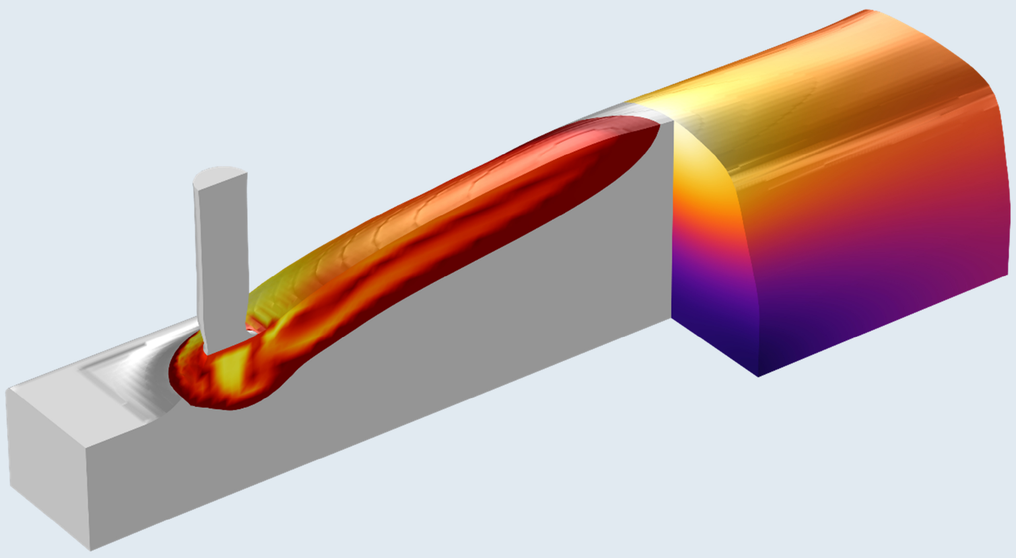

Two-Scale Modeling of the WAAM Process: Link Between Thermo-Hydrodynamics and Solid Mechanics

Predict distortions/residual stresses induced by wire-arc additive manufacturing process (MAG-CMT) based on process parameters

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Introduction and Goals

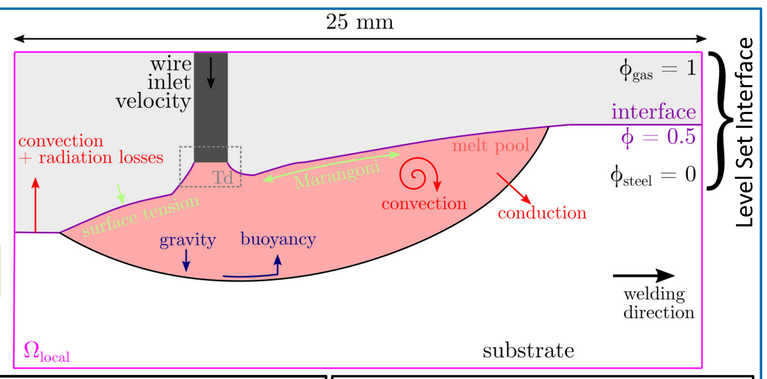
WAAM: manufacturing parts by molten metal deposition induce distortions/residual stresses → Numerical modelling: predict distortions/residual stresses of a part build of 316L stainless steel only based on process parameters (**no volume heat source**)

Multiscale Modeling with Scale Transition

Melt Pool scale (~25 mm) :

Material properties — Level Set — Material properties

Fluid Flow ⇄ Temperature / Velocity ⇄ Heat Transfer



Fluid Flow

Mass and momentum conservation

$$\frac{\partial \rho}{\partial t} + \mathrm{div}(\rho \vec{v}) = 0$$

$$\rho \left[\frac{\partial \vec{v}}{\partial t} + \mathbf{grad}(\vec{v}) \cdot \vec{v} \right] = \vec{\mathrm{div}} \left[-P\, \underset{\sim}{\mathbf{Id}} + \mu_{eq} \left(\mathbf{grad}(\vec{v}) + {}^{t}\mathbf{grad}(\vec{v}) \right) - \frac{2}{3} \mu_{eq}\, \mathrm{div}(\vec{v})\, \underset{\sim}{\mathbf{Id}} \right] + \vec{F}_v$$

Level Set

Transport equation

$$\frac{\partial \phi}{\partial t} + \vec{v} \cdot \vec{\mathrm{grad}}(\phi) = \gamma_{ls} \vec{\mathrm{div}} \left[\varepsilon_{ls} \vec{\mathrm{grad}}(\phi) - \phi(1-\phi) \frac{\vec{\mathrm{grad}}(\phi)}{|\vec{\mathrm{grad}}(\phi)|} \right]$$

Material properties

$$\rho = \rho_{steel} + (\rho_{gas} - \rho_{steel}) \times \phi$$

Heat Transfer

$$\rho C_p^{eq} \left(\frac{\partial T}{\partial t} + \vec{v} \cdot \vec{\mathrm{grad}}(T) \right) = \mathrm{div}(\vec{q}) + Q$$

$$\vec{q} = \underset{\sim}{\boldsymbol{\lambda}}\, \vec{\mathrm{grad}}(T)$$

Heat Input : Dirichlet condition
→ imposed temperature Td = 2500 K
(*Pointwise Constraint operator*)

Scale Transition

Part scale (~130 mm) :

Heat Transfer → Temperature → Solid Mechanics

Heat Transfer

$$\rho C_p^{eq} \frac{\partial T}{\partial t} = \mathrm{div}\left(\underset{\sim}{\boldsymbol{\lambda}}^{eq}\, \vec{\mathrm{grad}}(T) \right) + Q$$

Thermal field from melt pool scale used as input
General Extrusion + Pointwise Constraint + Withsol operators

Material addition

Level Set interface from melt pool scale used as input
General Extrusion + Withsol + Activation operators

Solid Mechanics

Strain partition (small-strain assumption):

$$\varepsilon = \varepsilon^{e} + \varepsilon^{th} + \varepsilon^{vp}$$

elasticity — *thermal expansion*

Lemaitre-Chaboche visco-plastic model [1]:

$$\dot{\varepsilon}^{vp} = \left\langle \frac{|\sigma - X| - \sigma_y - R}{K} \right\rangle^{n} \mathrm{sign}(\sigma - X) \text{ if } |\sigma - X| > (\sigma_y + R)$$

Linear brick element with reduced integration

Experimental setup: Cambon's study on WAAM (316L) [2]

Results – Melt Pool Scale

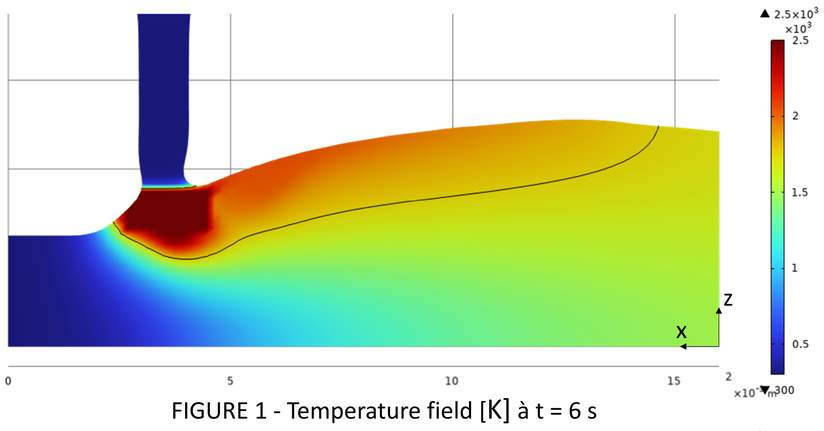


FIGURE 1 - Temperature field [K] à t = 6 s

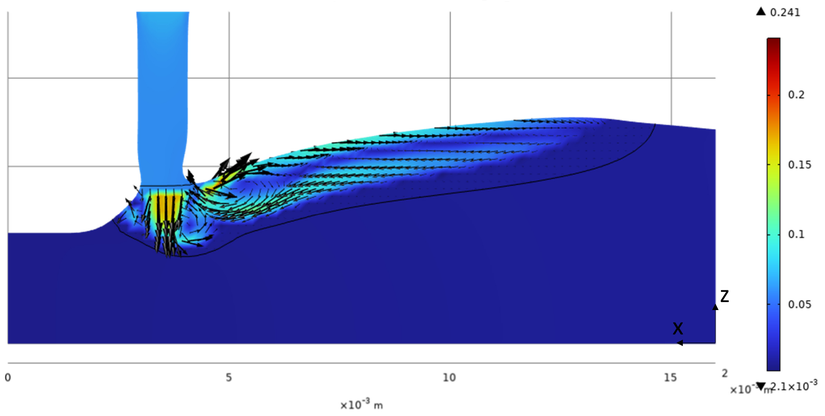


FIGURE 2 - Fluid velocity field [m/s] à t = 6 s

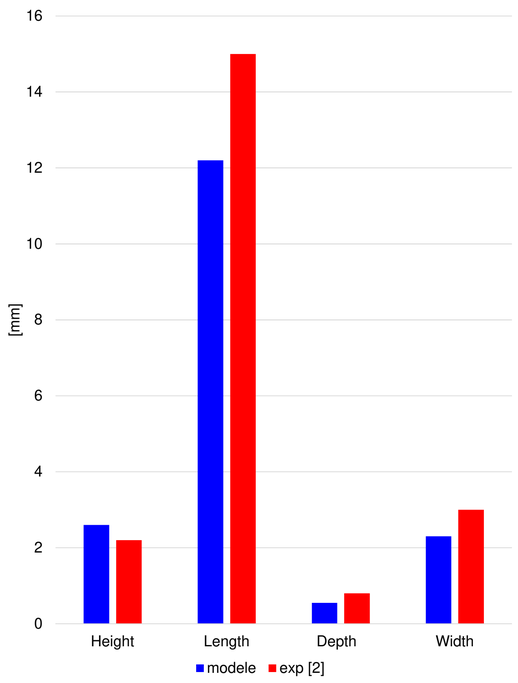


FIGURE 3 – Melt pool dimensions à t = 6 s

Calculation times (14 cores):

Melt Pool model: 50 h

Part model: 17 m (Heat Transfer) + 1 h 15 min (Solid Mechanics)

Results – Part Scale

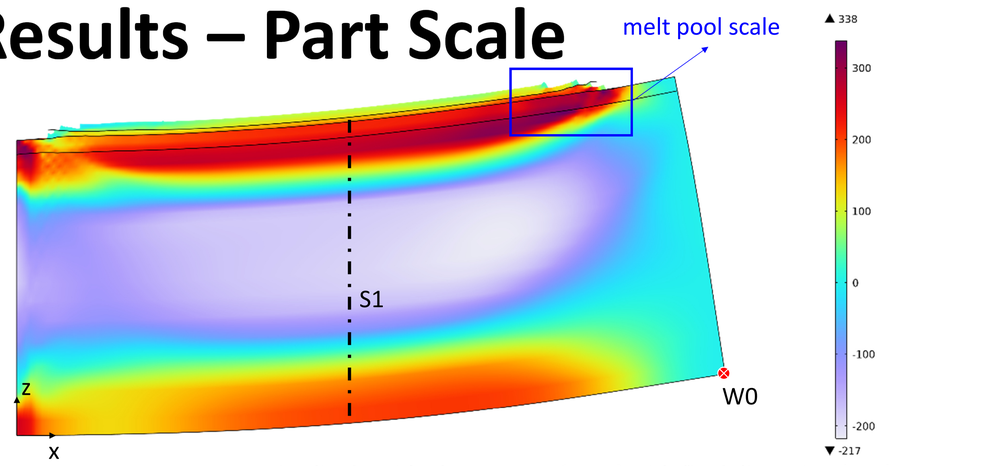


FIGURE 4 – Longitudinal residual stress σ_{xx} [MPa] with final distortion (x10)

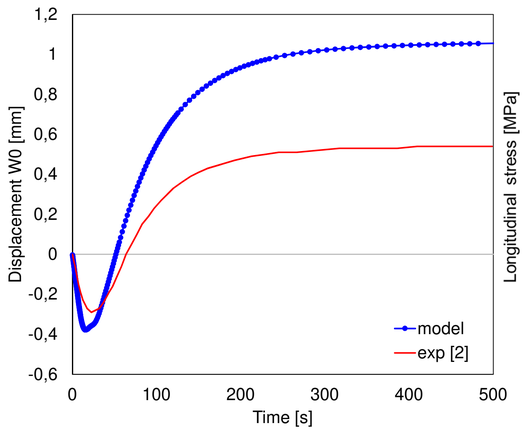


FIGURE 5 – Displacement of point W0 during deposit

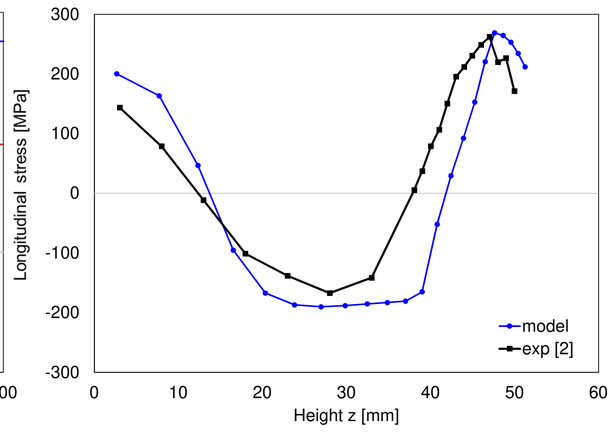


FIGURE 6 – Longitudinal residual stress σ_{xx} [MPa] along S1 line

REFERENCES

[1] - Lemaitre, J. and Chaboche, J.-L. (1994). Mechanics of solid materials. Cambridge university press.
[2] - Cambon, C. (2021). Étude thermomécanique du procédé de fabrication métallique arc-fil : approche numérique et expérimentale. PhD Thesis, Université de Montpellier.

IMN INSTITUT DES MATÉRIAUX DE NANTES JEAN ROUXEL

IRDL Institut de Recherche Dupuy de Lôme

IRT JULES VERNE LE FUTUR DE VOS USINES

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