2D FE Simulations of High Speed Steel Laser Cladding Process

R.T. Jardin, H.S. Tran, N. Hashemi,

J.T. Tchuindjang, R. Carrus, L. Duchêne, A. Mertens and A.M. Habraken

Research goal
Prediction of Microstructure

For High Speed Steel (M4 grade) wt%

C	Cr	Mo	V	W	Ni	Si	Fe
1.35	4.30	4.64	4.10	5.60	0.34	0.9	0.33

Particle size [50 to 150 µm]

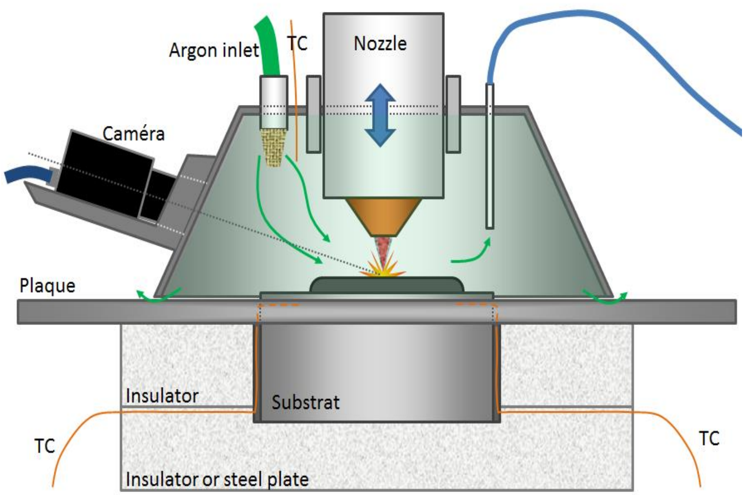
For thick deposit,

Direct Energy Deposition DED process

or Laser cladding

→ heterogeneity in depth

if no optimization



Material High Speed Steel M4

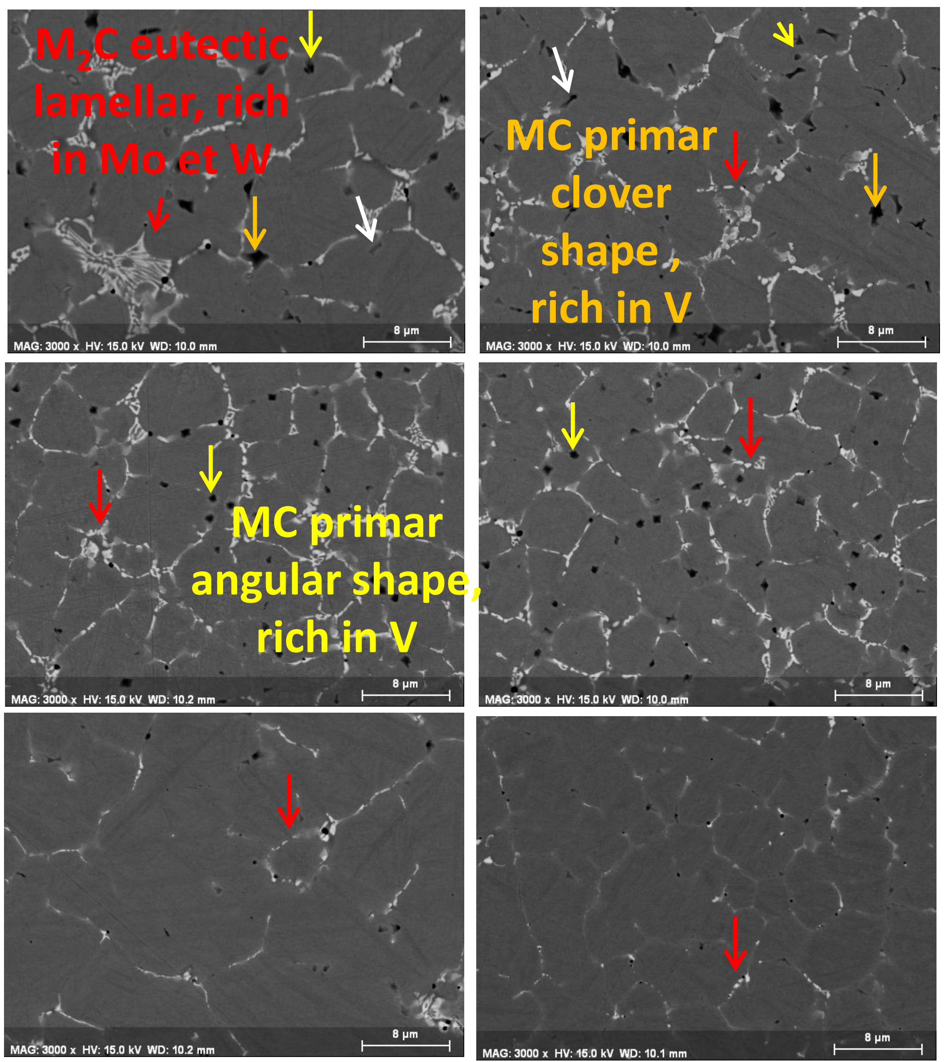
- Fe-Cr-C-X alloys with X: carbide-forming element (i.e. V, Nb, Mo or W)
- Hard carbides ⇒ High hardness and wear resistance
- Applications: high speed machining, cutting tools, cylinders for hot rolling mills, molds...



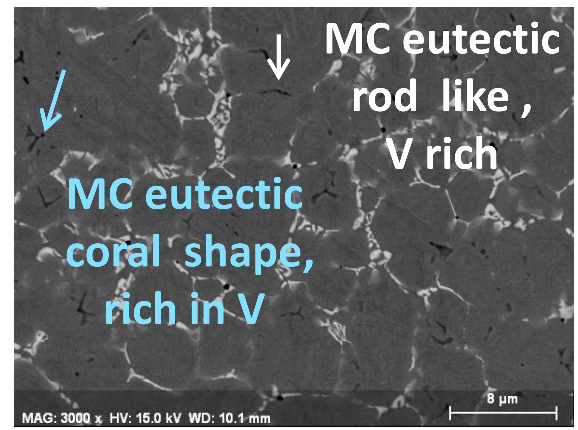
Microstructure - Depth Heterogeneity

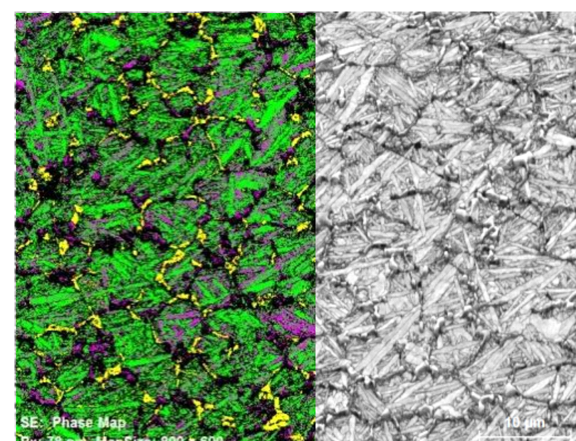
LC B I300 | LC B S250

0.5 mm from free surface | Middle height | Near substrate



LC B S250 - 4.5, 6.5 et 8.5 mm



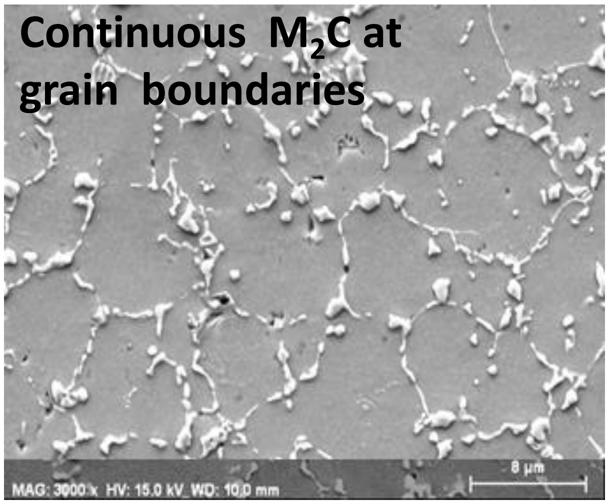


Martensitic Matrix

Heterogeneous wear property

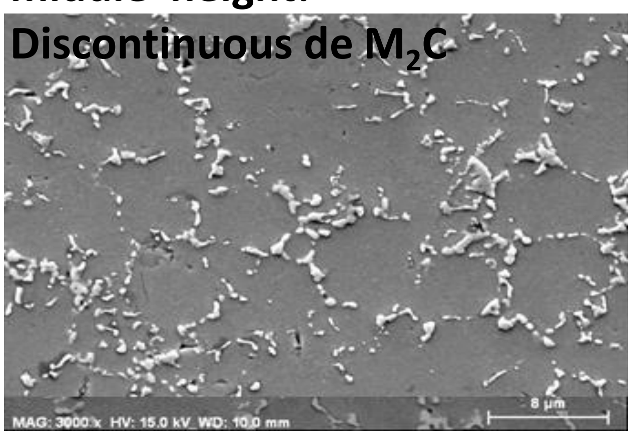
LC B, near surface

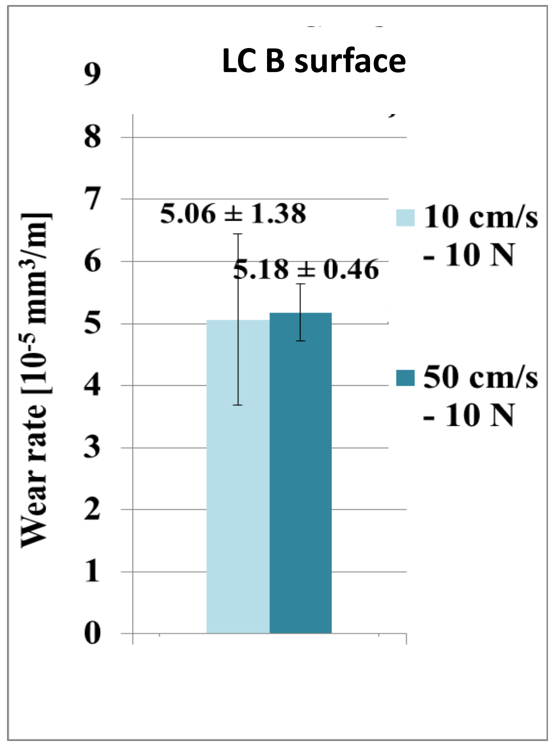
Continuous M_2C at grain boundaries

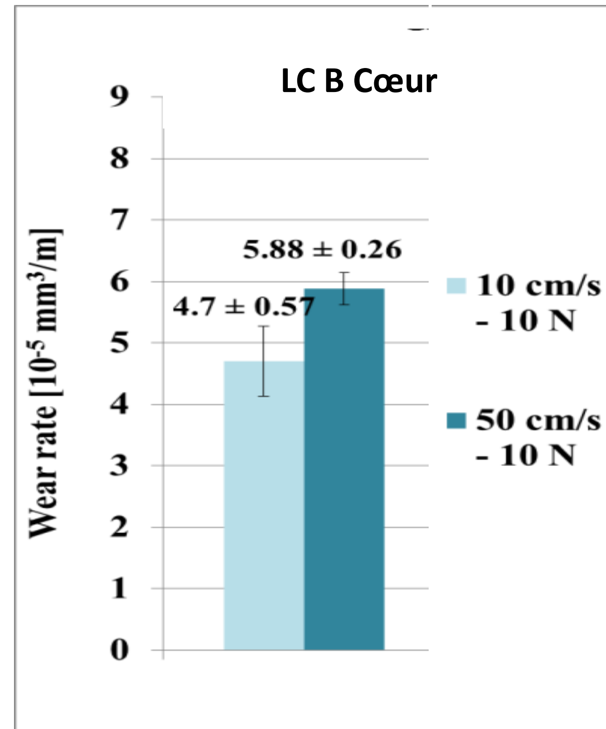


middle height:

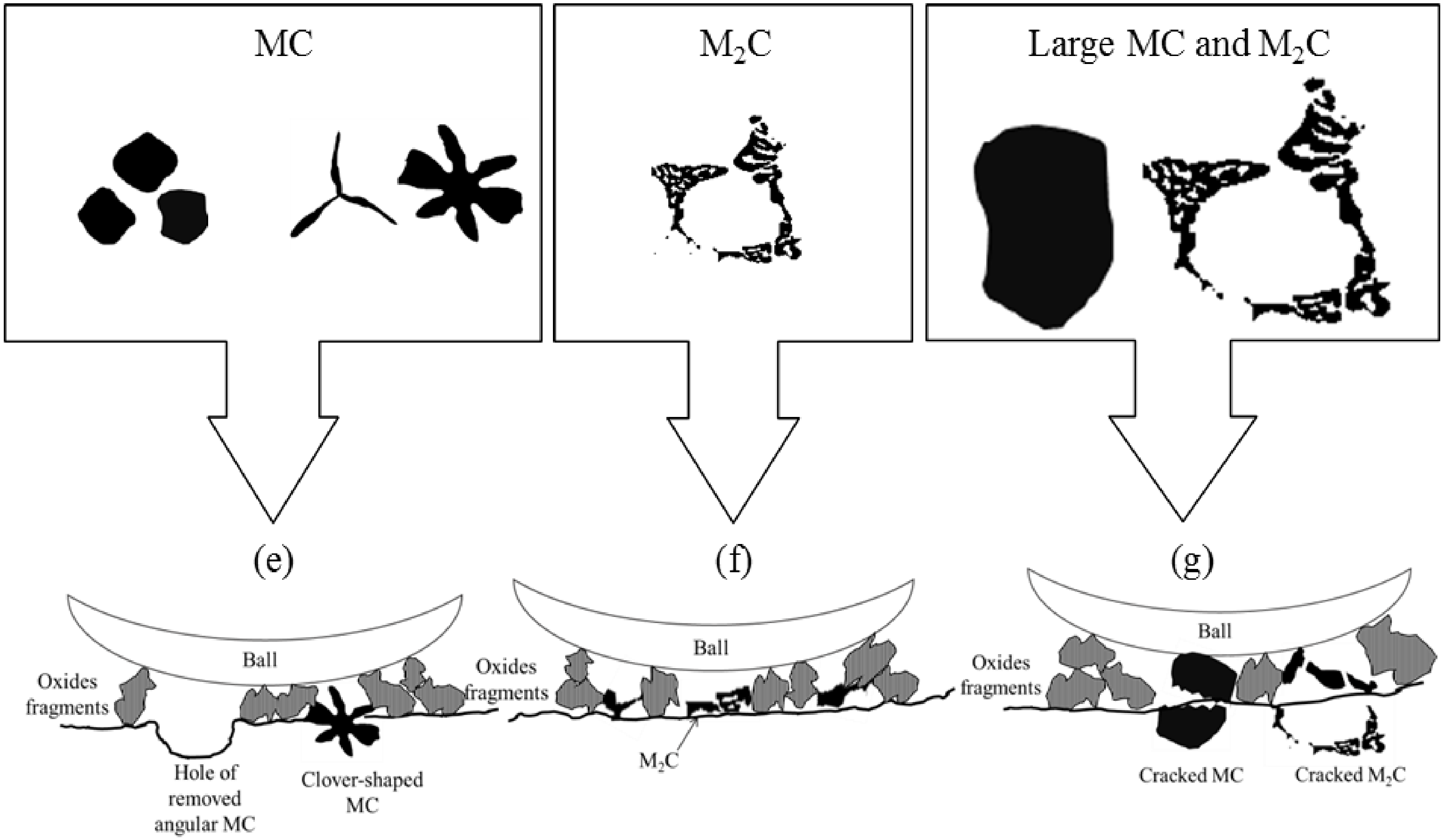
Discontinuous de M_2C







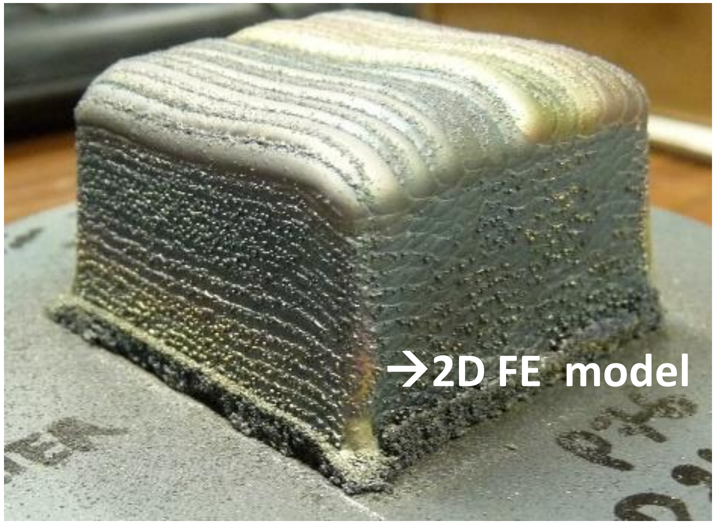
Wear mechanisms linked to microstructure



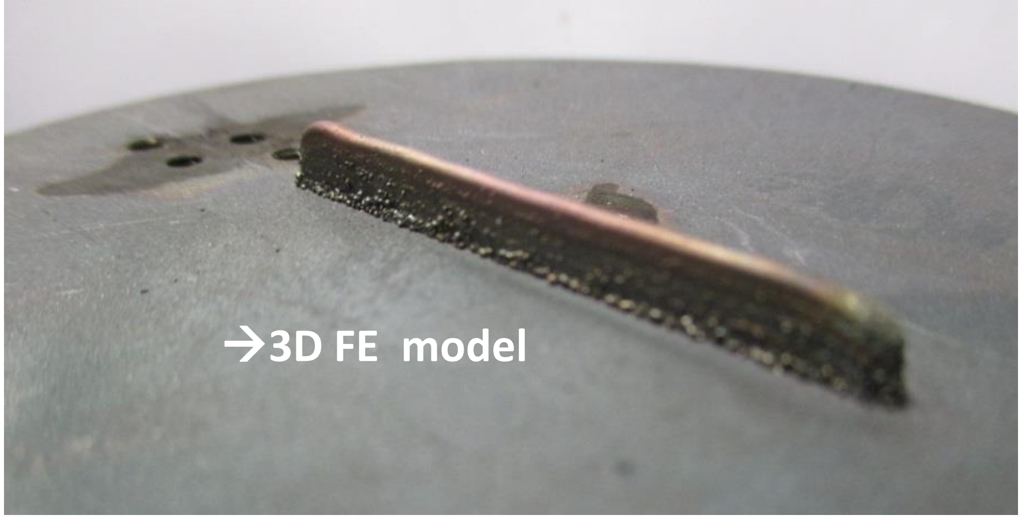
N. Hashemi et al., Surf. Coat. Technol. (2017), **315**, 519

Thin and bulk samples

	Bulk Sample	Thin wall
Laser beam speed (mm/s)	6.67	7
Laser power (W)	1100	420
Pre-heating (°C)	300	438
Mass flow (mg/s)	76	83
Number of tracks per layer	27	1
Total number of layers	36	5



40 x 40 x 27.5 mm **(874 tracks)**



40 x 1.5 x 4.3 mm 5 tracks

Thermal equations

Heat transfer per conduction

$$\frac{\partial}{\partial x}\left(k\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k\frac{\partial T}{\partial y}\right)+\frac{\partial}{\partial z}\left(k\frac{\partial T}{\partial z}\right)+Q_{\text{int}}=\rho c_p\frac{\partial T}{\partial t}$$

Conductivity

Volume energy

Density

Heat Capacity

Heat transfer per convection and radiation

$$-K.(\nabla T.n)=-h(T-T_0)-\varepsilon\sigma(T^4-T_0^4)$$

Convection Coef.

Emissivity

Stefan-Boltzmann Constant

Melting latent Heat

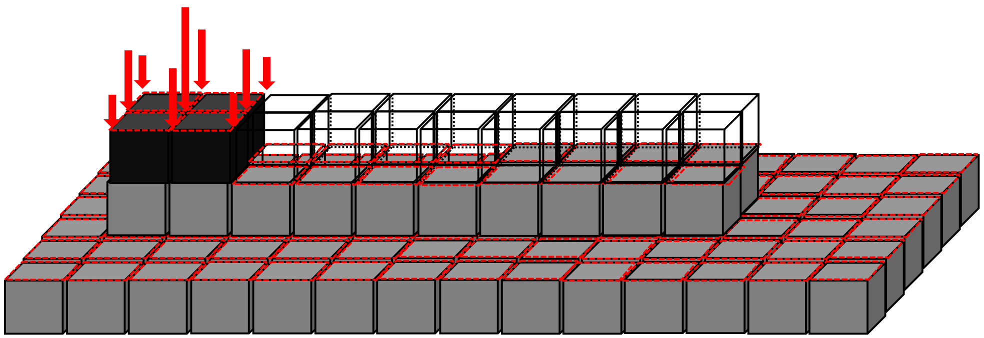
$$C_p{}^* = \frac{L_f}{T_{em}-T_{sm}}+C_p$$

Enthalpic formulation

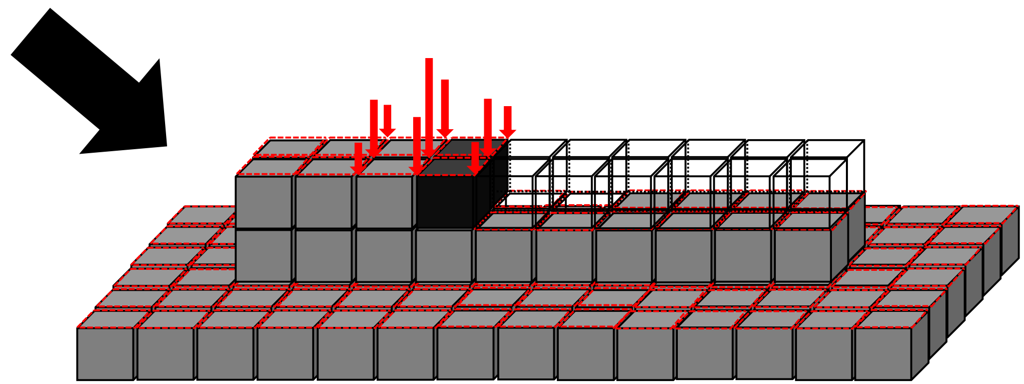
Enthalpy

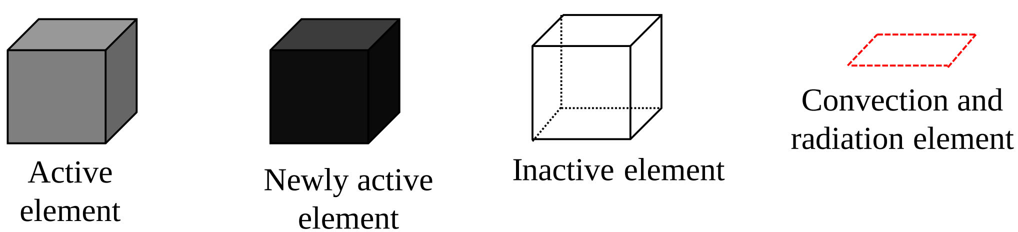
$$H=\int\rho\cdot c(T)\mathrm{d}T$$

Element birth technique



For a thin wall 3D
Bulk Sample 2D



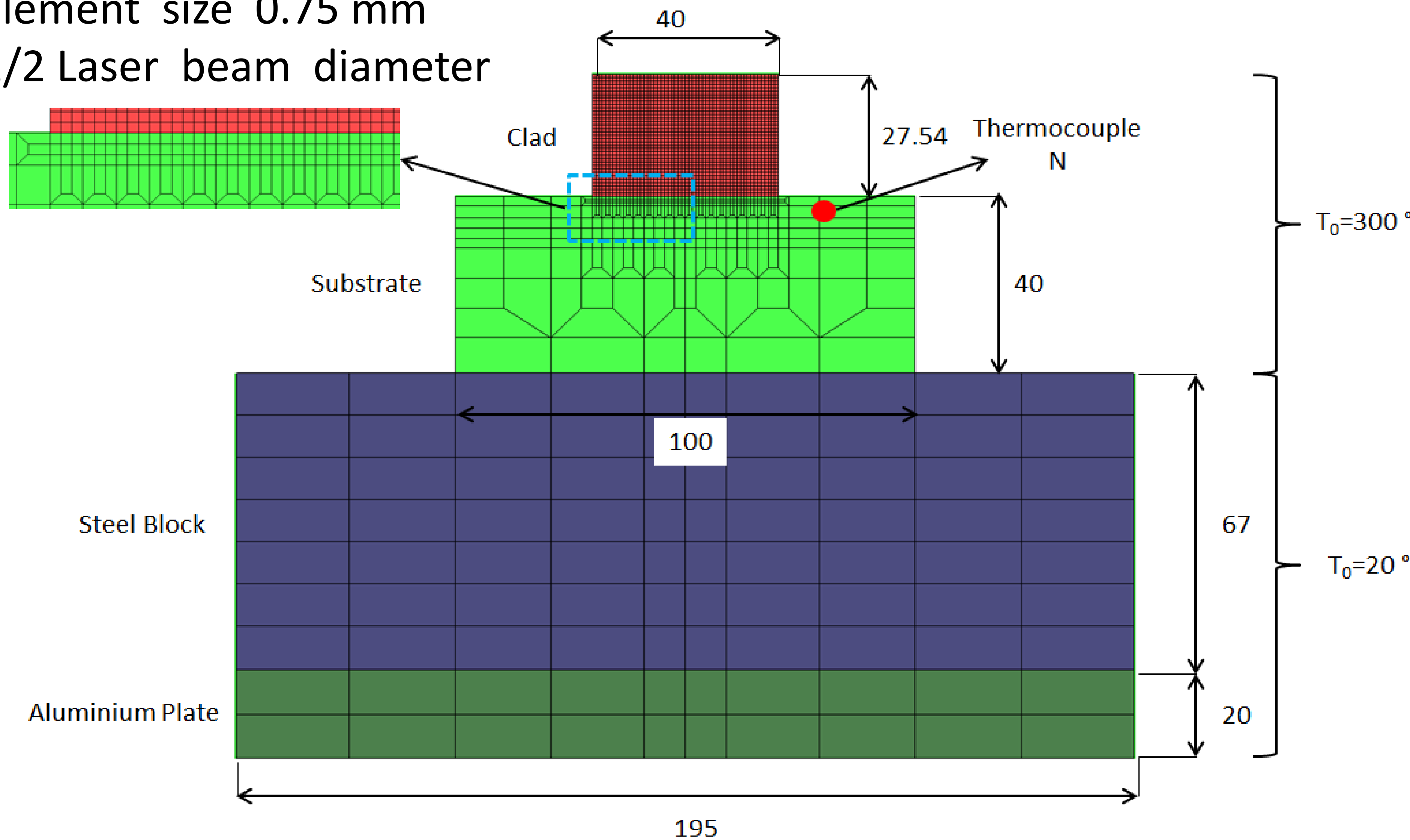


convection-radiation elem. on vertical planes of the clad not drawn

2D mesh (convergence analysis)

Element size 0.75 mm

1/2 Laser beam diameter



Simulation Parameters

Thermo-physical parameters : k c_p L_f ρ

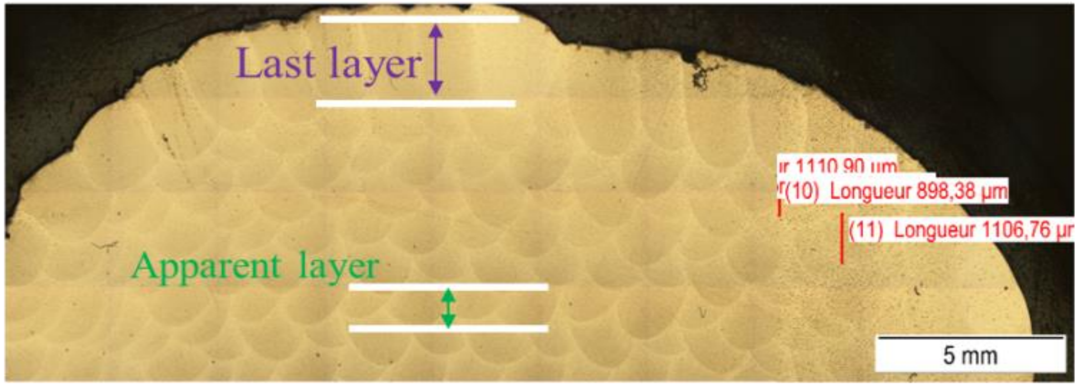
!! sensitivity analysis of melt pool size prediction
to conductivity and heat capacity

(soon J. of Materials Processing Technology Jardin et al.2018)

Absorption factor of laser energy β : physical meaning in 3D simulations but still adjusted by inverse modelling

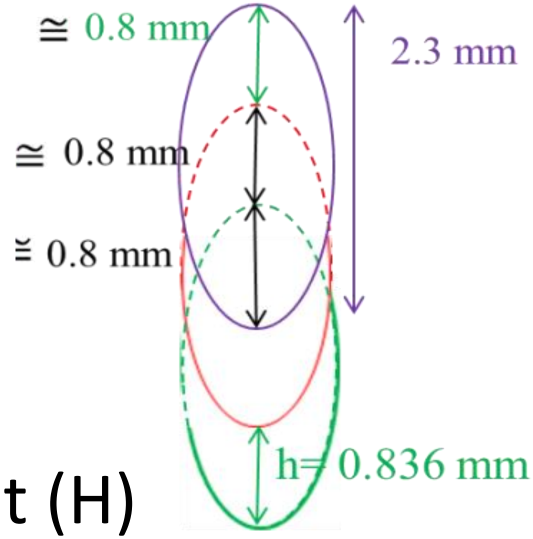
In 2D analysis: β just a fitting parameter
(effect of transversal thermal leak
+ FE assumption layer thickness…)

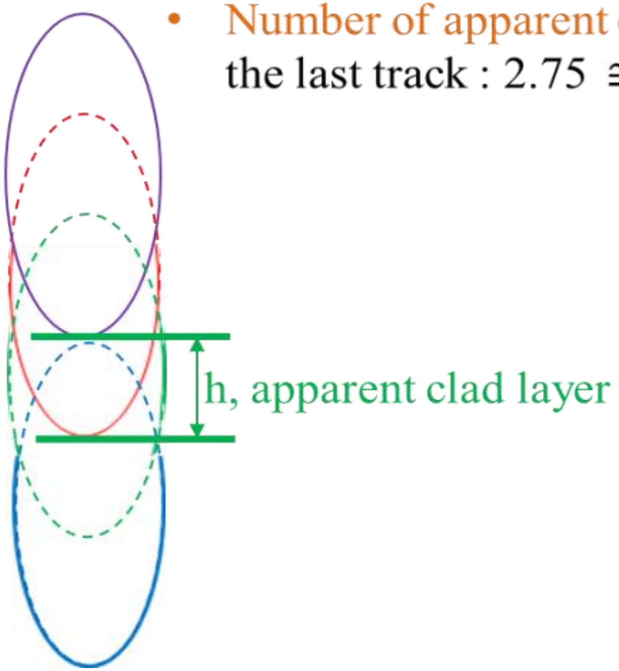
Experimental results -> FE Validation



- Average height of the last clad layer (H_{layer}) (top of the deposit) : 2300 µm = 2.3 mm = real clad layer height
- Average height of apparent clad layer (h) : 836 µm = 0.836 mm
- Number of apparent clad layers in the last track : 2.75 ≅ 3

H
last clad
layer

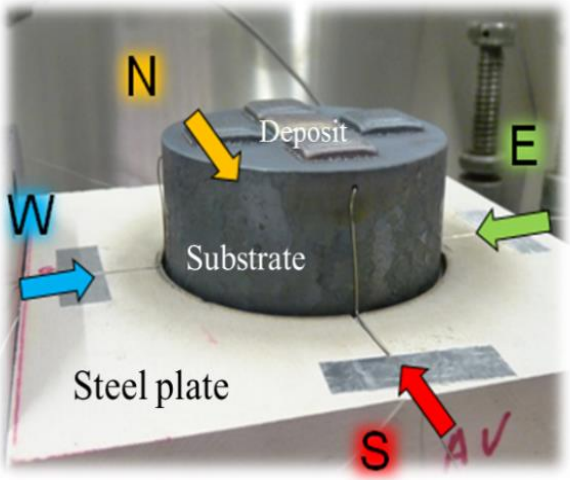


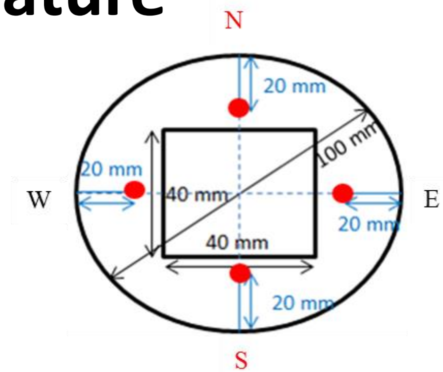


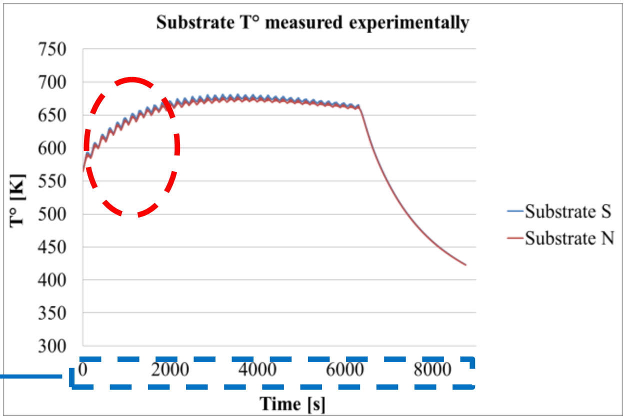
Mean height (H)
of last layer : 2.3 mm

Experimental results

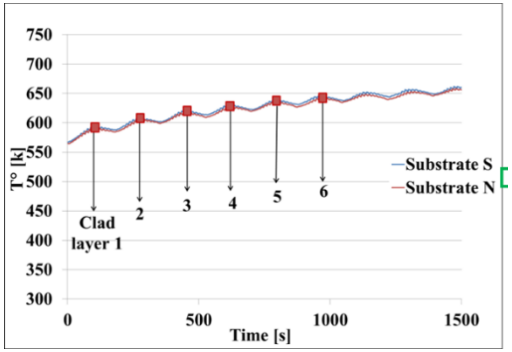
Substrate temperature



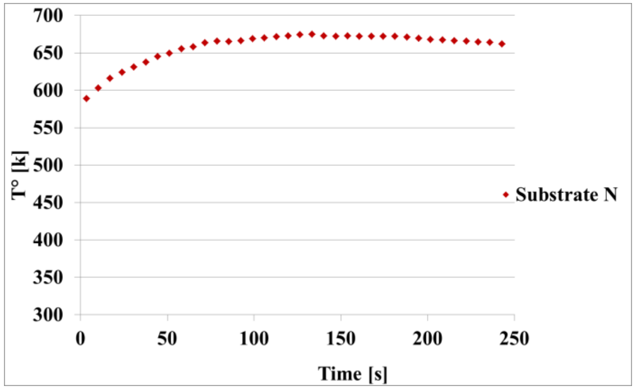




Simulation time : 246.46 s



Hashemi approach Uliege PhD thesis 2017



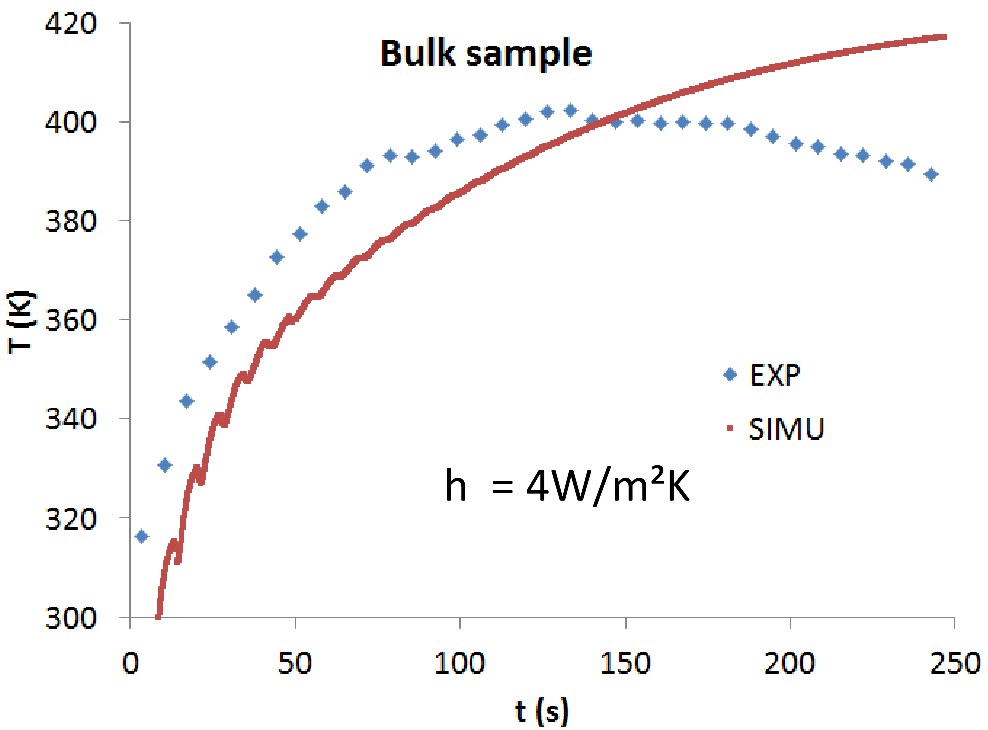
Simulation Parameters (boundary conditions)

ajdusted on first layers β on whole layers h and ε	Convection (h) (W/m²K)	Emissivity (ε)
Set Hashemi	4	1
Set Jardin	230	1

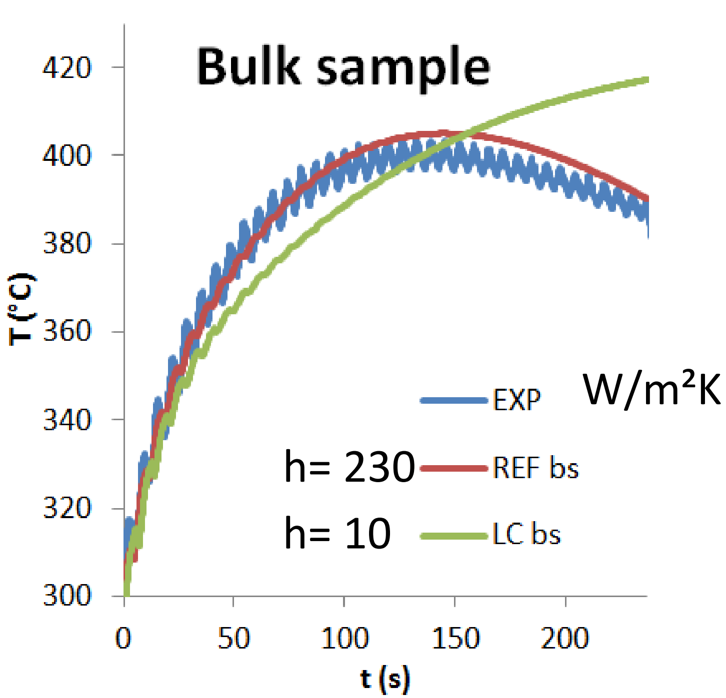
Both respect the constraint of 2.3 mm height of last layer however temperature history better predicted by Jardin

Validation of Model and set of parameters

Hashemi



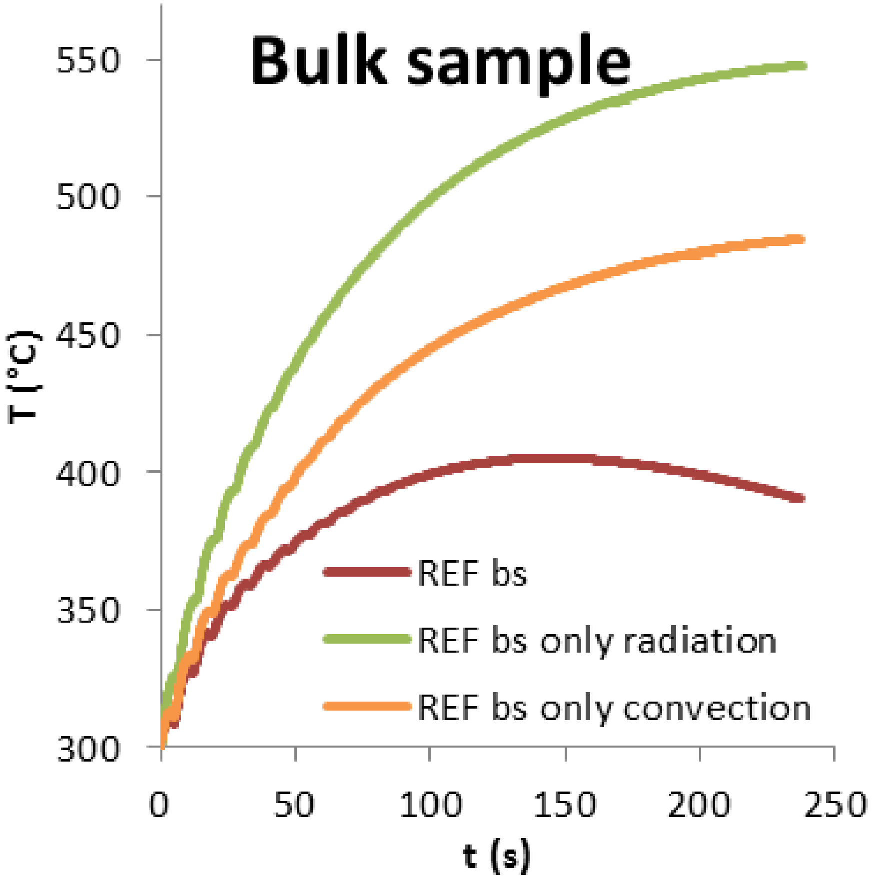
Jardin

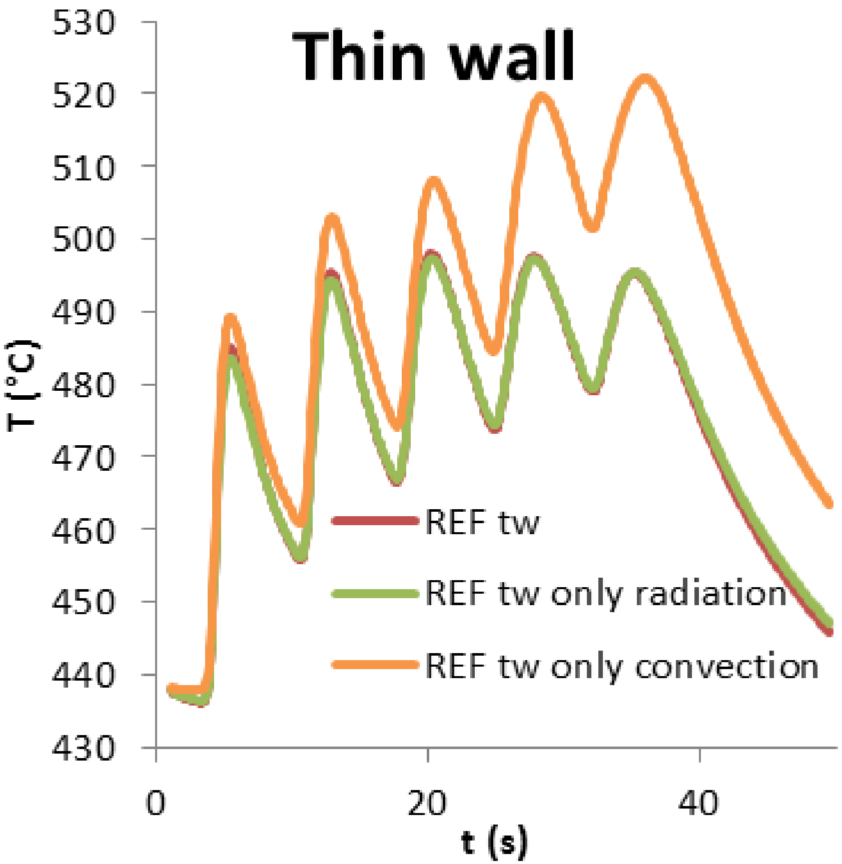


Two ways of extraction of experimental data

One temperature per layer (Hashemi) or the whole temperature history of the middle track (Jardin)

Key heat transfers ?



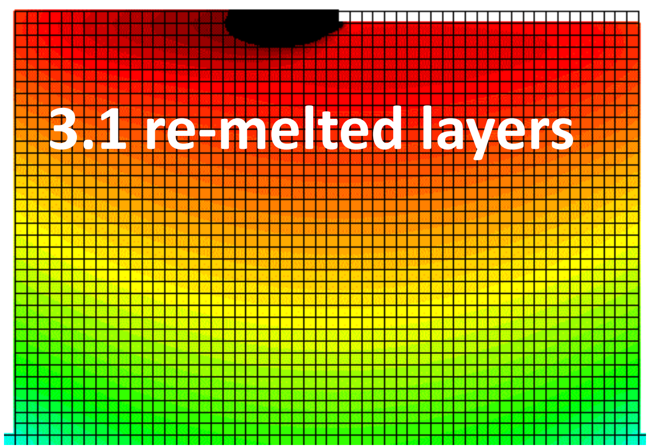


In bulk sample: radiation and convection = key factors

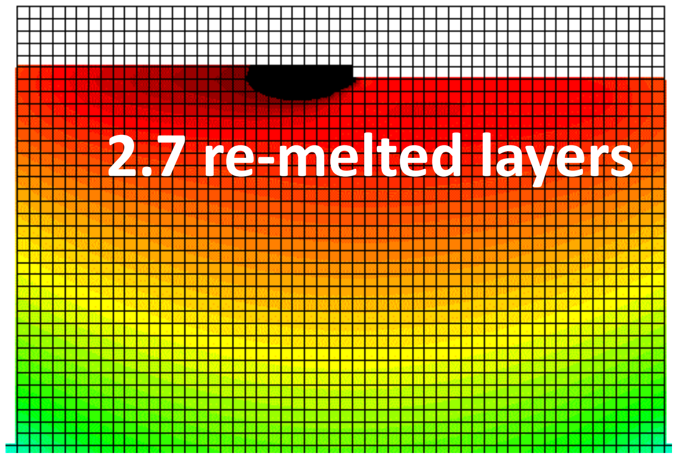
In 5 layers thin wall heat convection has poor effect

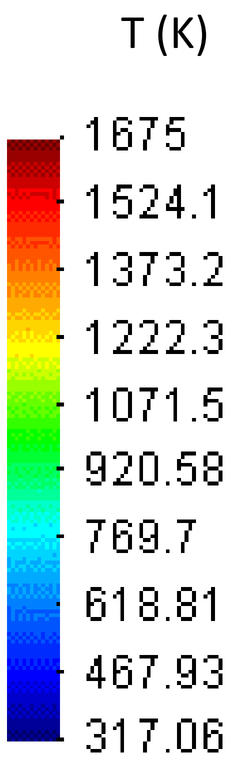
Melt pool prediction/ layer
Bulk sample

Depth 0.76 mm

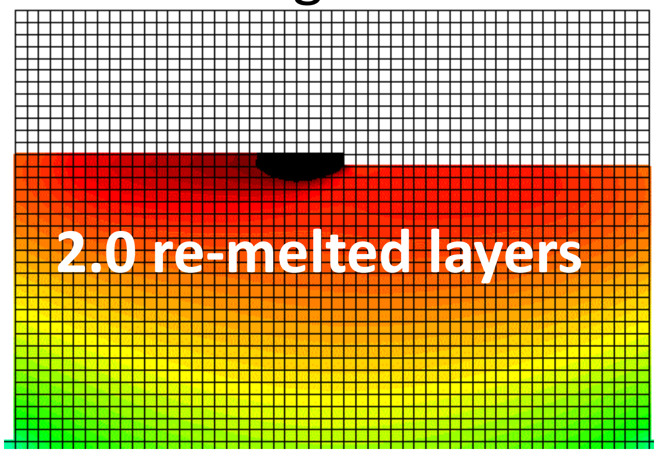


Depth 4.5 mm

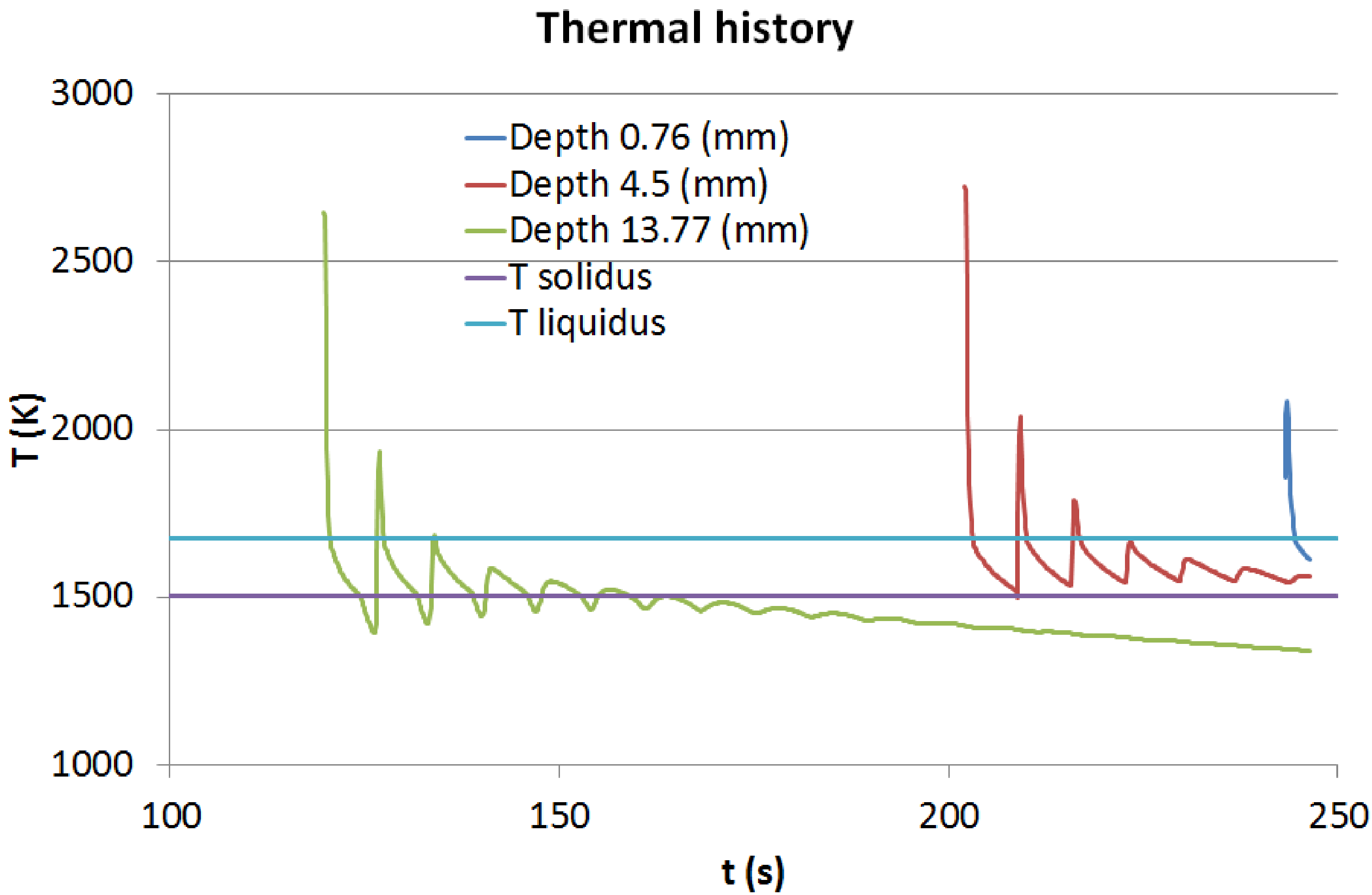




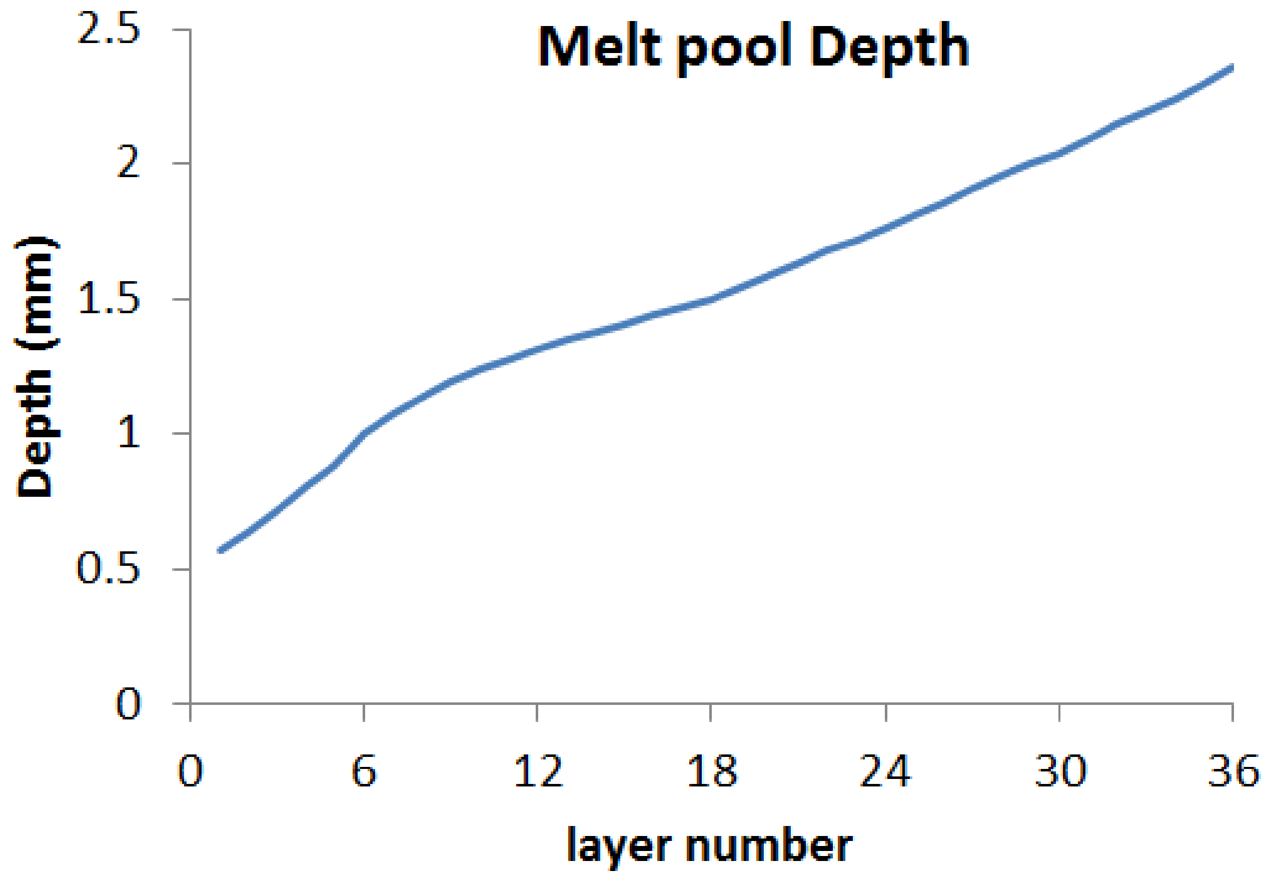
Mid Height - 13.77 mm



Predicted thermal field Bulk Sample

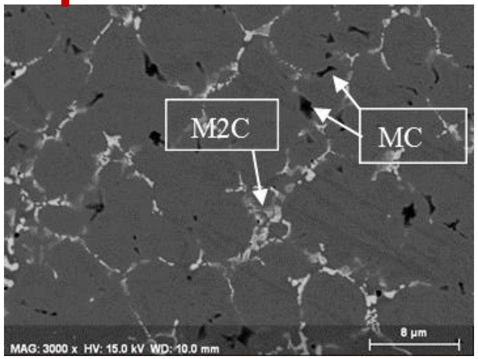


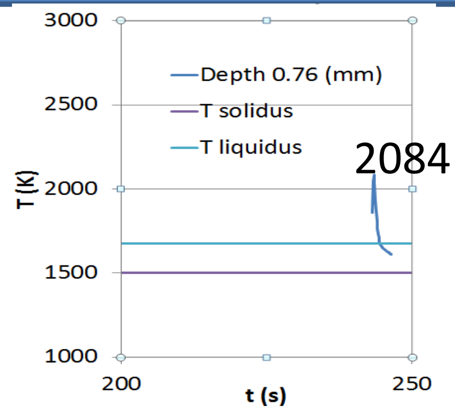
Melt pool prediction/ layer Bulk sample



Thermal field → microstructure

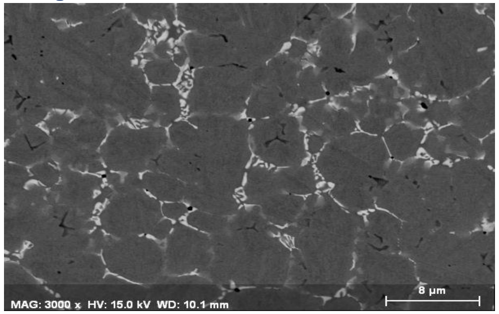
Depth 0.764 mm

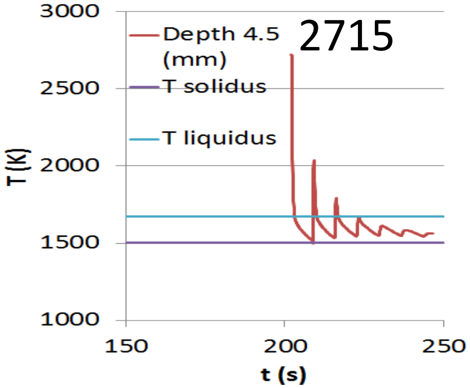




- VC primar angular carbides at maximum temperature
- Coalescence of VC → large massive angualar carbides (3 re-melting) → for this zone …

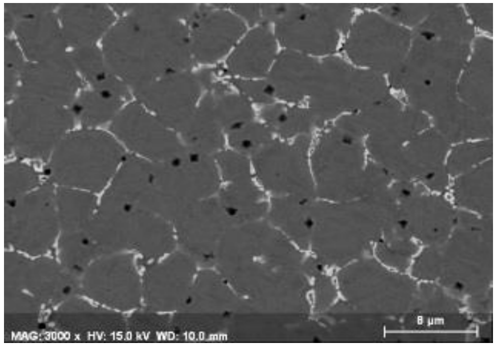
Depth of 4.5 mm

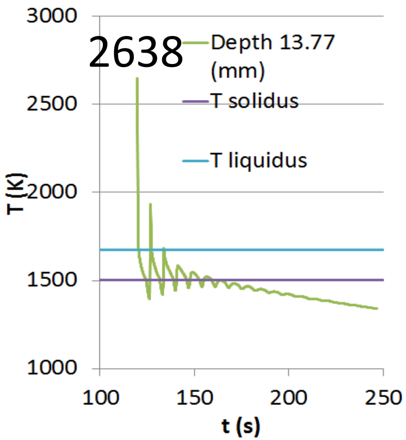




- VC eutectic carbides in coral shape because of 3 re-melting but higest super heating temperature

Middle height





- VC primar angular carbides at maximum temperature
- VC smaller because of lower number of remelting (2) even if higher temperature

Conclusion

- Microstructure heterogeneity in depth could be explained by FE thermal simulations
- Thermo physical properties need accurate measurements
- 2D model enough for bulk samples

NB - Similar type of work for Ti6AL4V repair by Laser cladding

Paydas,et al. **Materials and Design 2015.**

Tran et al. **Materials & Design 128 2017**

Future on M4

- Use predicted thermal field

  to optimize process parameters

  to keep constant melt pool size

→ more homogeneous microstructure

- Validation by measurements of residual stress field predicted by FE thermo mechanical model

For Single Point Incremental forming process I search a PHD student, please advertise