Sensitivity analysis of melt pool - Finite Element prediction in laser cladding process of HSS material

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Research goal
Prediction of melt pool size

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

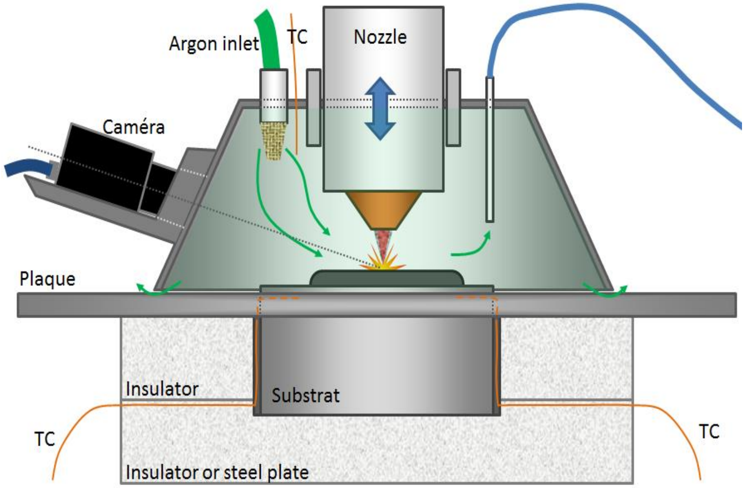
Particle size [50 to 150 µm]

For thick deposit,

Direct Energy Deposition DED process

or Laser cladding

→ heterogeneity in melt pool size in depth if no optimization



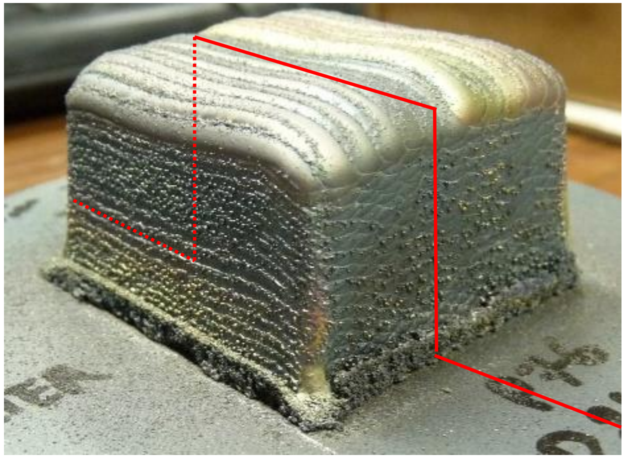
Material High Speed Steel M4

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

Thin and bulk samples

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

→**2D FE model**



40 x 40 x 27.5 mm **(972 tracks)**

Thermal equations

Heat transfer by conduction

Density

Heat Capacity

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

Power gen. per volume
(= 0)

Heat transfer at boundary

- $k(\nabla T.n) = q_{laser} - h(T - T_0) - \varepsilon\sigma(T^4 - T_0^4)$

Laser Power

Convection Coef.

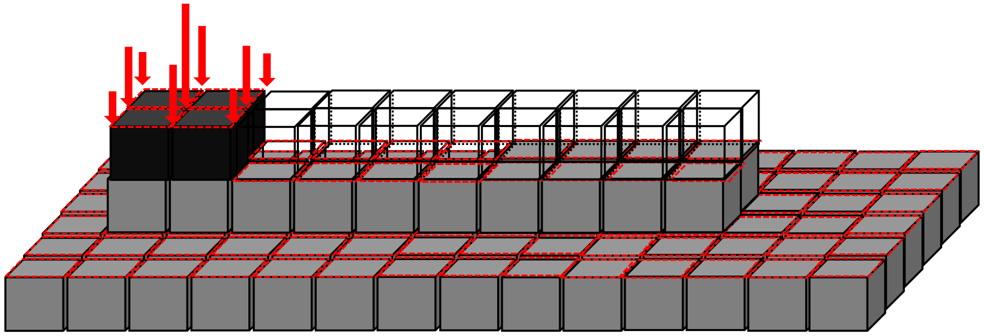
Emissivity

$$q_{laser} = \beta\, I(x, y, z, U, t)$$

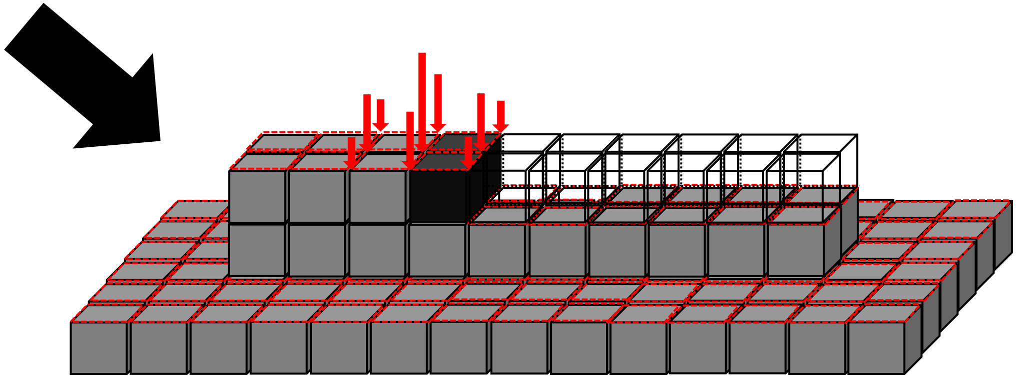
Latent heat of fusion

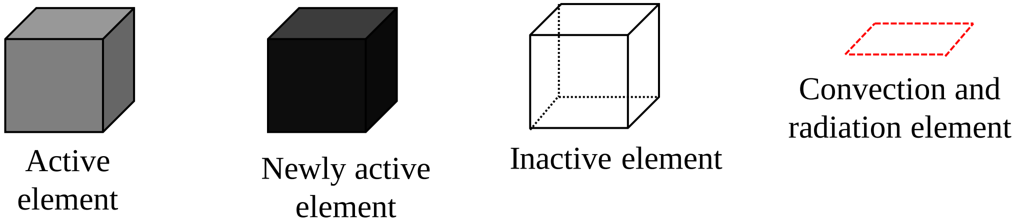
$$c_p^* = \frac{L_f}{TD - T_m} + c_p$$

Element birth technique



Bulk Sample 2D

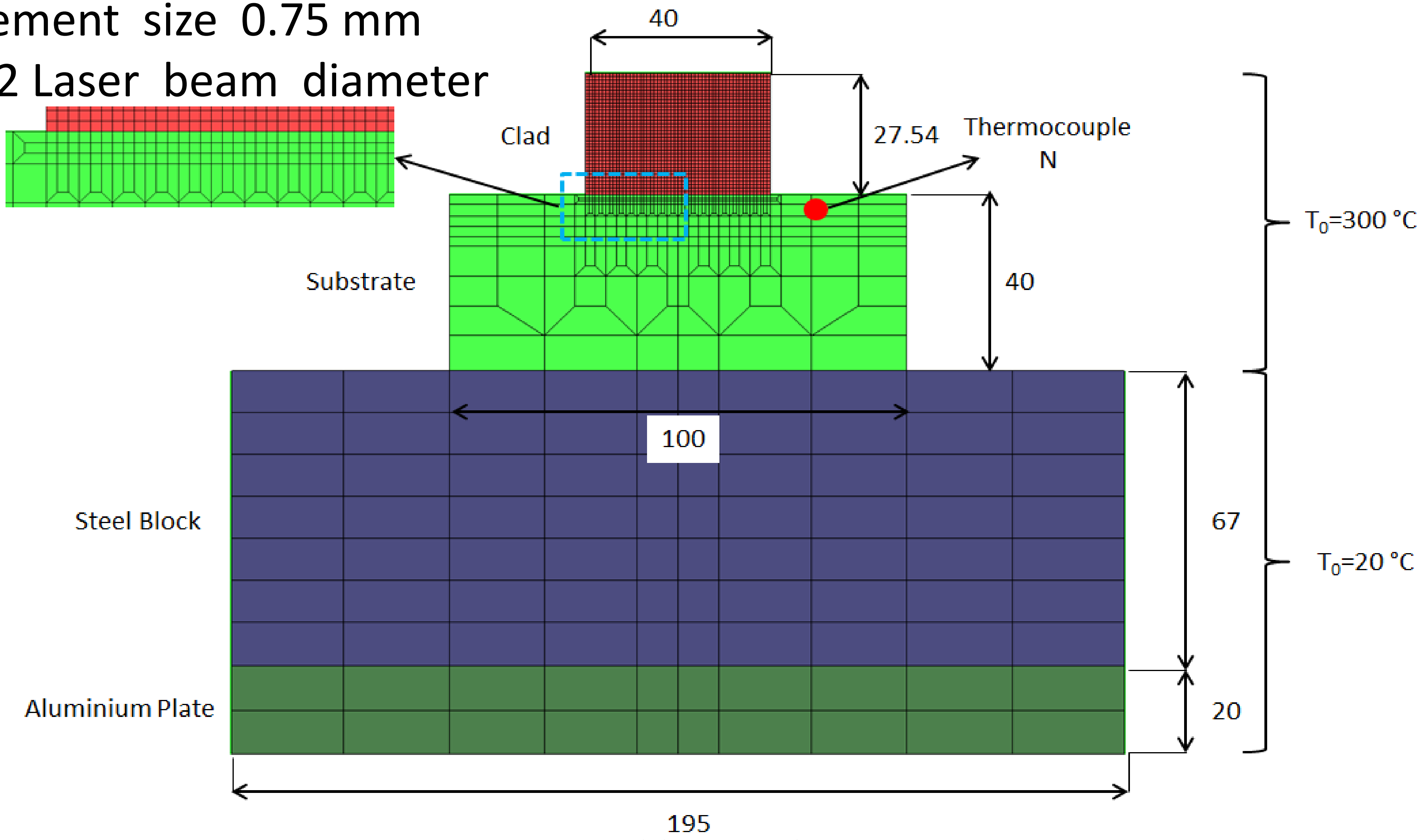




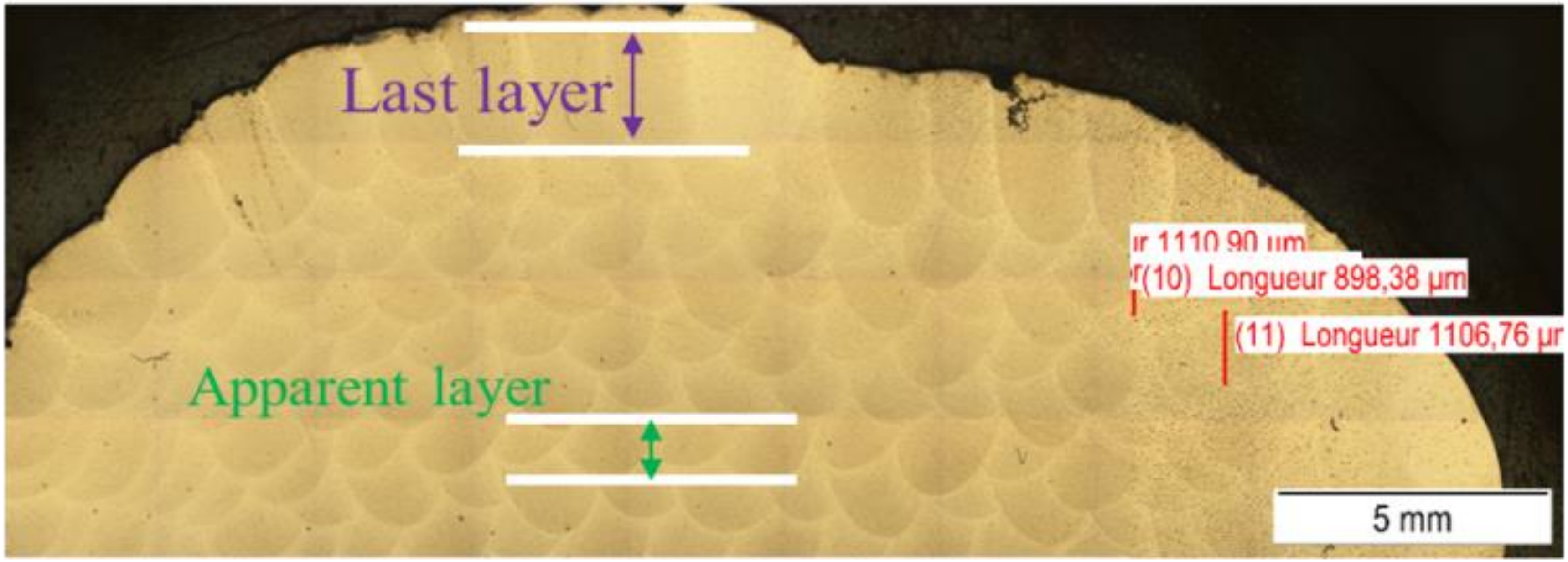
2D mesh (convergence analysis)

Element size 0.75 mm

1/2 Laser beam diameter



Experimental results -> FE Validation



Last layer melt pool depth: 2.3 mm

Average layer height: 0.76 mm

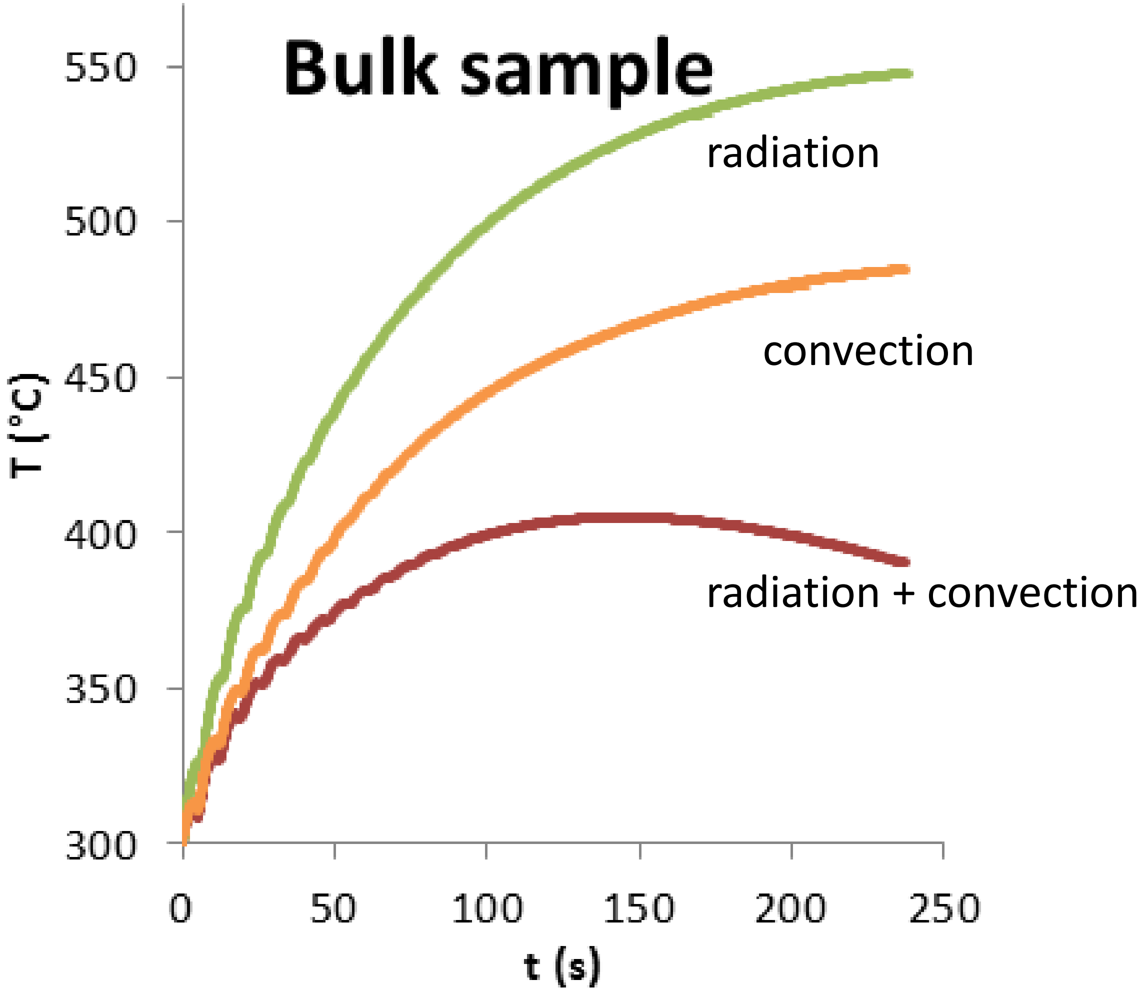
Parameters identification

- Fitting using the absorption factor of laser energy (β) and convection coef. (h);
- Calibration using thermal history and last layer melt pool depth

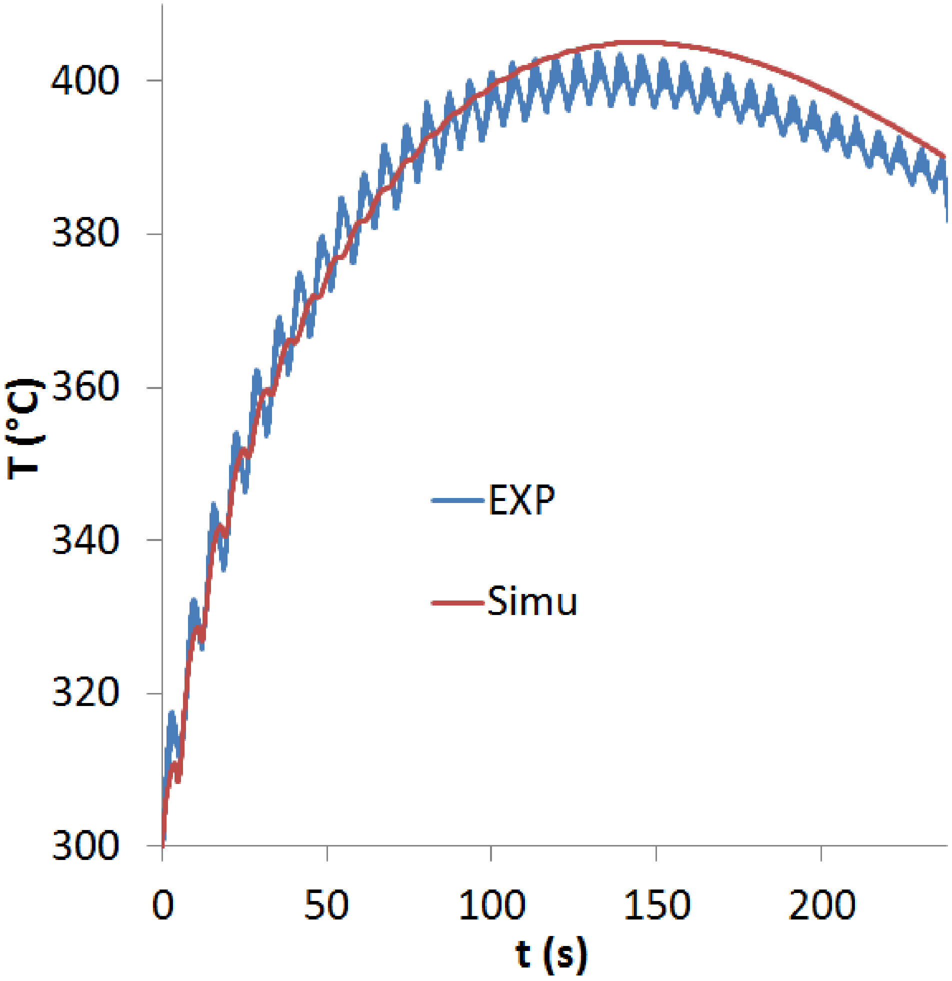
Simulation Parameters (boundary conditions)

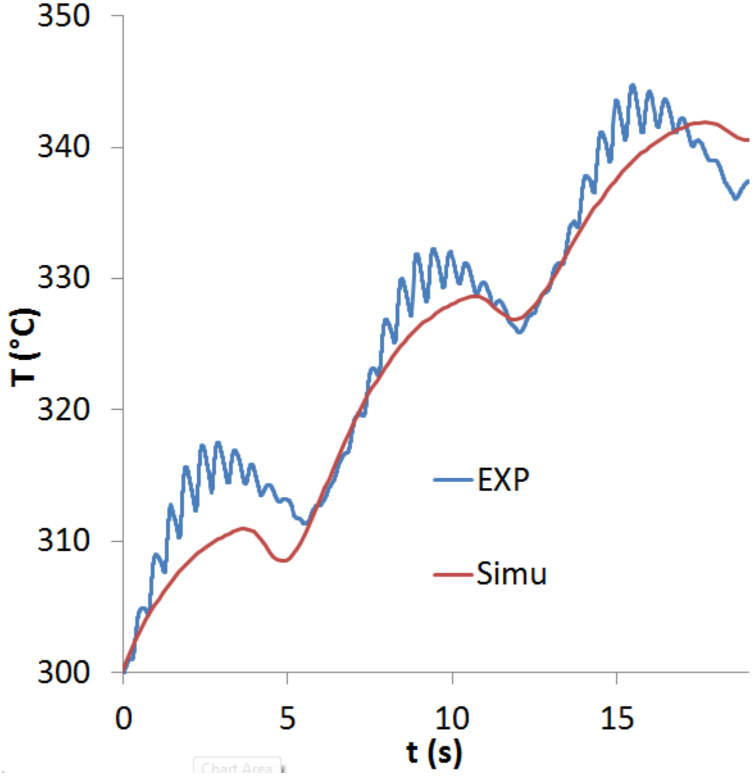
	Convection (h) (W/m^2K)	Emissivity (ε)	Absorption factor (β)
Set	230	1	0.067

Key heat transfers?



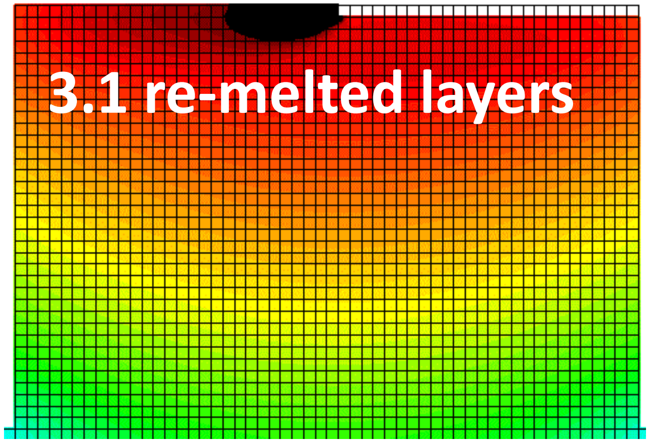
Model Validation



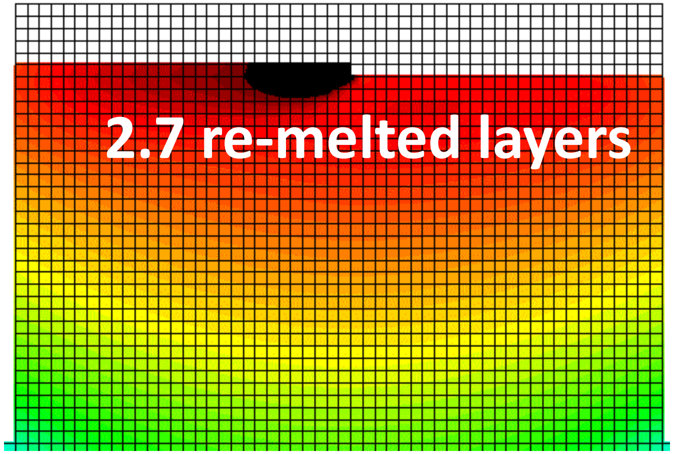


Melt pool prediction/ layer
Bulk sample

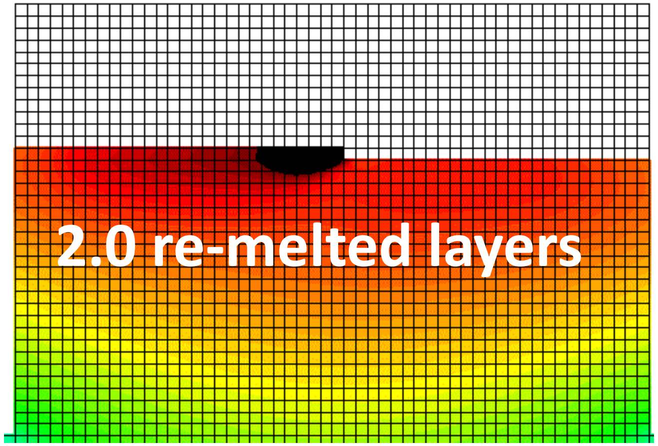
Depth 0.76 mm

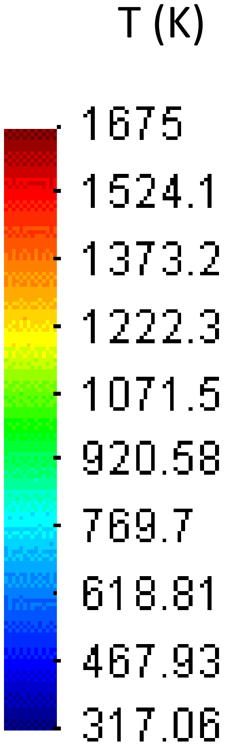


Depth 4.5 mm



Mid Height - 13.77 mm





Sensitivity analysis

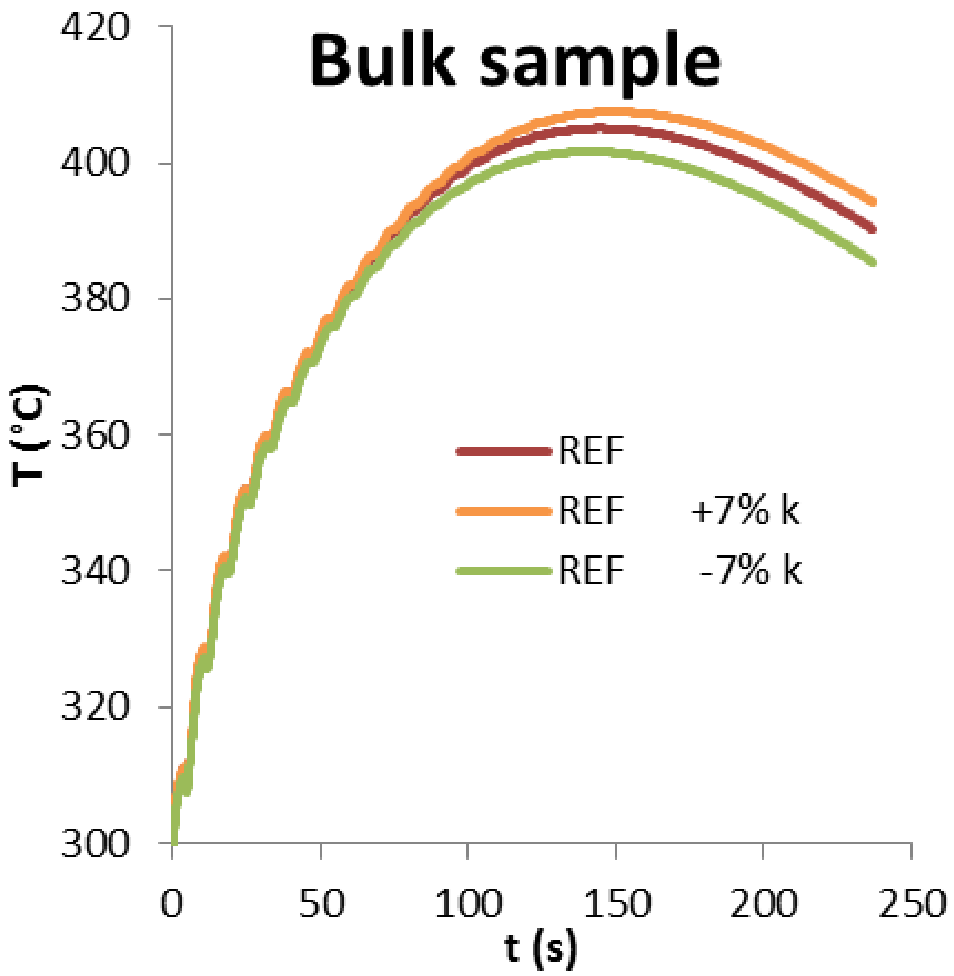
- Measured Thermo-physical parameters: **k** (±7%) **$\rho.c_p$** (±3.6%) L_f

- A sensitivity analysis of **melt pool size** and **thermal history** to **conductivity** and **heat capacity**

- Which parameter is key?

- Is it relevant to analyse the measurement errors in the model?

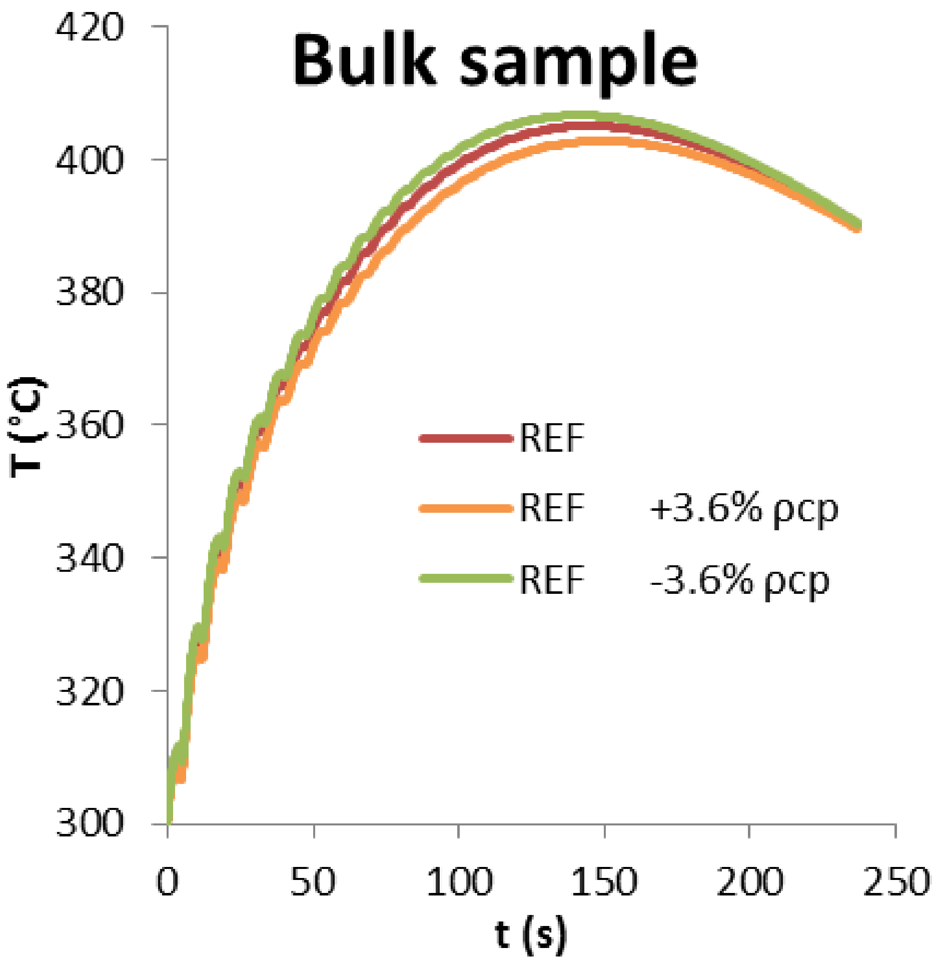
Sensitivity to conductivity k



- Equilibrium at 150 s
- 22 layers
- $q_{laser} = q_{conv} + q_{rad}$

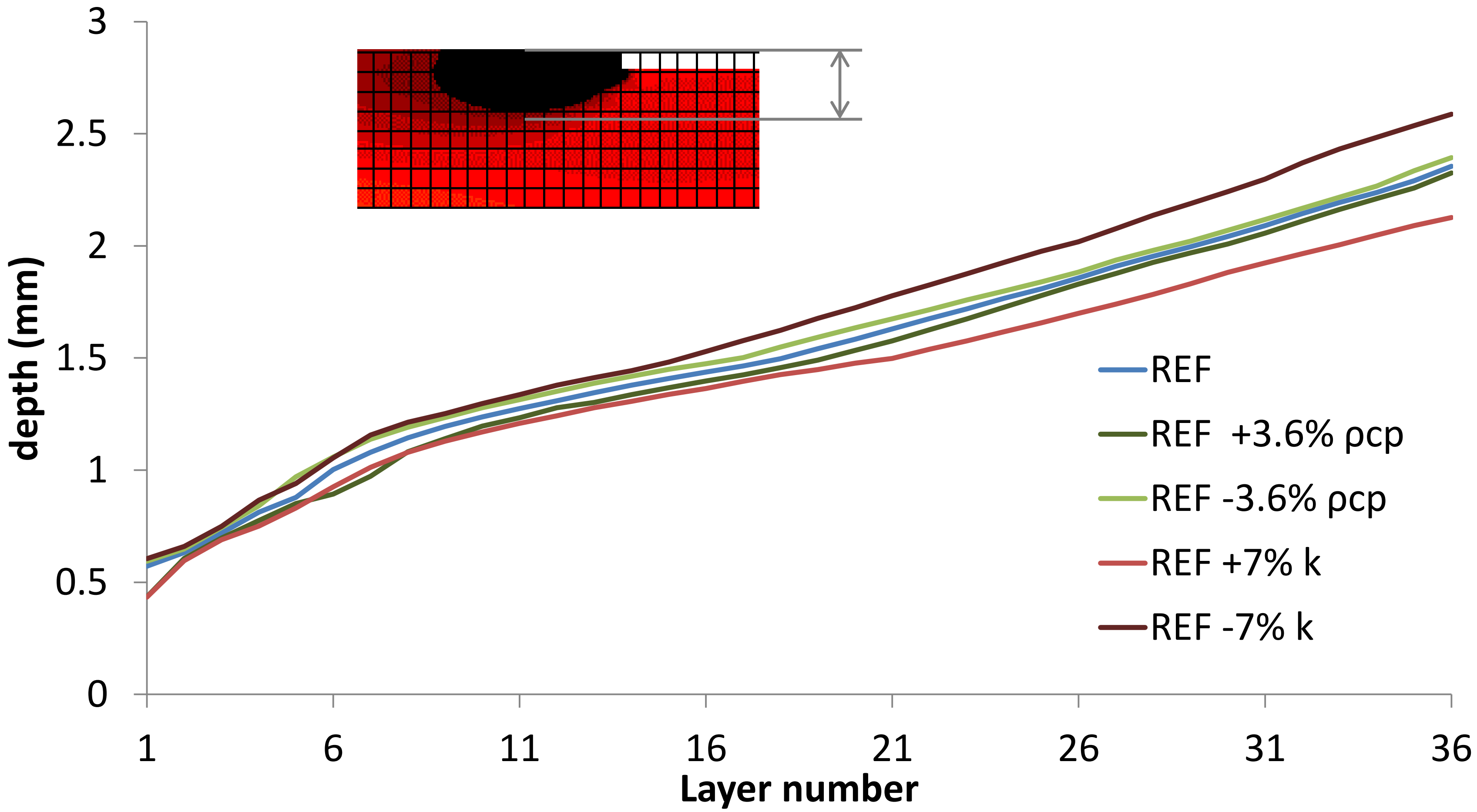
- Maximum difference = 9 °C

Sensitivity to heat capacity ρc_p



- Long time to generate a layer
- Strong convection
- Maximum difference = 4 °C

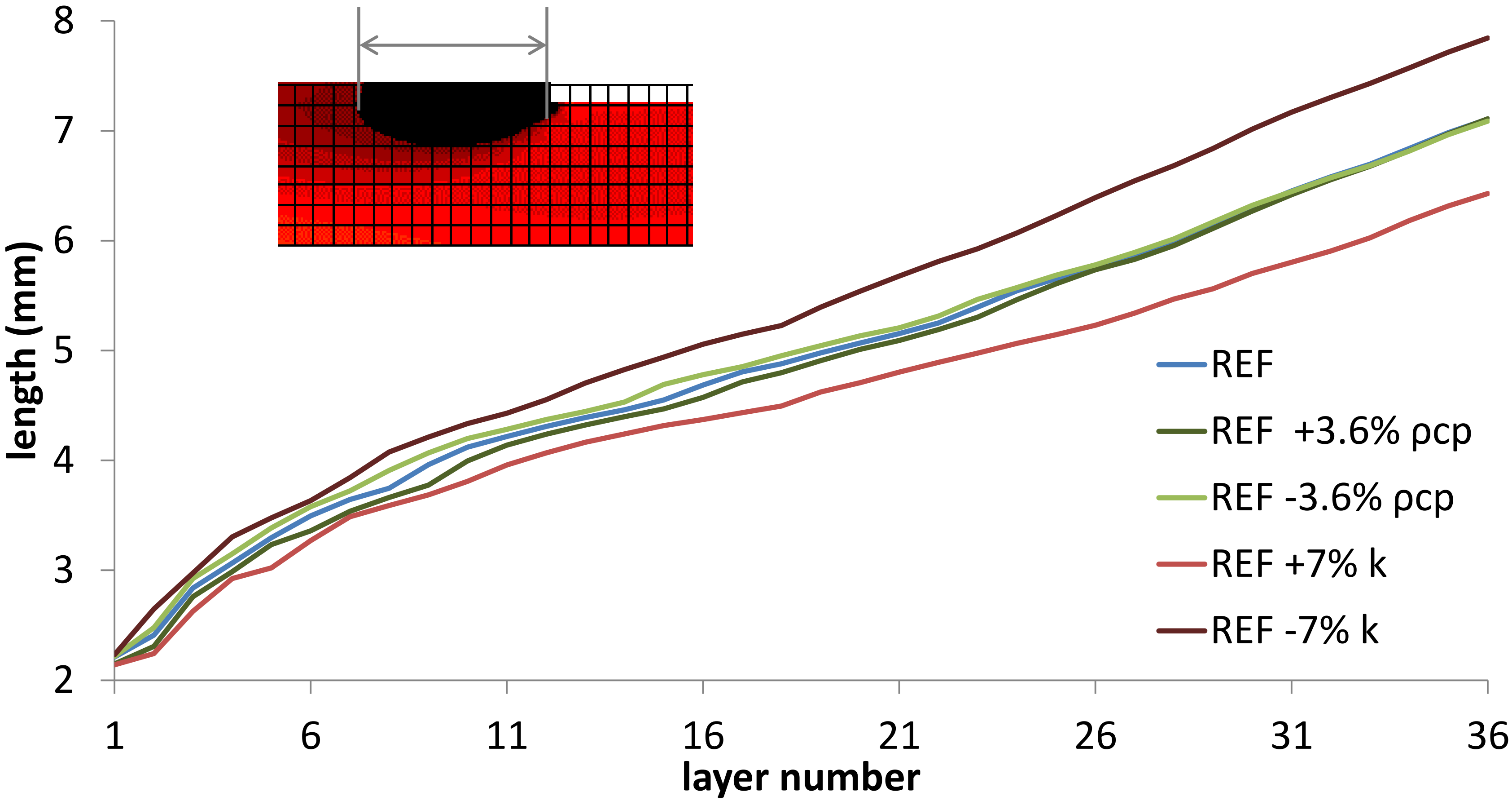
Melt pool depth prediction/ layer Bulk sample



Difference +7% k to -7% k = 0.46 mm (0.6 layer)

Layer height = 0.76 mm

Melt pool lenght prediction/ layer Bulk sample



Difference +7% k to -7% k = 1.41 mm
Impact in amount of material added

Conclusion

- Thermo physical properties need accurate measurements
- Critical to use temperature dependent properties and analyse the impact of measurement error
- 2D model enough for bulk samples

Future on M4

- Use predicted thermal field
  to optimize process parameters
  to keep constant melt pool size
  → more homogeneous microstructure

Questions?

Thank you for your attention!