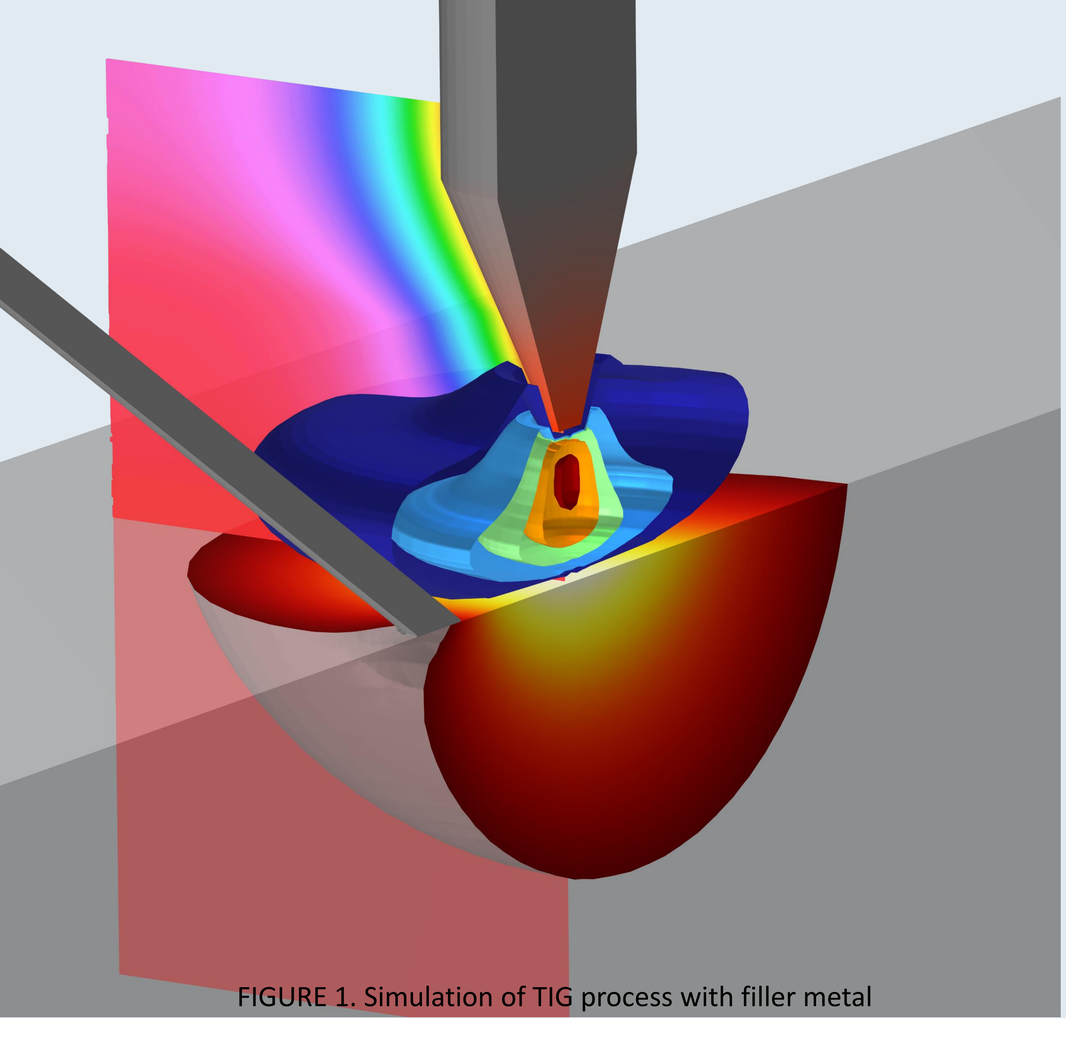


FIGURE 1. Simulation of TIG process with filler metal

Magneto-Thermo-Hydrodynamic Modeling of Arc Welding

The TIG pulsed process is simulated with coupling between the arc column and the melting pool. This model can be used, for example, to analyse the dynamic behavior of the melting pool. Some modifications of fluid-fluid interface are developed and a multi-scale approach is used.

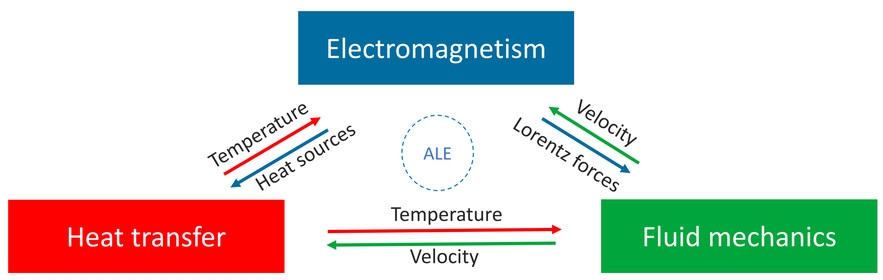
M. Le Gal La Salle[1, 2] , S. Cadiou[1], M. Courtois[1], M. Carin[1], P.-O. Barrioz[2], A. Brosse[2]

1. Univ. Bretagne Sud, UMR CNRS 6027, Lorient, France
2. Framatome-DTIM, Lyon, France

Multiphysics Simulation

Operating parameters:
Voltage, Current
Gas flow rate
Torch speed
Wire feed ratel
....

Material properties:
Density
Viscosity
Enthalpy
Thermal conductivity
Surface tension
....



Electromagnetism

$$\nabla \times E = 0$$
$$\nabla . E = 0$$
$$\nabla \times B = \mu_0 j$$
$$\nabla . B = 0$$

Mass and momentum conservation

$$\frac{\partial \rho}{\partial t} + \nabla . (\rho u) = 0$$
$$\rho \frac{\partial u}{\partial t} + \rho (u . \nabla) \mathrm{u} - \nabla . \sigma = F_{vol}$$
$$\sigma = \mu(\nabla u + (\nabla u)^T) - \frac{2}{3}\mu(\nabla . u).I$$

Heat transfer

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p u . \nabla T + \nabla . q = S_{vol}$$
$$q = -k \nabla T$$

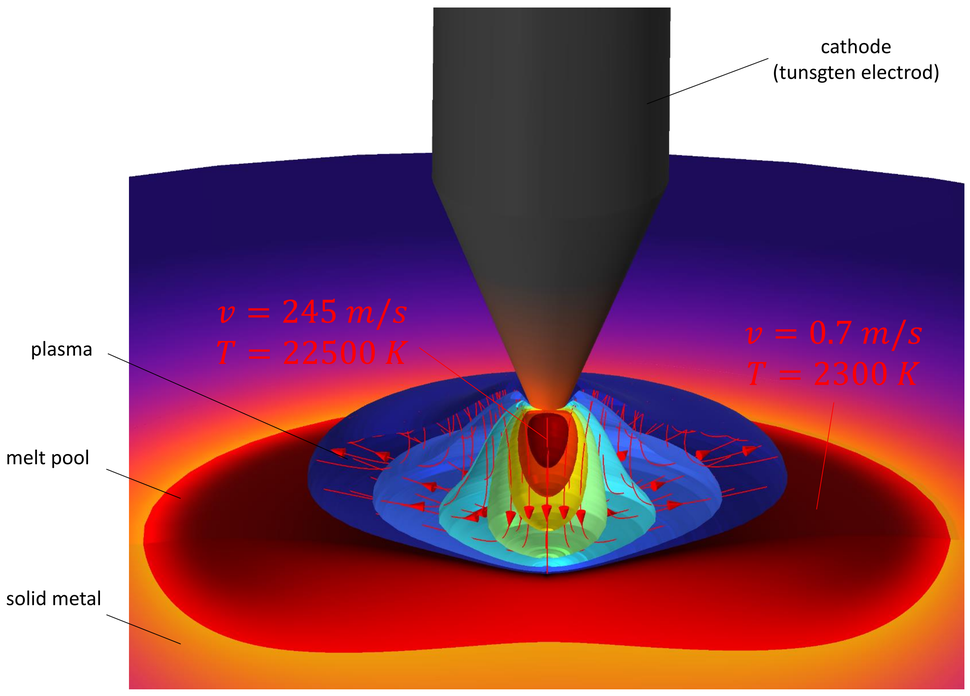
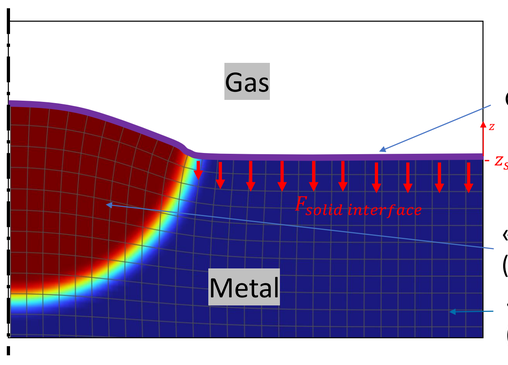


FIGURE 2. Temperature field in the arc column and metal

Gas-Metal Interface Modification

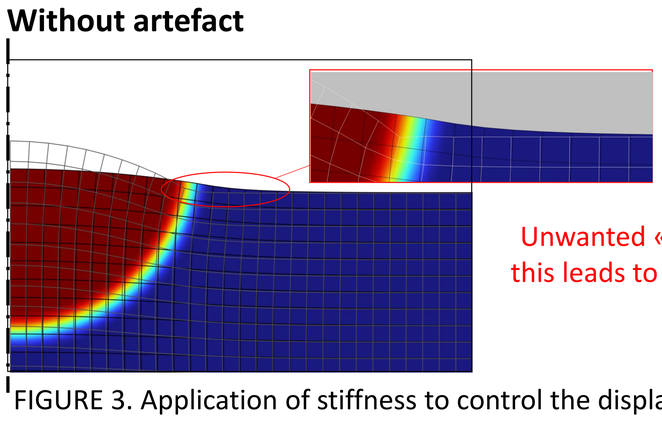
The ALE (Arbitrary Lagrangian-Eulerian) moving mesh method is used to simulate the deformation of the melting pool under the effect of arc pressure and filler metal. A numerical artefact has been developed to optimize control of the moving interface in areas of high viscosity gradient.

With $F_{solid\ interface}$; an added stiffness to control « solid interface »



$$n.(\sigma_{gas} - \sigma_{metal}) = \gamma(\nabla_t . n)n - \nabla_t \gamma + F_{solid\ interface}$$
$$F_{solid\ interface} = \begin{cases} 0\ if\ liquid \\ -K \times (z_{solid} - z)\ if\ solid \end{cases}$$
$$u_{gas} = u_{metal}$$
$$u_{mesh} . n = u_{gas} . n$$

Without artefact



Unwanted « solid » interface movement
this leads to a change of the melted zone.

FIGURE 3. Application of stiffness to control the displacement of the gas-metal interface

Multi-Scale Approach

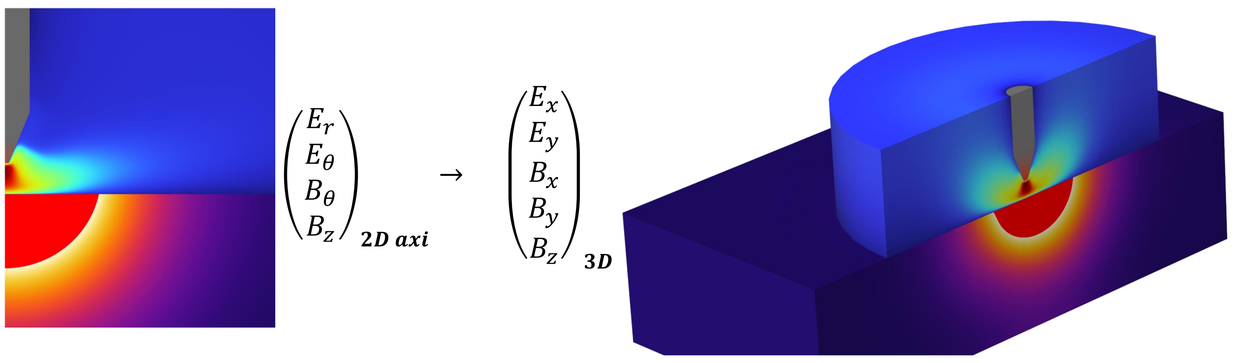


FIGURE 4. Schematic representation of multi-scale resolution

A multi-scale approach is adopted to optimize calculation times. A 2D axisymmetric model is used to solve the electromagnetic equations. These results are synchronously integrated into a 3D heat transfer and fluid flow model, allowing electromagnetic effects to be taken into account.

Perspectives

- Experimental validation of the 2D axisymmetric model from the entire characterized material parameters
- Progress of 3D model development
- Integration of particle tracing and transport equation to understand the formation of defects

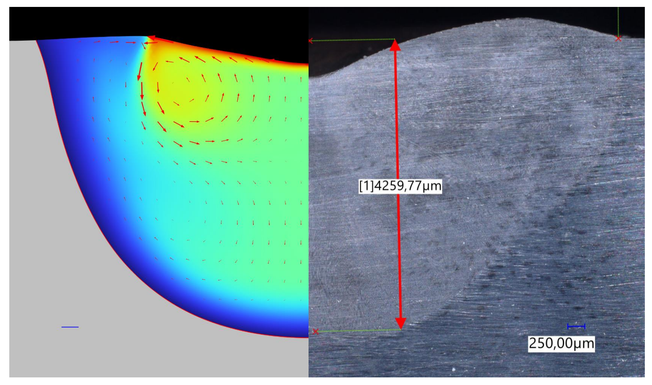


FIGURE 5. Numerical and experimental comparison of the weld in TIG spot configuration

REFERENCES

[1] Mr. Brochard. Cathode-plasma-part coupled model for the simulation of the TIG arc welding process (Doctoral dissertation, Aix-Marseille 1), 2009
[2] C. Nahed, *Magneto-thermo-hydrodynamic modelling of TIG welding: a 3D unified coupling of the arc-plasma and the weld pool* (Doctoral dissertation, Aix Marseille Université), 2021
[3] S. Cadiou et al., 3D heat transfer, fluid flow and electromagnetic model for cold metal transfer wire arc additive manufacturing (Cmt-Waam). *Additive Manufacturing*, *36*, 101541, 2020