements
Boundary conditions = interface elements adapted to solid element

Element birth technique



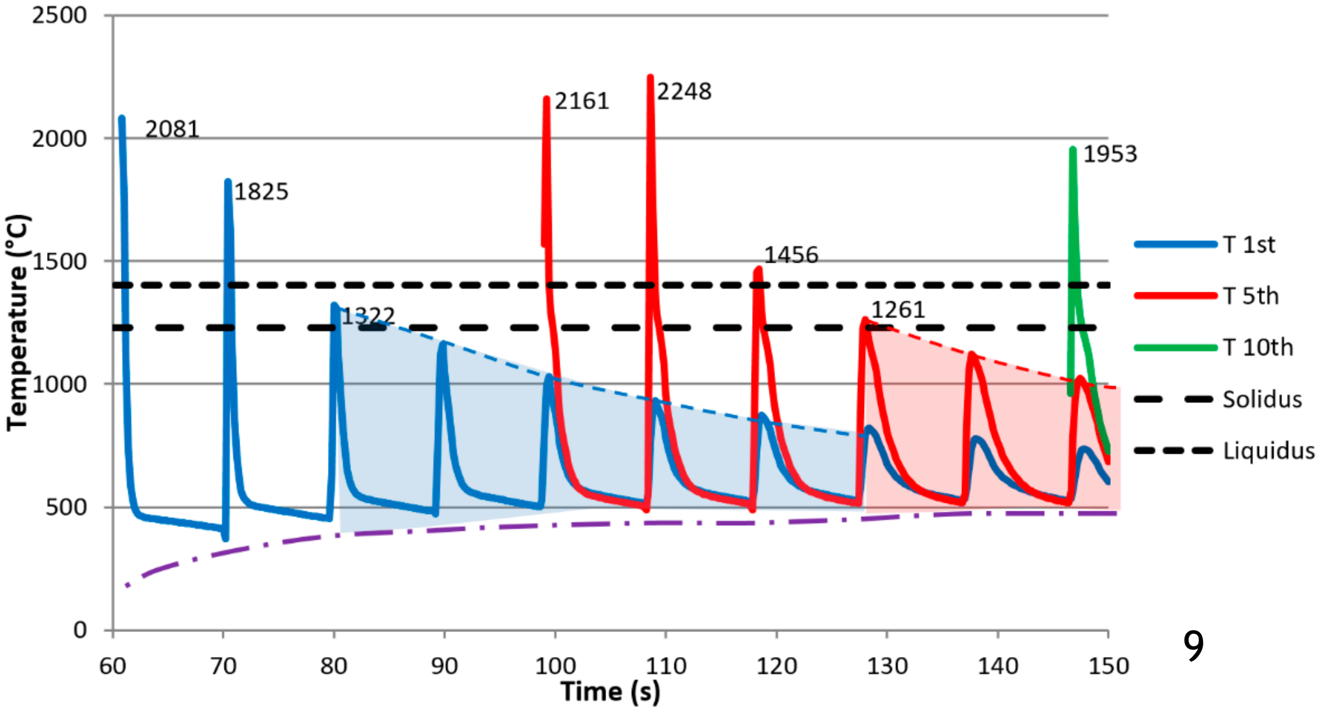
**For a thin wall: 3D**
**Bulk sample: 2D**

Element size defined by laser beam size
→ Direct mesh convergence

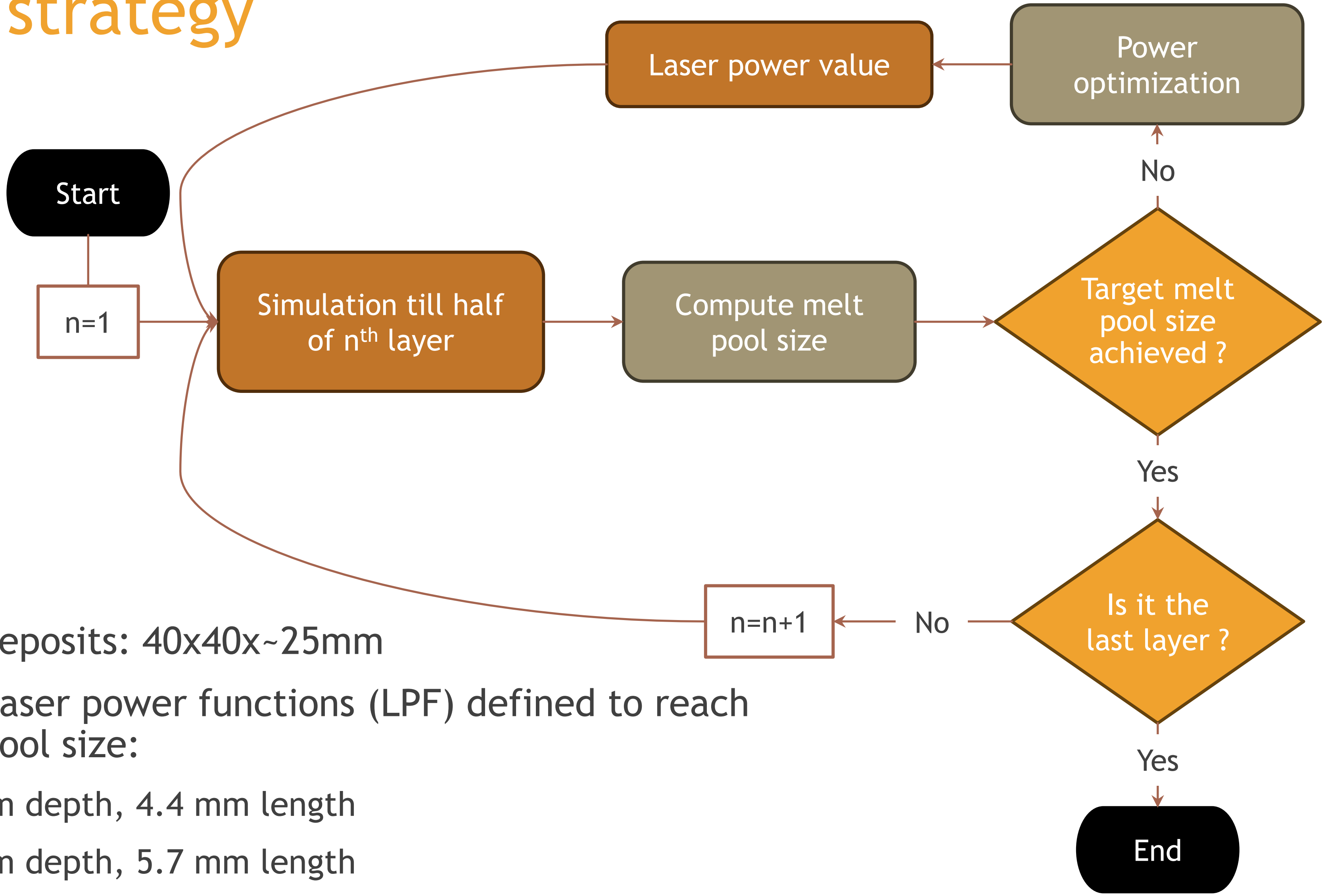


# The thin wall


- Thermal history of the first, fifth, and 10th layer during the thin-wall cladding process computed at a central point
- Red and blue shading zones give the range of temperature variations after the last total remelting
- The purple line (minimum temperature reached during the deposition process) increases until a maximum value of around 500 °C
  - → No bainitic/martensitic transformations during the process time
  - → Transformed when the laser is OFF
  - → When the laser is ON, a pseudo-isothermal annealing (PIA) period can be assumed
- The first peak is higher for the 5th layer than the 1st and the second peak of the 5th layer is higher
  - → Heat accumulation



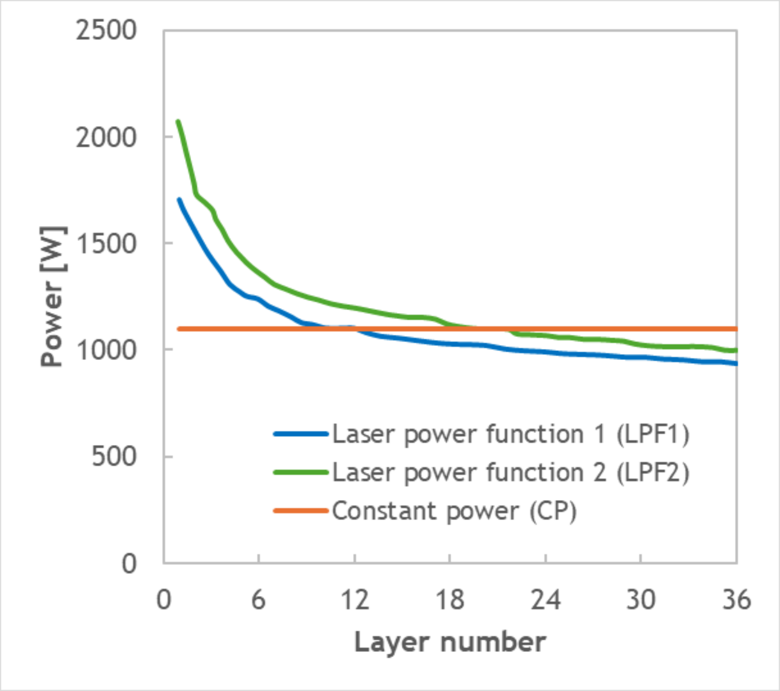
# Large deposits: Laser power optimization process strategy



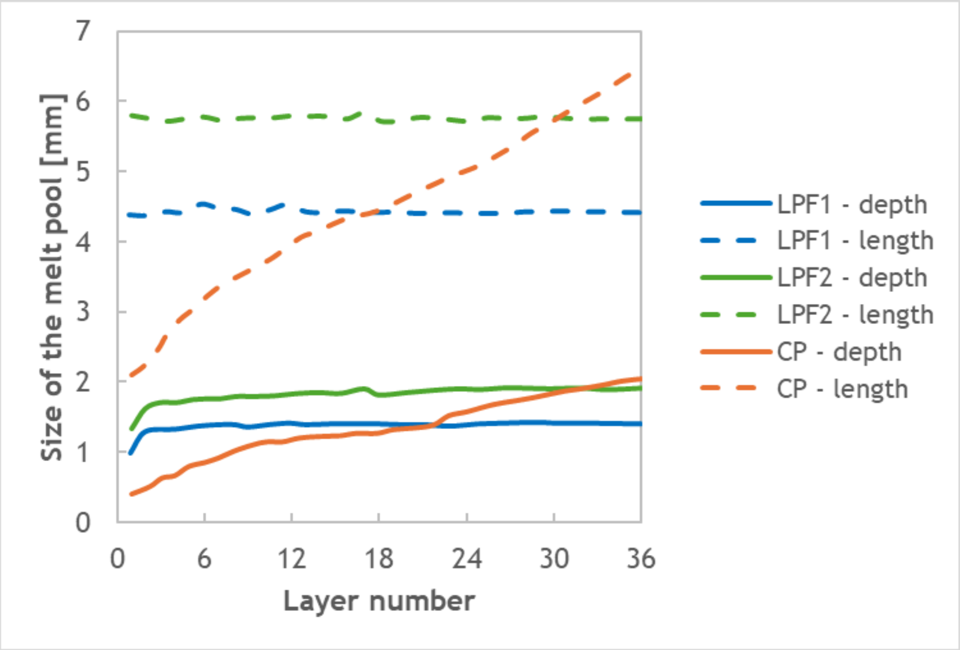

- Dimensions of deposits: 40x40x~25mm
- Two optimized laser power functions (LPF) defined to reach constant melt pool size:
  - LPF 1: 1.4 mm depth, 4.4 mm length
  - LPF 2: 1.8 mm depth, 5.7 mm length

# Laser power optimization process strategy

- Two optimized laser power function defined (LPF1 & LPF2) and constant power at 1100 W

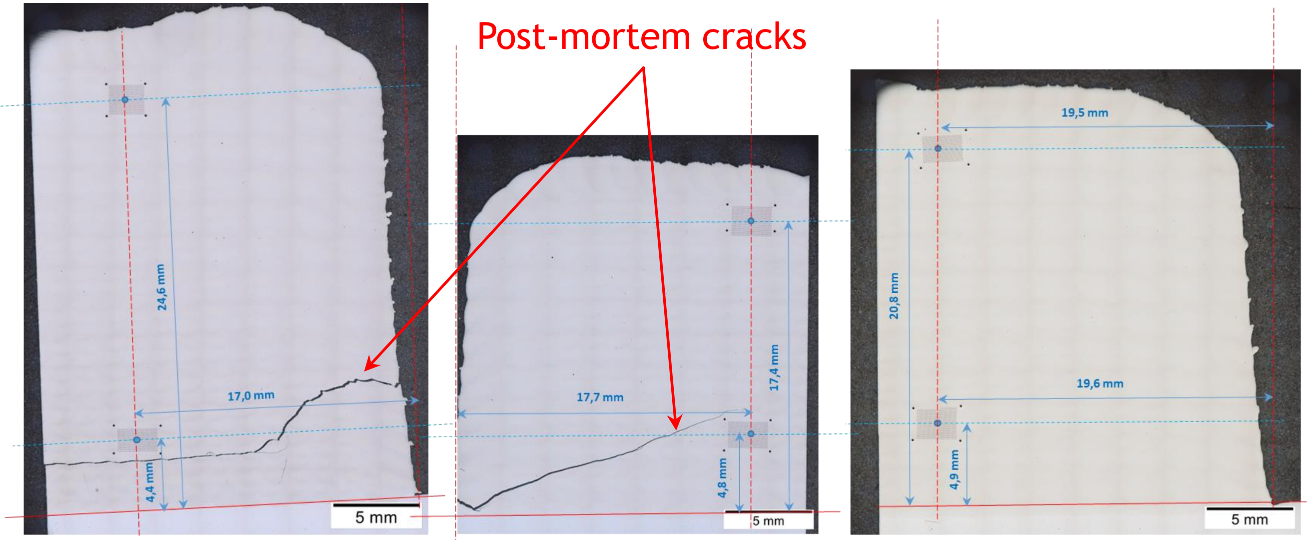



- Predicted melt pool depth & length




- Parameters:
  - Nozzle scanning speed: 6,87 mm/s
  - Powder feed rate: 76 mg/s
  - Preheating temperature: 300°C
  - 42CrMo4 substrate (diameter 100 mm, height: 40 mm)

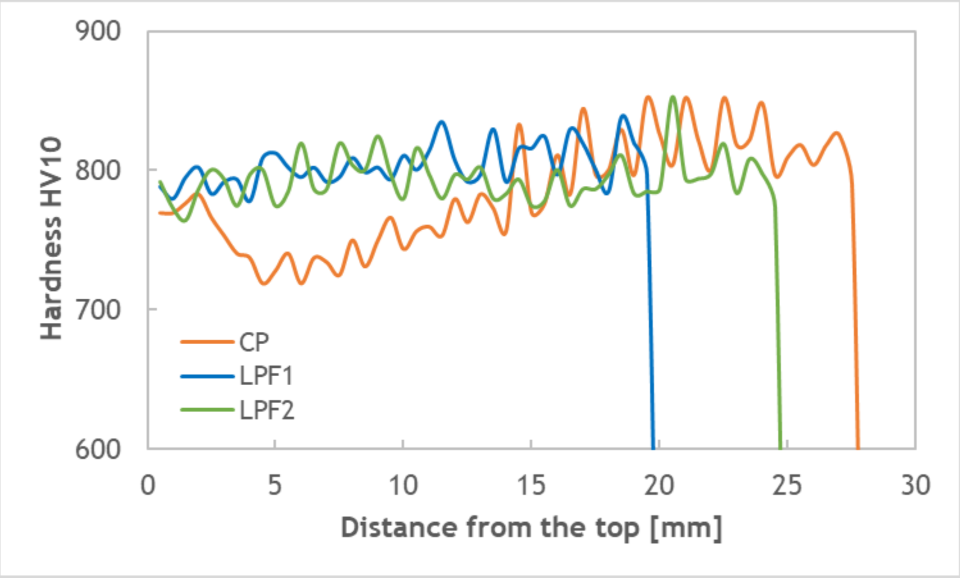
# Hardness measurements




Constant power (CP) | Laser power function 1 (LPF1) | Laser power function 2 (LPF2)

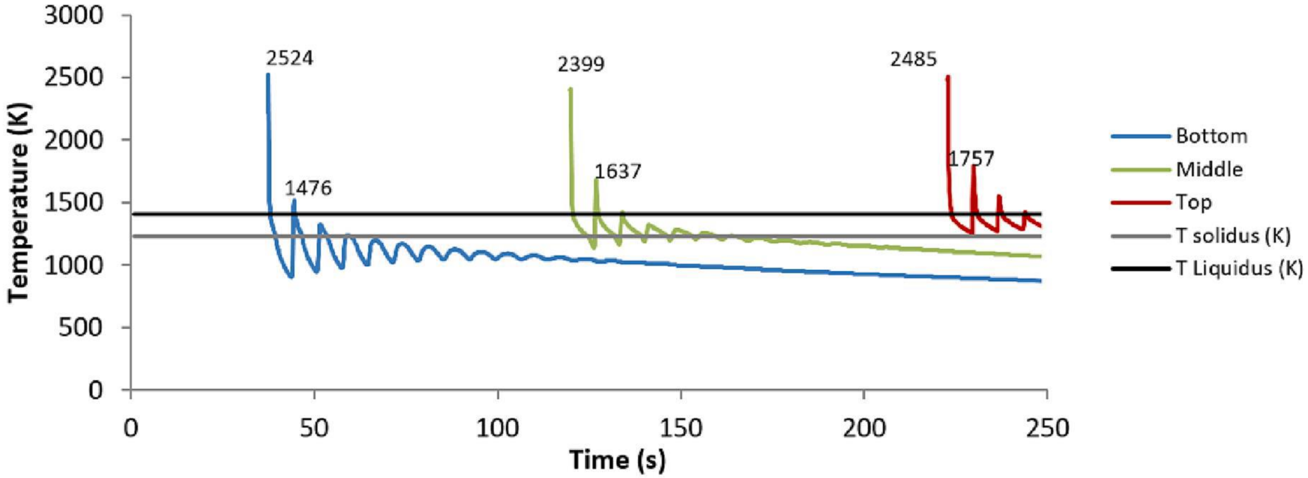
- Hardness measurements:
  - HV10
  - First indent at 500 µm
  - One indent every 500 µm
  - Last indent when substrate reached
  - Parallel to the dotted red line

| Average values of Vickers microhardness of DED M4 steel | |
|---|---|
| Laser Power Function | HV10 |
| Constant power | 783 ± 38 |
| LPF1 | 803 ± 15 |
| LPF2 | 793 ± 16 |

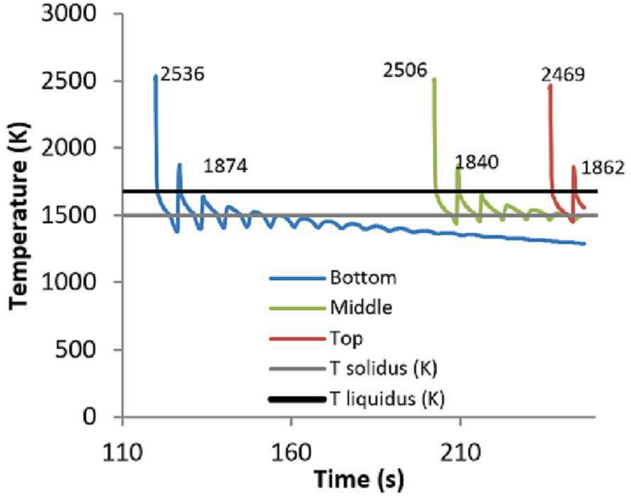


# Thermal modelling results

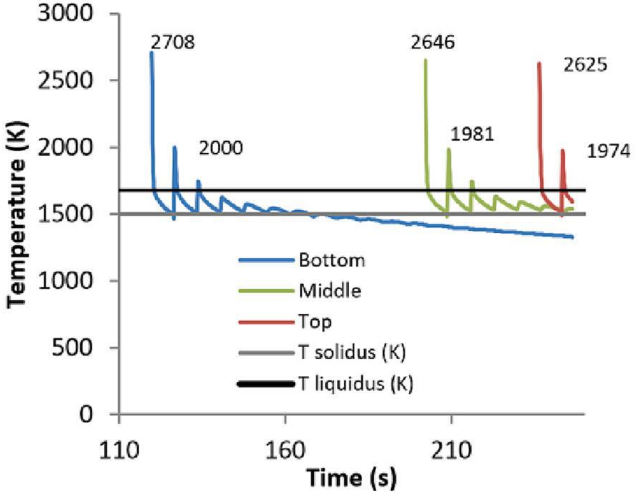
Constant power

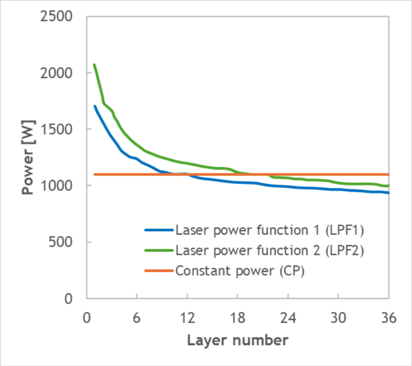



LPF1



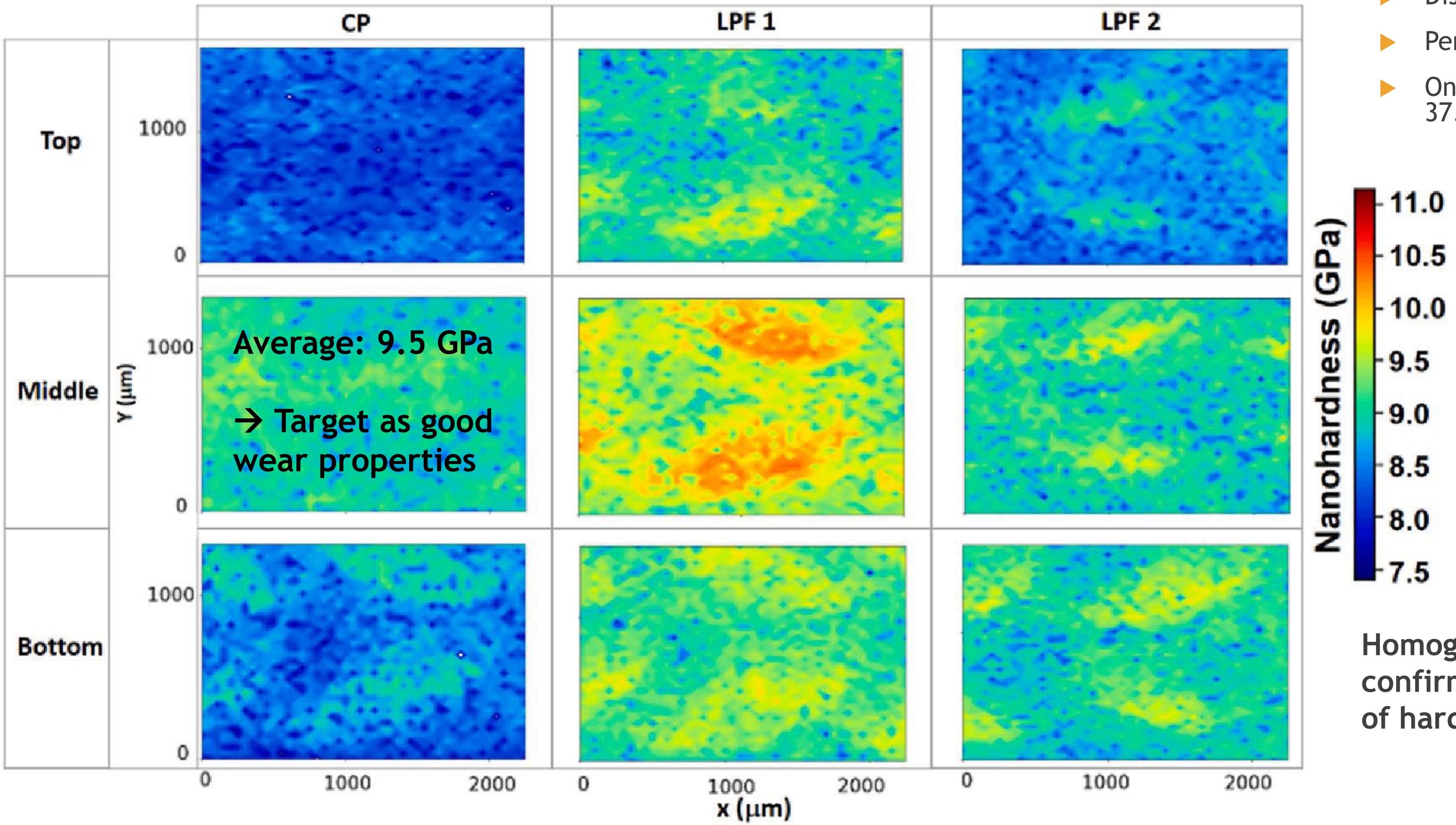

LPF2




- LPF2:
  - Higher homogeneity
  - Higher in situ annealing temperature
- Average max peak temperature:
  - LPF1: 2505 K
  - LPF2: 2660 K
  - CP: 2470 K
- Higher accumulation of heat
  - → Slower cooling process
  - → More homogeneous microstructure
  - → Lower residual stresses
  - → No cracks in LPF2 sample at cutting

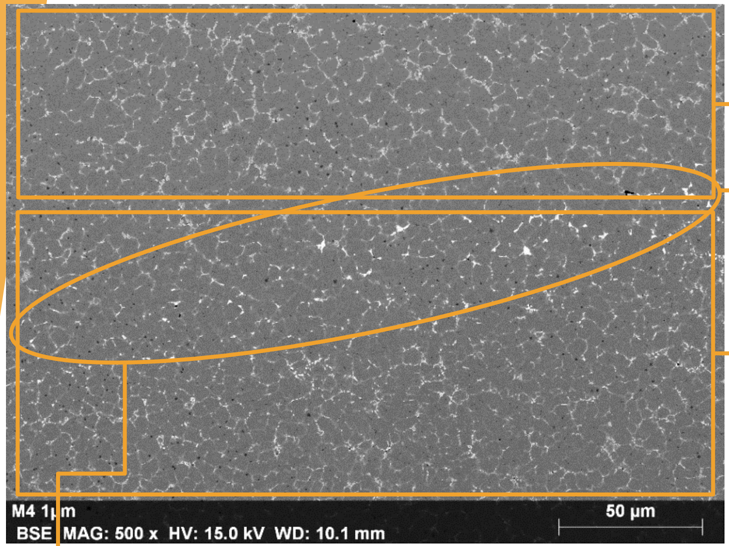
# Nanohardness measurements



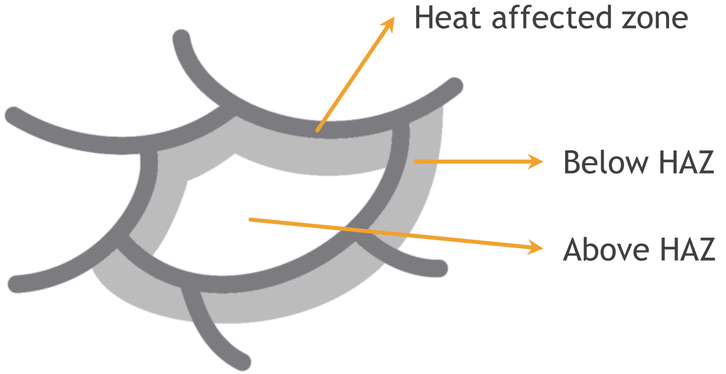

- Parameters:
  - High Load Berkovich indenter
  - Displacement control mode
  - Penetration depth: 3 µm
  - One indent every 50 µm in x, 37.5 µm in y

**Homogeneity of LPF2 confirmed + high level of hardness = optimum**

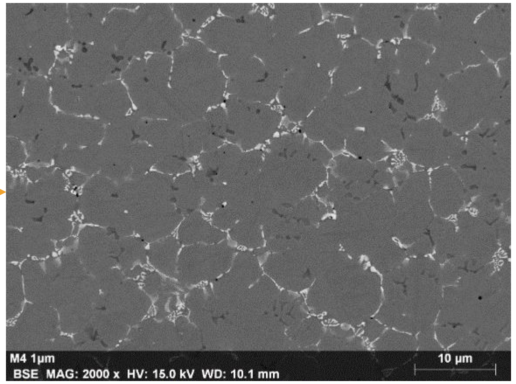
# Microstructure

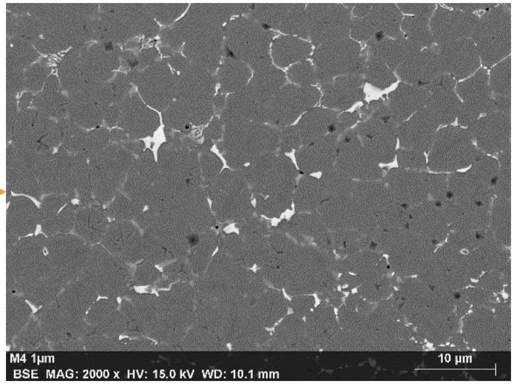


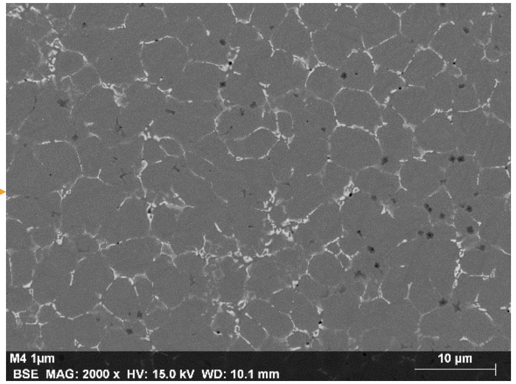

Zone with brighter carbides = heat affected zone (HAZ)



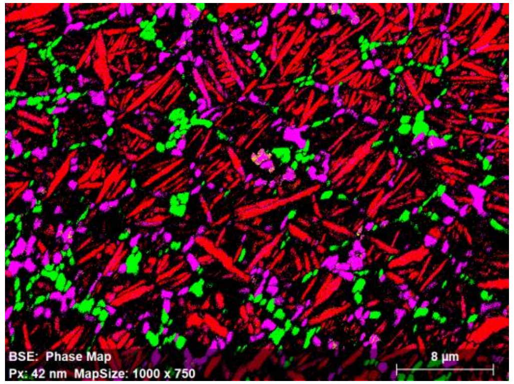

Mirror polished

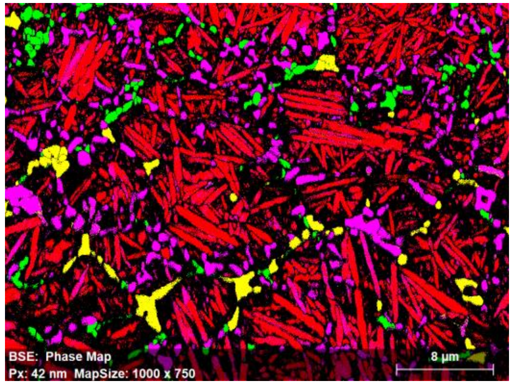


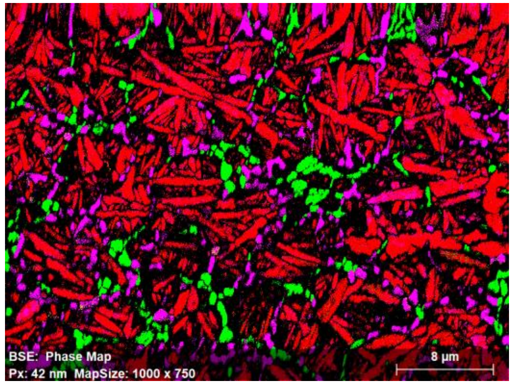



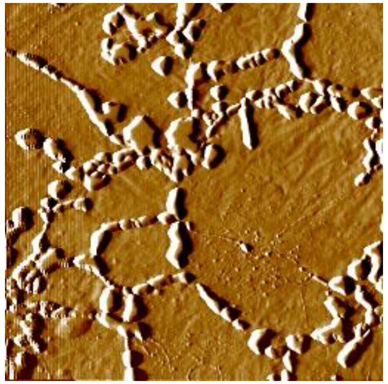

EBSD



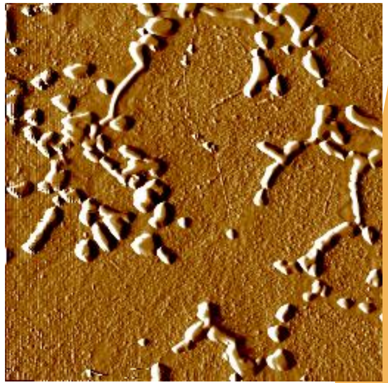




Scanning nano (10x10 µm)



- BCC phase
- MC carbide
- $M_2C$ carbide
- $M_6C$ carbide



# Conclusions

- HSS M4 manufactured by DED shows interesting wear properties
- To improve the macro-homogeneity of the deposits, thermal models were developed to adjust the laser power to obtain a constant melt pool size: laser power function LPF1 & LPF2
- Using hardness and nanohardness show that the macro-homogeneity is improved for LPF2
- If macro-homogeneity is improved between the upper and lower part of the deposit, it’s also the case for the micro-homogeneity with less hardness difference between the lower part of the melt pool and the HAZ

# Thank you for your attention