DIRECTION DES ÉNERGIES
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Numerical prediction of layer composition for multi-material Directed Energy Deposition

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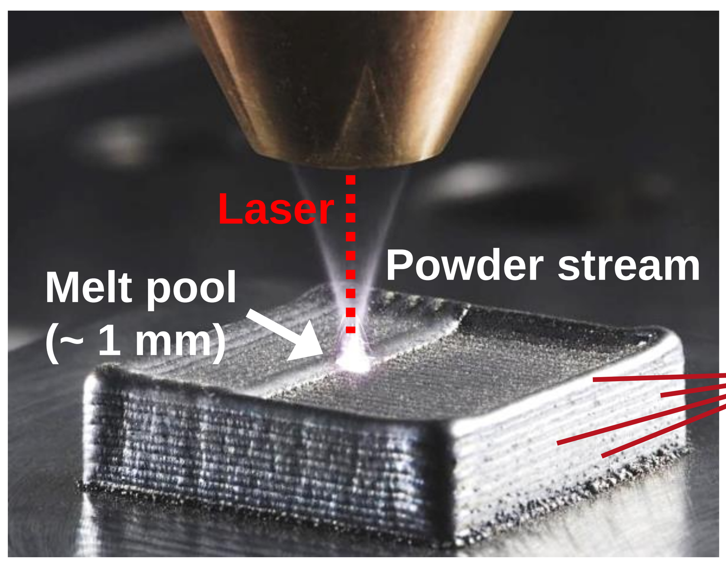
Directed Energy Deposition of metals



Additive manufacturing by DED (Directed Energy Deposition) [Trumpf]

- 3D **fabrication**, **repair**, **coating**
- **Dense** and strong deposits
- **Complex** physic and parameters selection

Multi-material possibilities by varying the injected powder:
- multi-material **structures**
- material **gradient**
- local and in-situ **alloying**

Goals for a multi-material simulation

Understanding of phenomena and defects

Parameters ↔ deposit characteristics

Managing the **complexity** of multi-material DED
- Given parameters → characteristics **prediction**
- Desired characteristics → parameters **optimization**

An efficient stationary model at the melt pool scale

Inputs
- Laser, Powder stream
- Powder and substrate **properties** f(T, wt%)
- Translation velocity, Hatching Distance

Outputs
- Melt pool and layer **dimensions**
- Feedstock **efficiency**
- Layer **composition**
- Temperature and velocity

Melt pool physic (with Comsol®)

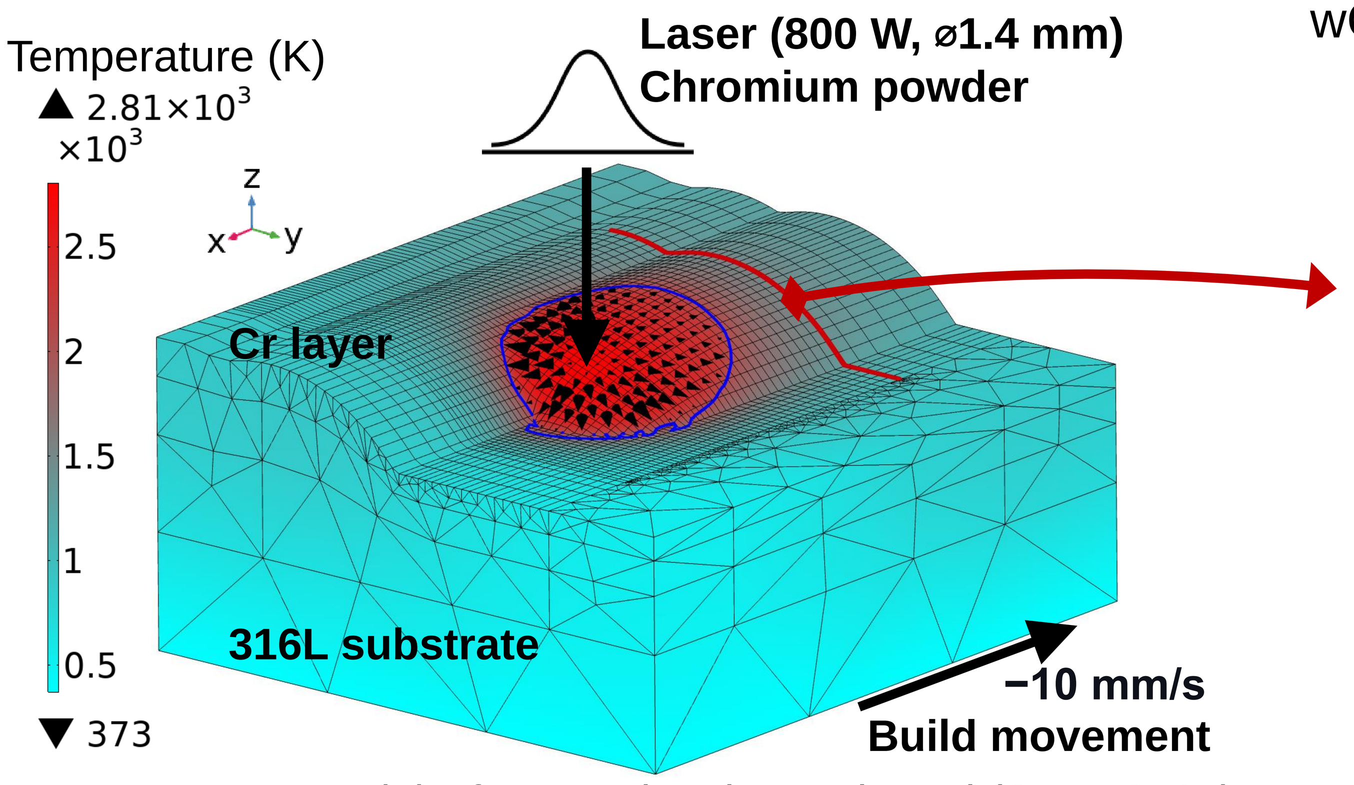
Thermal (T)
- Conduction
- Advection f(**v**)
- Laser input

Fluid (v)
- Navier-Stokes
- Turbulence RANS v²-f
- Marangoni f(**T**, **wt%**)

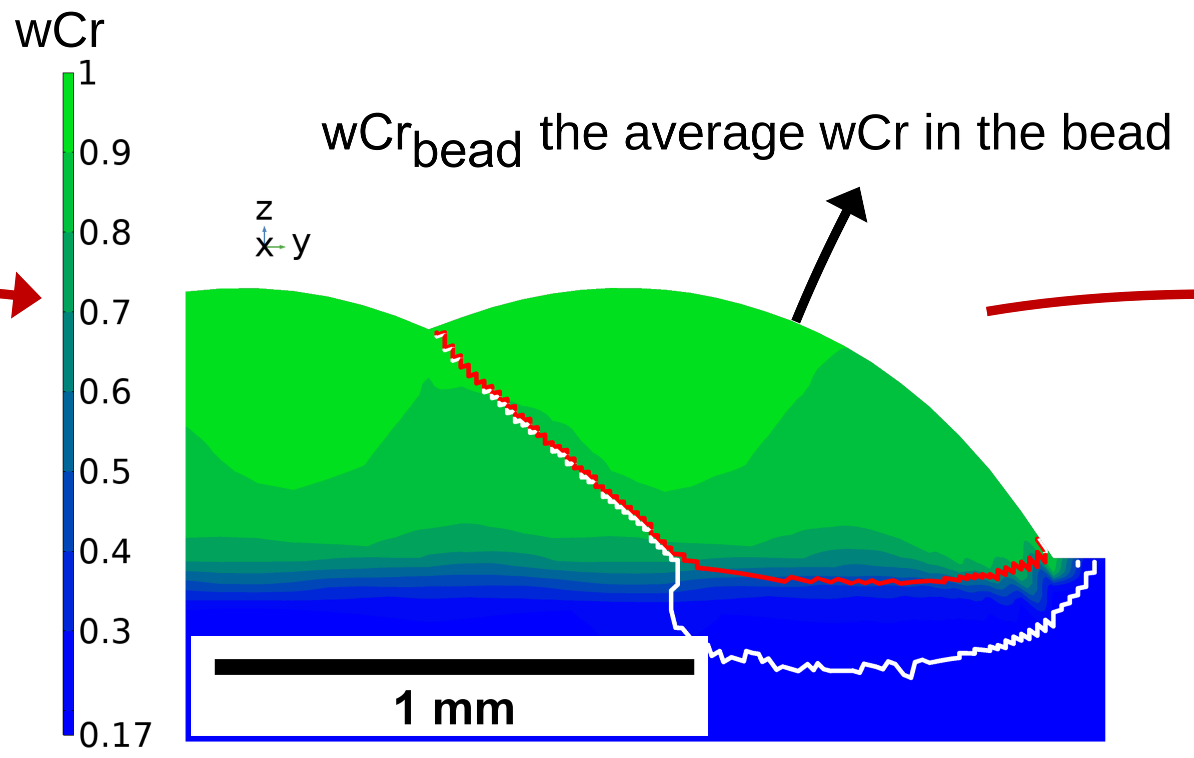
Composition (wt%)
- Conduction
- Advection f(**v**)
- Powder inflow

Free surface (ϕ)
- Equilibrium of Forces
- Surface tension
- Fluid stresses f(**v**)

Numerical realization
- Fluid cancelling at $T_{L_{bead}}$ to accelerate convergence:
  $T_{L_{bead}} = (w1_{bead}) * T_{L_1} + (1 - w1_{bead}) * T_{L_2}$
  with $w1_{bead}$ the mean wt% of material 1 in the bead
- Fast free surface by deforming the mesh in z only:
  $dz = \phi * (1 - (-z_0)/(domain\ thickness))$
- **Fast solution (25 min**) after a first step (5 min) with:
  - coarse mesh
  - uniform wt% in the bead: $w1_{bead} = \frac{layer\ height}{pool\ thickness}$
  - uniform turbulence: $\mu_{turbulence} = 0{,}0004 * \overline{U}_{pool} * L_{pool}$



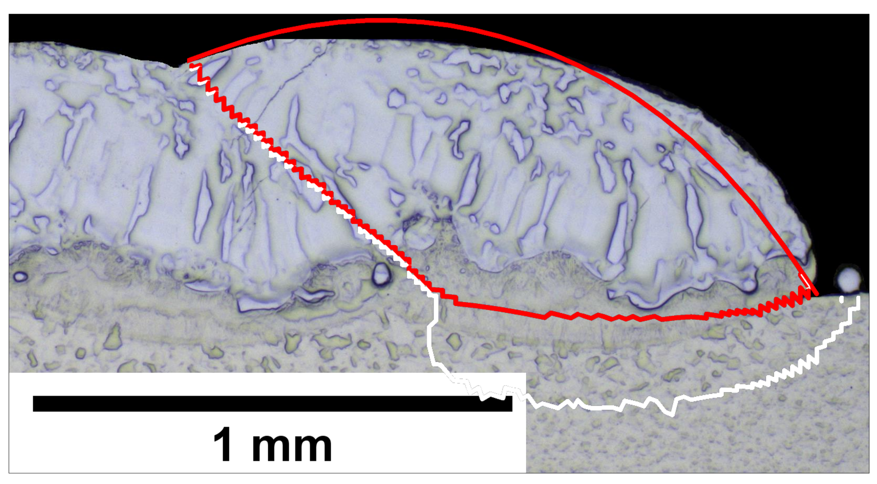
Temperature (K) of an overlapping melt pool (Cr on 316L), velocity vectors at the melt pool surface, and local T_L contour (blue)



Solidified cross-section with Cr mass fraction wCr, $T_{L_{bead}}$ contour (red), and local T_L contour (white)

wCr_{bead} experimental = 98±1%

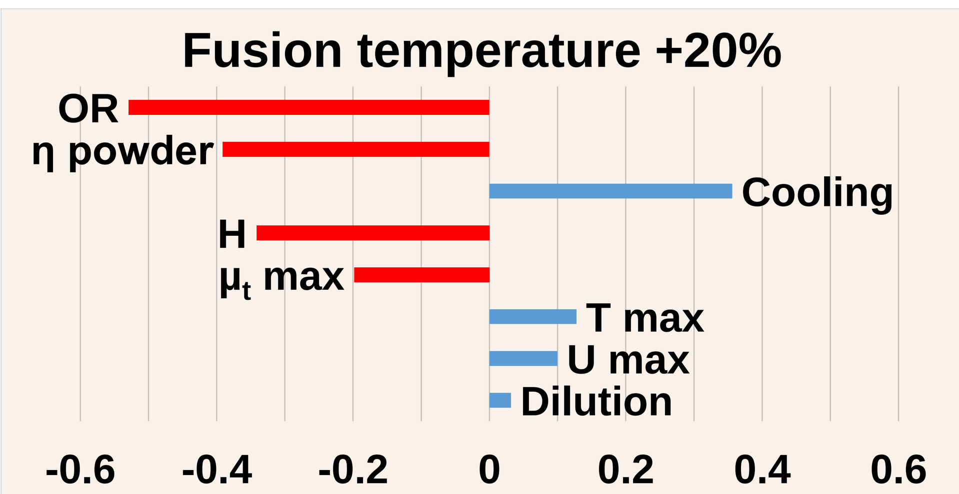
wCr_{bead} simulation = 93%

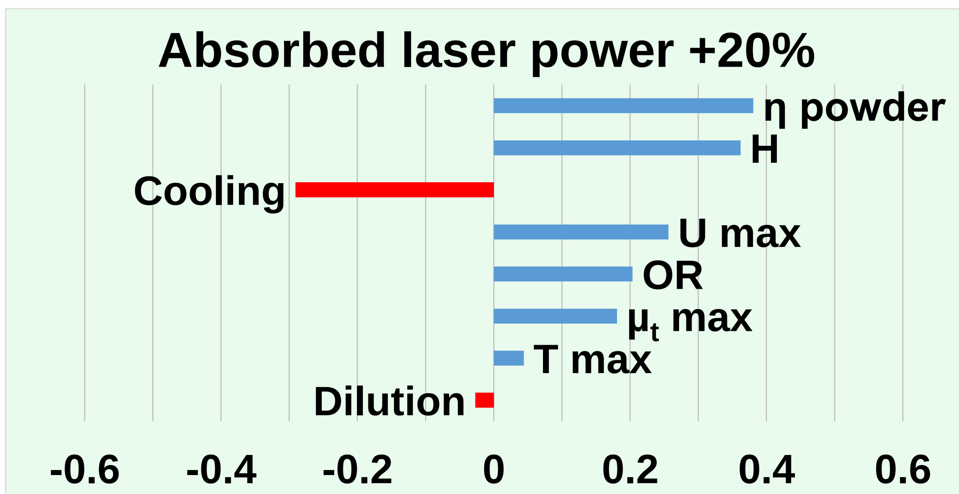


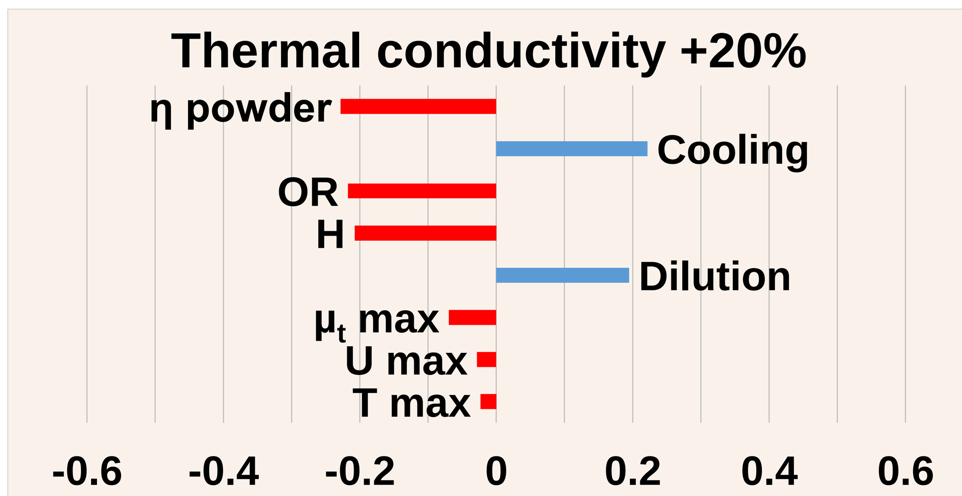
Experimental cross-section of the last bead of one layer, with calculated $T_{L_{bead}}$ (red), and local T_L (white)

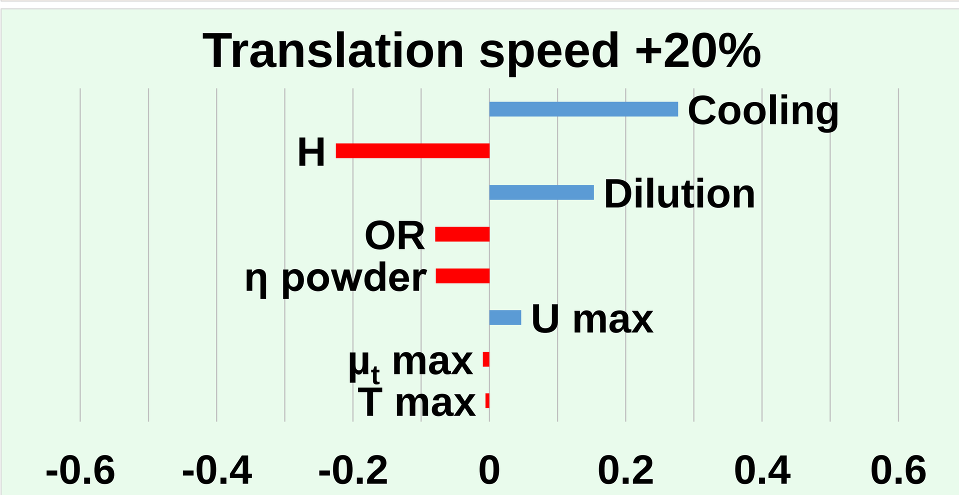
Sensitivity analysis of the model, 6 most influent inputs

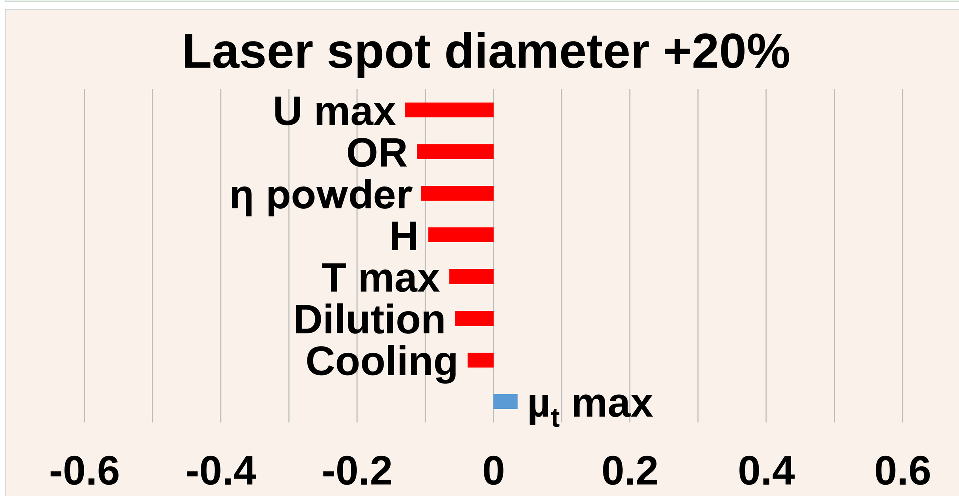
Selected outputs		Initial
OR	Bead overlapping ratio	36%
H	Bead height (mm)	5.6
η powder	Powder efficiency	13%
Dilution	Dilution with substrate	7%
Cooling	Solidification cooling rate (K/s)	6606
T max	Max temperature (K)	2801
U max	Max fluid velocity (m/s)	2.0
μ_t max	Max turbulent viscosity (Pa·s)	0.035

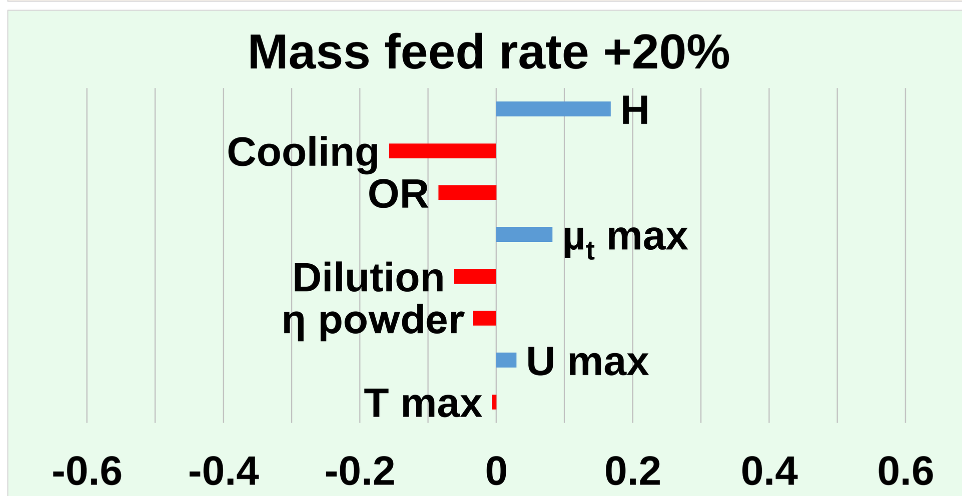












- Melt pool **dimensions** and **Cooling rate**: very sensitive
- ↗**Fusion temperature** with same Power: ↗**T max**
- Fluid **velocity** and **turbulence** ↗ when ↗ **Power**
- Need to measure **laser and powder distributions**
- Need accurate data for **Fusion temperature and Thermal conductivity**, a **challenge** for multi-material fabrications

Conclusion

Fast solution (30 min on a desktop work station) of the melt pool during **multi-material DED** of multi-bead fabrication

- **Sensitivity analysis**: sensitive outputs, influent inputs
- Parameter **optimization** capabilities (power, feed rate)