A numerical and experimental study of heat and mass transfer during GTA welding of different austenitic stainless steels

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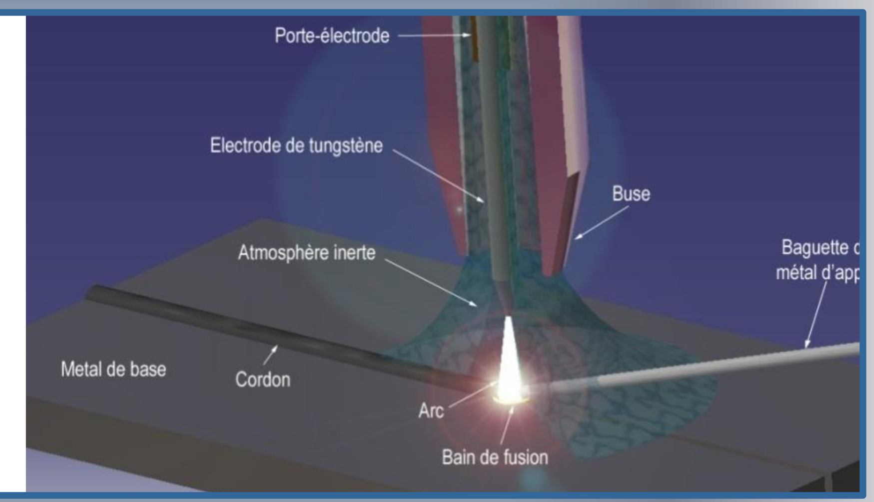


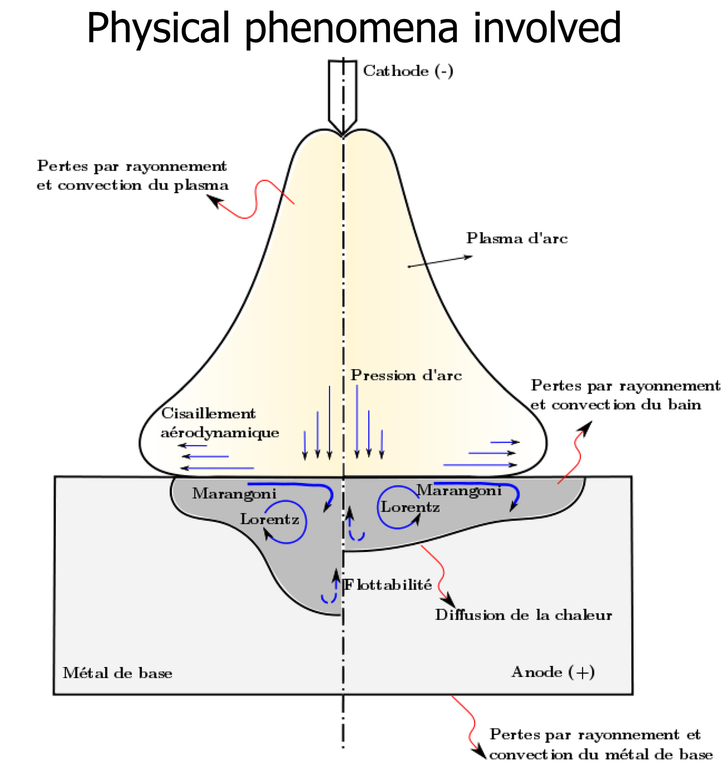
Introduction - Objectives

Because of the high quality of weld metal and of the weld bead surface, GTA welding is one of the most used arc welding processes. However, weld pool convection and the resulting thermal kinetic can affect the microstructure and properties of the resultant weld. This study aims to elaborate a predictive model for heat and mass transfer in the weld pool in order to investigate the weldability of stainless steel 304L with different chemical concentrations. The computed results were compared with the corresponding experimental ones for specimens containing low sulfur and high sulfur respectively.

Physical model

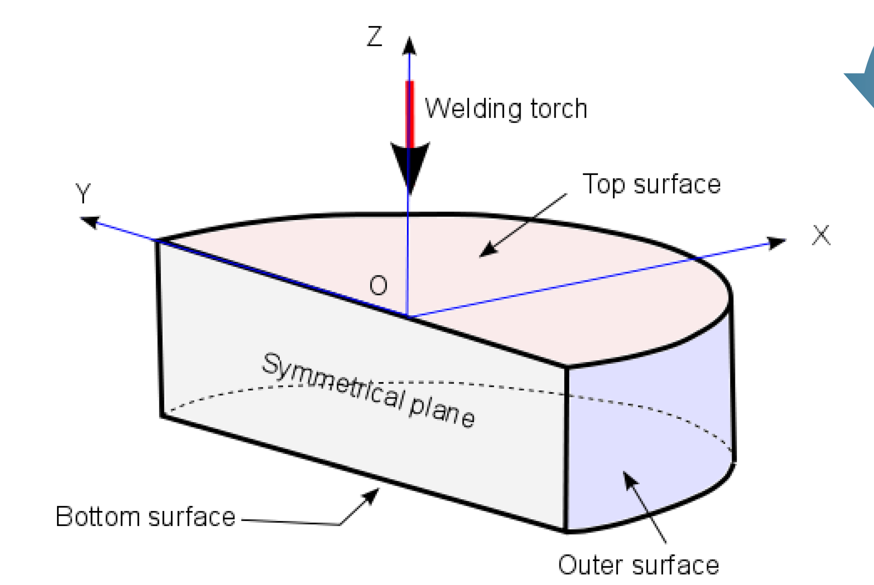
Convection in the weld pool and consequently the shape of the weldment depends on the balance among several forces, which includes Marangoni for electromagnetic force and buoyancy force. The **Marangoni** force, which depends on surface tension gradient, can be the main factor involved in w pool convection [1]. Heiple et al. [2 - 4] showed that trace elements alter fluid flow patterns by changing surface tension gradients on the weld p surface. The set of equations solved includes both **Navier-Stokes fluid dynamics equations and Maxwell's electromagnetic equatio** ***Code_Saturne®*** software is used to implement the developed model [5].

Physical phenomena involved



Assumptions :

In the developed numerical model, it has been assumed that the liquid metal flow is incompressible, Newtonian and laminar; the heat and current source from the arc torch have **Gaussian distribution** (boundary condition at the top surface); the weld pool surface remains horizontal and flat and the liquid fraction varies linearly with temperature in the solidification range. Energy loss is taken into account through constant emissivity and heat transfer coefficient (boundary condition at outer and bottom surfaces). In the mushy zone, the velocity field varies smoothly from a finite value in the liquid zone to zero in the solid one using a frictional dissipation according to Carman-Kozeny equation for flow through a porous media.



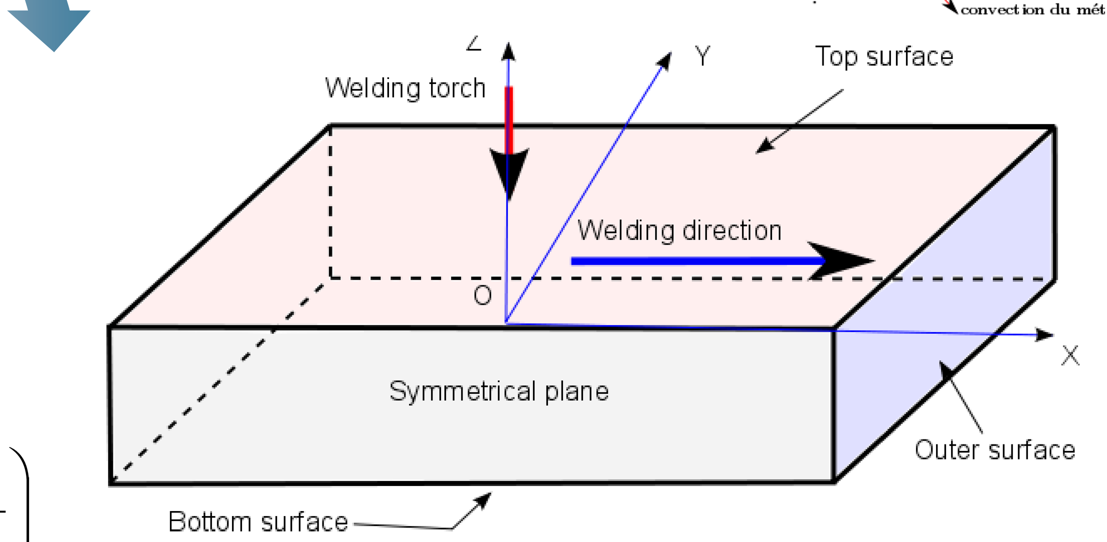
Schematic illustration of the spot welding configuration (with fixed energy source) and its associated boundary conditions

At the top surface :

$$\varphi_{source}(x,y)=\frac{IU\eta}{2\pi r_t^2}\exp\left(-\frac{x^2+y^2}{2r_t^2}\right),\quad j_z(x,y)=\frac{I}{2\pi r_e^2}\exp\left(-\frac{x^2+y^2}{2r_e^2}\right)$$

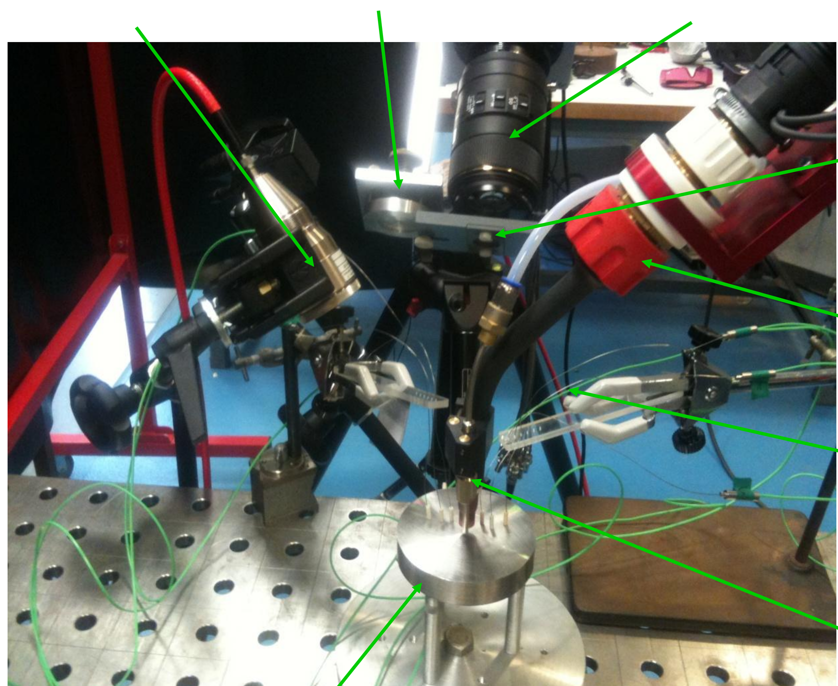
$$\mu\frac{\partial u}{\partial z}=\frac{\partial\gamma}{\partial T}\frac{\partial T}{\partial x},\quad \mu\frac{\partial v}{\partial z}=\frac{\partial\gamma}{\partial T}\frac{\partial T}{\partial y},\quad w=0$$

$$\frac{\partial\gamma}{\partial T}=-A-8314T\ln(1+Ka_S)-\frac{Ka_S\Delta H^0\Gamma_S}{T(1+Ka_S)}\qquad K=k_1\exp\left(-\frac{\Delta H^0}{RT}\right)$$

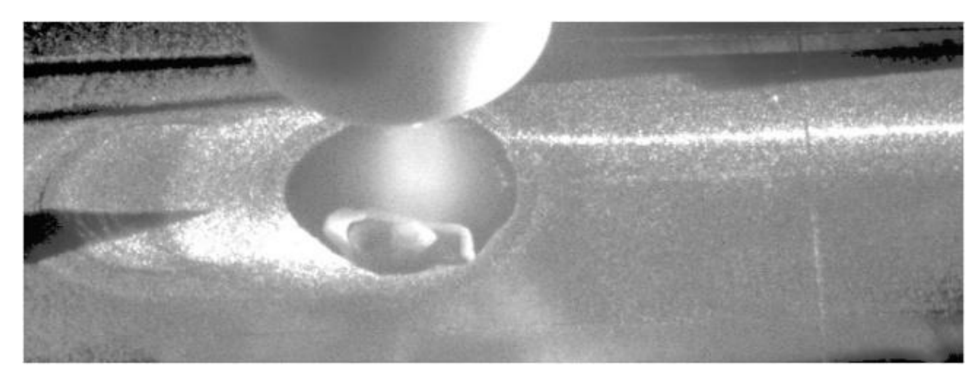


Schematic illustration of the standard welding configuration (with moving energy source) and its associated boundary conditions

Experimental approach

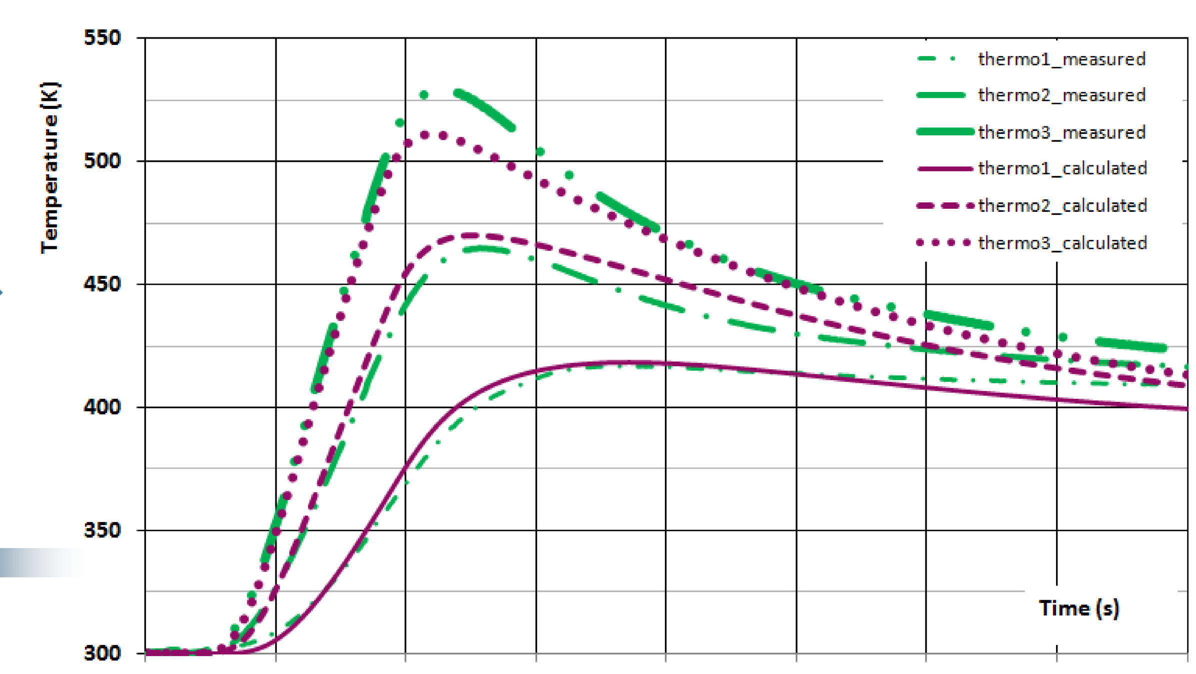


Best understanding of phenomena: fluid flow and deformation at the top surface of weld pool



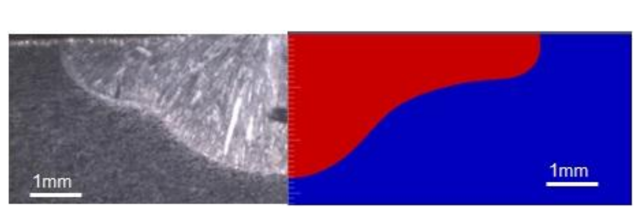
Weld pool visualization during welding

To validate the characteristics of energy source applied on the top of specimen

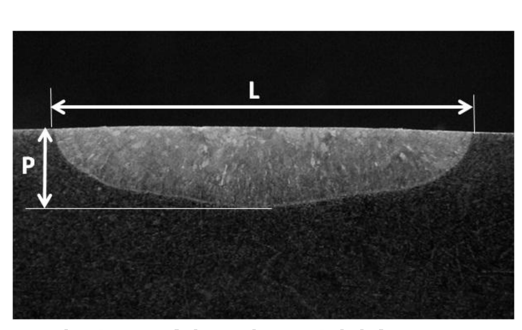


Experimental and calculated thermal time evolution

To validate weld pool shapes and sizes

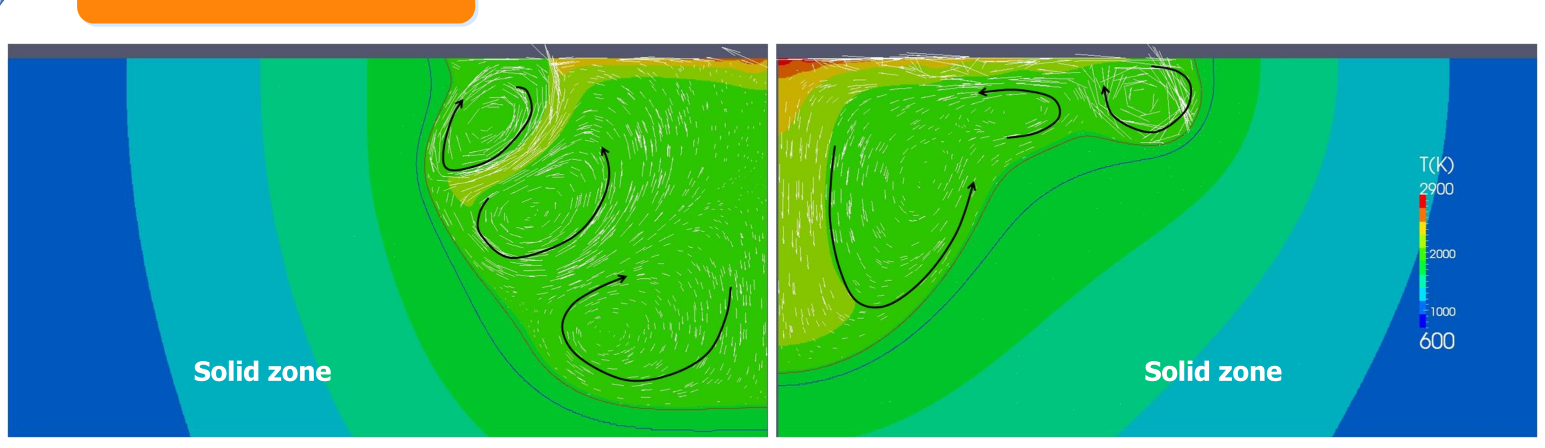


Experimental and calculated weld pool shapes

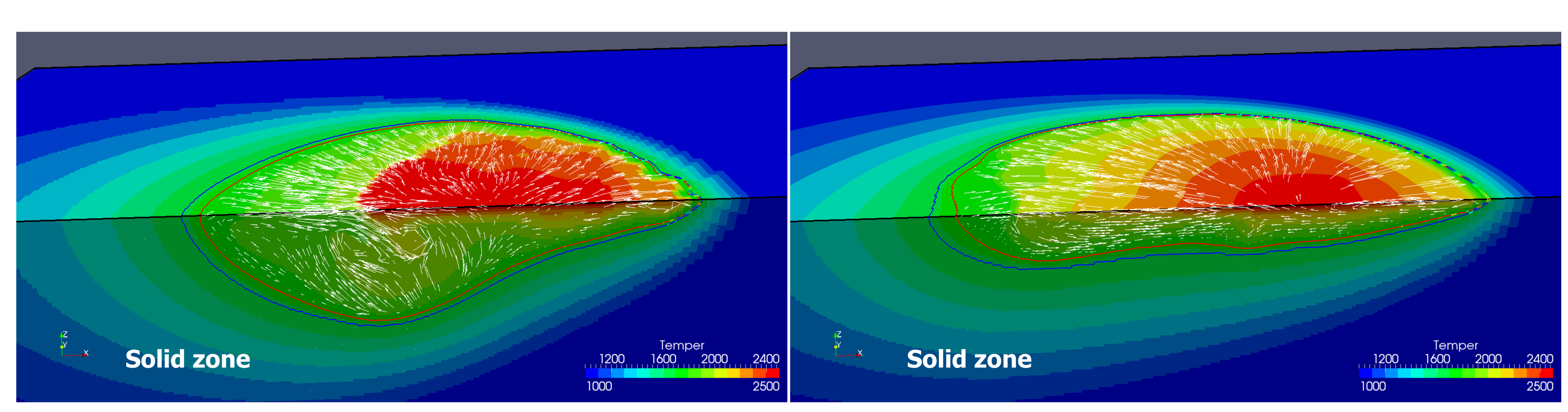


Weld pool sizes (depth, width) measurement

Results



Computed flow pattern in the molten pool of stainless steel of 0.026 wt% **(at left)** and 0.007 wt% **(at right)** of sulfur content in spot welding configuration with mesh of 750 000 elements

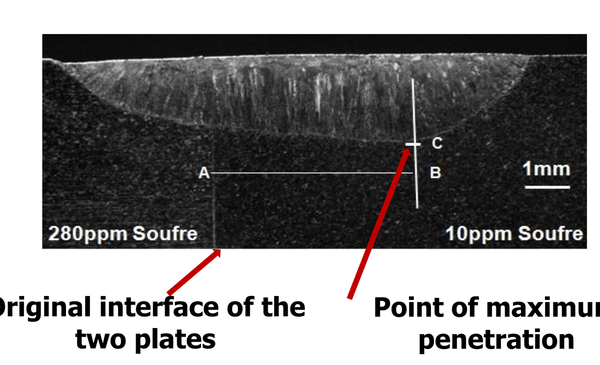


Computed flow pattern in the molten pool of stainless steel of 0.026 wt% **(at left)** and 0.007 wt% **(at right)** of sulfur content in standard welding configuration with mesh of 750 000 elements

COMPARISON EXPERIMENTAL - CFD CALCULATION

Welding configuration, Material sulfur content	Weld pool depth (mm)		Weld pool width /2 (mm)	
	Experimental	Calculated	Experimental	Calculated
Spot welding, Cs = **0.007** wt %	5.1 ±0.1	5.1	6.1 ±0.2	6.3
Spot welding, Cs = **0.026** wt %	5.6 ±0.1	6.1	5.9 ±0.2	5.1
Standard welding, **15** cm/mn, Cs = **0.007** wt %	2.2 ±0.1	1.1	3.9 ±0.2	4.8
Standard welding, **15** cm/mn, Cs = **0.026** wt %	2.4 ±0.1	2.5	3.9 ±0.2	4.3
Standard welding, **30** cm/mn, Cs = **0.026** wt %	1.5 ±0.1	1.5	3.3 ±0.2	3.6

Work is in progress to address simulation of assembly of stainless steel plates of different material compositions



Weld pool characteristics when welding stainless steel plates with different sulfur concentration

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