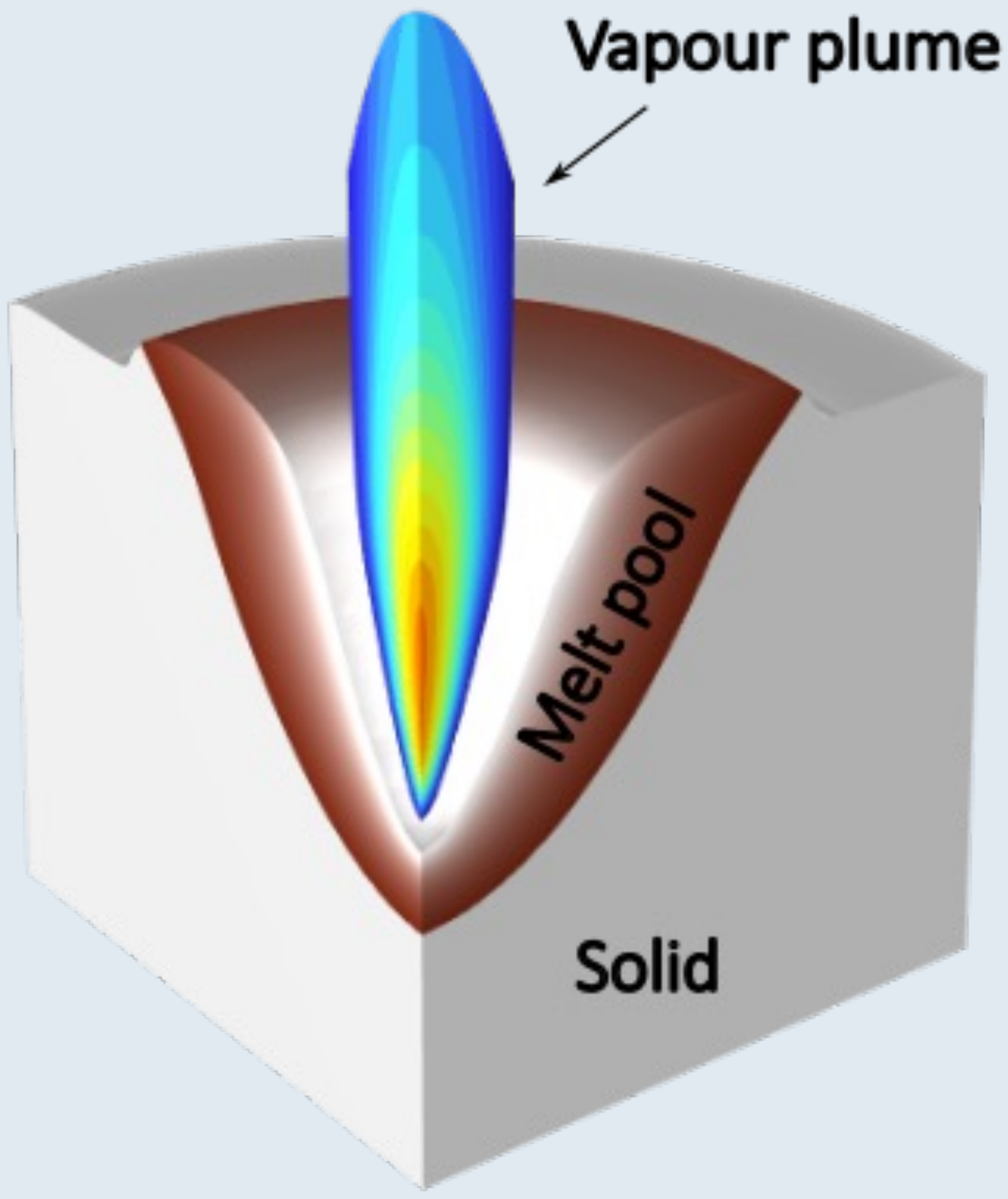

Numerical and Experimental Study of Melt Instabilities During Spot Laser Welding of Aluminium

Study melt instabilities and resulting porosities using a simple model. Two new ideas concerning the vaporisation simulation and the Level Set method.

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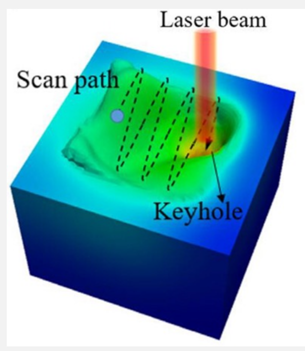
Introduction and Goals

- Increasing need to weld reflective materials such as aluminium.
- Development of new laser technologies (beam shaping).
- How to choose optimal laser parameters and control the process?



⟹ Need to develop a simple but accurate model for prediction.

Main Physics

Level-Set transport

$$\frac{\partial \phi}{\partial t} + \vec{u}.\vec{\nabla}\phi - \dot{m}\left(\frac{1-\phi}{\rho_v} + \frac{\phi}{\rho_l}\right)\delta(\phi) = \gamma_{ls}\,\vec{\nabla}.\left(\epsilon_{ls}\,\vec{\nabla}\phi - \phi(1-\phi)\frac{\vec{\nabla}\phi}{|\vec{\nabla}(\phi)|}\right)$$

Heat transfer

$$\rho c_p^{eq}\left[\frac{\partial T}{\partial t} + \nabla\cdot(\vec{u}\,T)\right] = \nabla\cdot(k\,\nabla T) + \left(q_{laser} - q_{evap}\right).\delta_1(\phi)$$

Optimisation of energy deposition in the metal : $\delta(\phi) \longrightarrow semi\ Dirac\ \delta_1(\phi)$

Fluid mechanics

$$\vec{\nabla}\cdot(\vec{u}) = \dot{m}\left(\frac{1}{\rho_v} - \frac{1}{\rho_l}\right)\delta_2(\phi)\ [1]$$

$$\rho\left(\frac{\partial \vec{u}}{\partial t} + (\vec{\nabla}\vec{u}).\vec{u}\right) = \vec{\nabla}.\left[-pI + \mu\left((\vec{\nabla}.\vec{u}) + (\vec{\nabla}.\vec{u})^T\right)\right] - \rho\beta(T - T_f)\vec{g} + K(T)\vec{u} + \sigma(T)\kappa\vec{n}\delta(\phi)$$

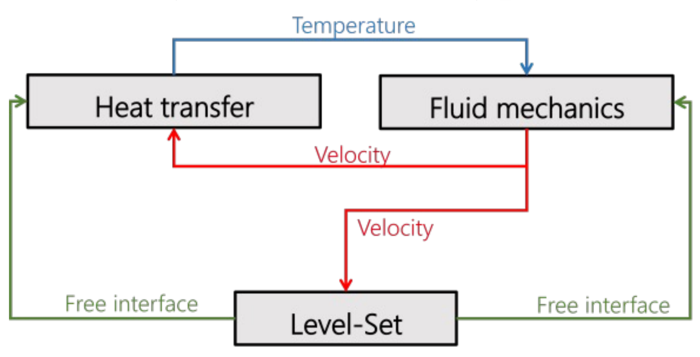


FIGURE 1. Coupling scheme.

Two New Ideas

Mass-conserving method

A corrective source term is added to mass conservation equation

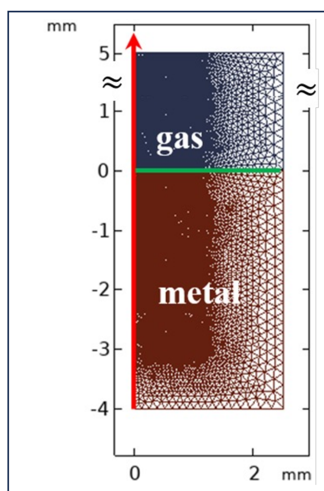
$$Q_{corr} = \eta_1 |m_0 - m(t)|.(\phi > 0.5)$$

Vaporisation and plume velocity

An external force is added to momentum equation

$$\vec{F}_{forcing} = \eta_2 \frac{m}{\rho}\vec{n}.(\phi \le 0.5)$$

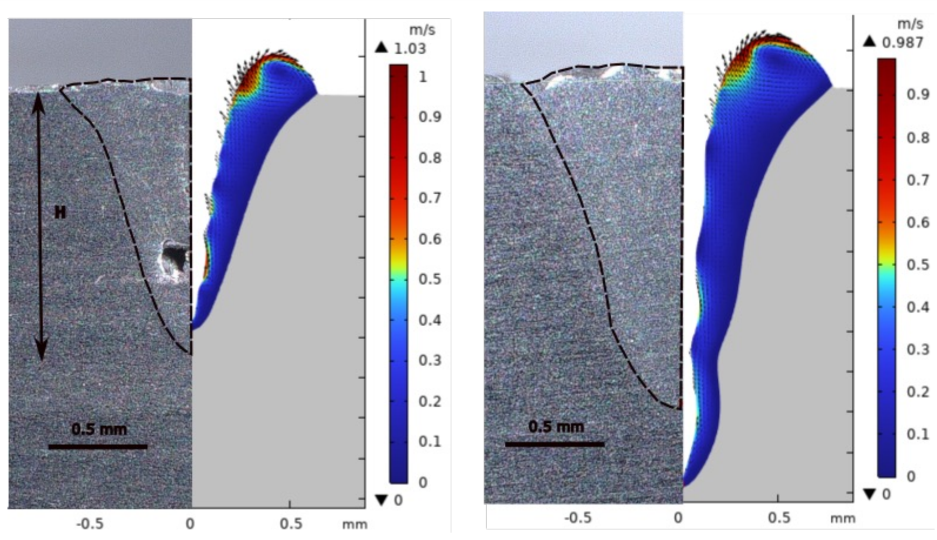
Numerical Configuration



→ 20 µm in CFD domain, 200 µm elsewhere
→ PARDISO solver, segregated approach
→ Time step : 2 µs
→ Computation time : 85 min/ ms of process

FIGURE 2. Meshing.

Validation of the Model



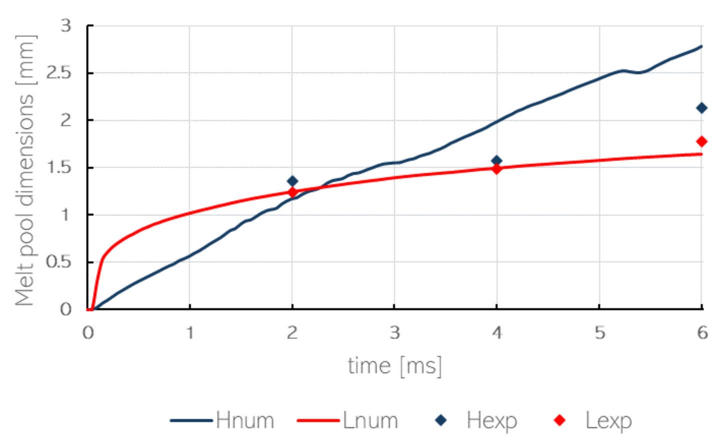


FIGURE 3.
Exp. vs Model
H = Depth
L = Diameter
P_{laser} = 4 kW

Melt Pool Dynamics

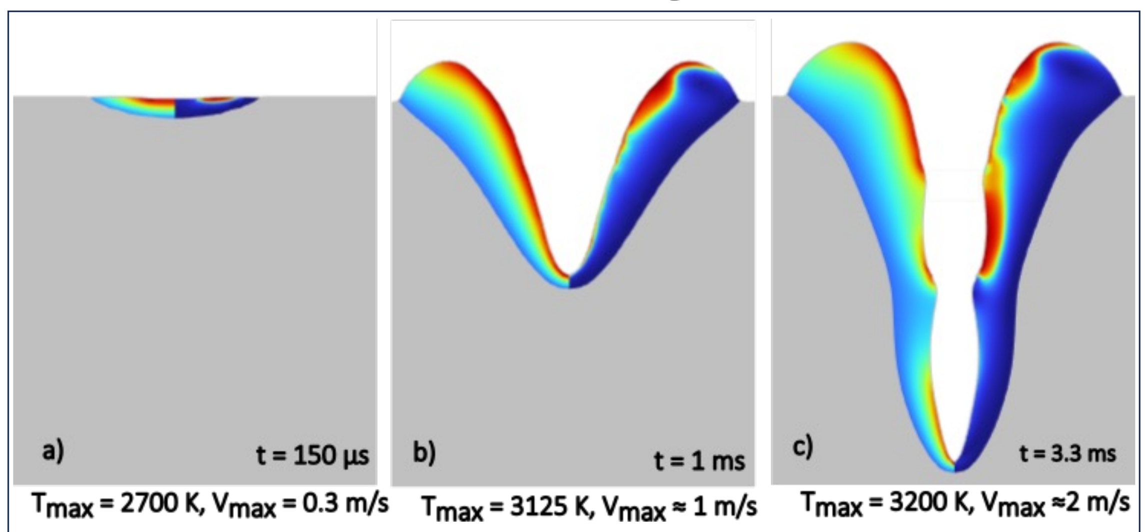


FIGURE 4. Dynamics of the melt pool. **Conduction** (a), **keyhole** (b), and **unstable keyhole** regime (c).

Formation of a Porosity

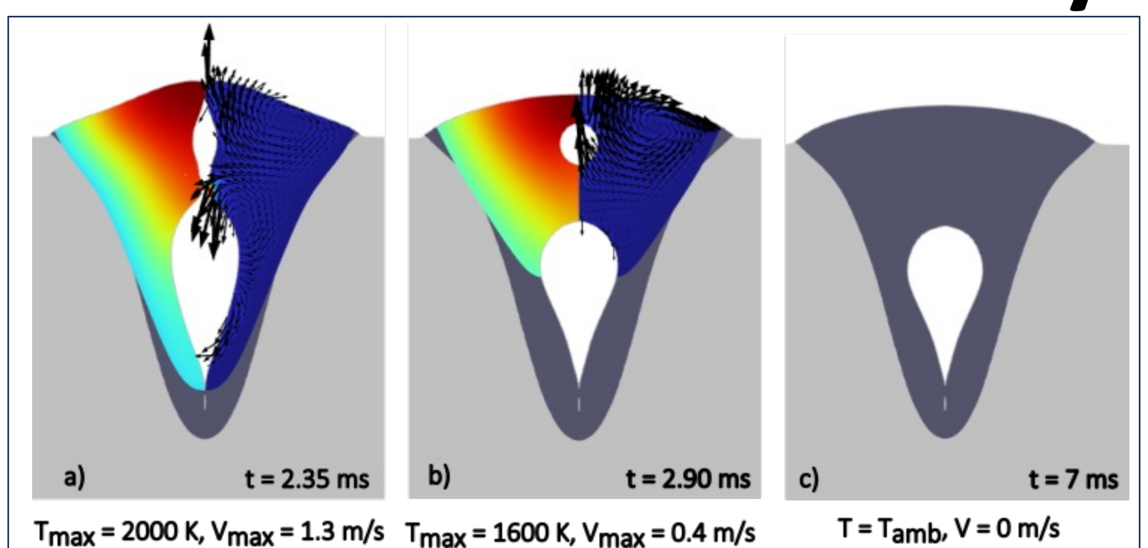


FIGURE 5. Mechanism of porosity formation. **Keyhole collapse** and gas bubbles formation (a), **bubbles floating** (b), and **residual porosity** (c).

Conclusions - Perspectives

→ Satisfying model. To be upgraded to 3D geometry + multiple reflections calculation
→ Need to beam shaping for melt instabilities control [2]

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