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Sensitivity Analysis on Numerical Simulation of the Weld Pool Shape in Tig Welding

Xiaofei KONG, Olivier ASSERIN, Stéphane GOUNAND, Philippe GILLES, Jean-Michel BERGHEAU et Marc MEDALE

9th International Trends in Welding Research Conference

08 June 2012



Outline

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Physical model

Mathematical model

Numerical model

Results and analyses

Influence of the free surface

Numerical sensitivity

Conclusion and perspectives

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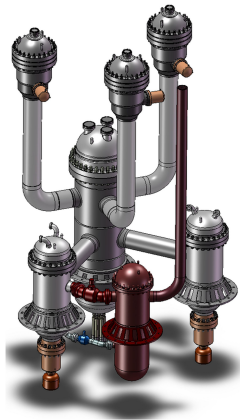
Contexts and challenges

The TIG welding in the nuclear industry

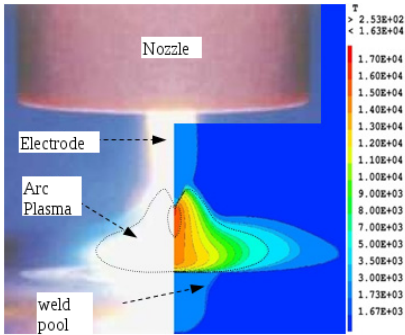
- Assembly of the nuclear components with large thickness by TIG welding
- Ensure quality and reliability of the weldment

Benefits of the simulation of welding

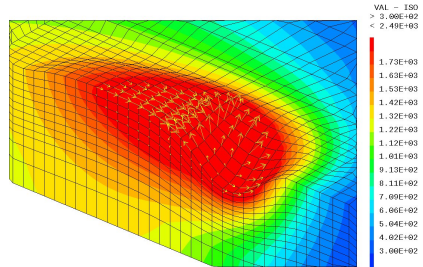
- Welding process design,
- Prediction of the deformations and the residual stresses, interpretation of the technological test,
- Help in understanding the limiting factors in the welding,
- Reduce the number of experiments.



Goal



2D axisymmetric unified model including electrode, arc plasma and molten pool (Michel Brochard, Phd Thesis 2008)



3D weld pool

3D Simulation of the weld pool for the TIG welding taking into account the free surface and the welding speed, and with the filler metal in the next step.

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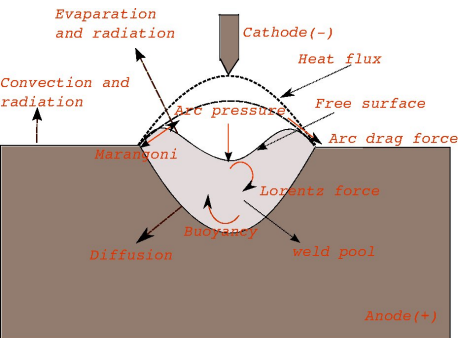
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Physical phenomena in the weld pool

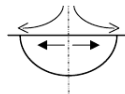


Widening the pool

Marangoni
 $d\gamma/dT < 0$



Arc drag force



Buoyancy



Deepening the pool

Marangoni
 $d\gamma/dT > 0$



Lorentz force



Importance of the various forces

Quantity of power :

- Power of the Marangoni force : $\int_{\Gamma} \mathbf{F}_{\text{Marangoni}} \cdot \mathbf{u} \, d\Gamma \approx 10^{-4} \text{ W}$
- Power of the arc drag force : $\int_{\Gamma} \mathbf{F}_{\text{Arc_drag}} \cdot \mathbf{u} \, d\Gamma \approx 10^{-4} \text{ W}$
- Power of the Lorentz force : $\int_{\Omega} \mathbf{F}_{\text{Lorentz}} \cdot \mathbf{u} \, d\Omega \approx 10^{-5} \text{ W}$
- Power of the Buoyancy force : $\int_{\Omega} \mathbf{F}_{\text{Buoyancy}} \cdot \mathbf{u} \, d\Omega \approx 10^{-7} \sim 10^{-6} \text{ W}$

Main forces : $F_{\text{Marangoni}}$ and $F_{\text{Arc_drag}}$

$$\frac{P_{\text{Arc_drag}}}{P_{\text{Marangoni}}} \approx 1, \quad \frac{P_{\text{Lorentz}}}{P_{\text{Marangoni}}} \approx 0.1, \quad \frac{P_{\text{Buoyancy}}}{P_{\text{Marangoni}}} \approx 0.01.$$

Developed Model

Hypothesis

- A laminar, Newtonian fluid of the liquid metal and a stationary state
- Boussinesq approximation
- Free surface of the weld pool
- Variation of $\frac{\partial \gamma}{\partial T}$ and thermophysical properties depending on temperature
- The constant speed v_s of welding, the equation solved in a reference frame moving with the heat source

Effect not modelled

- Lorentz force
- Metal evaporation

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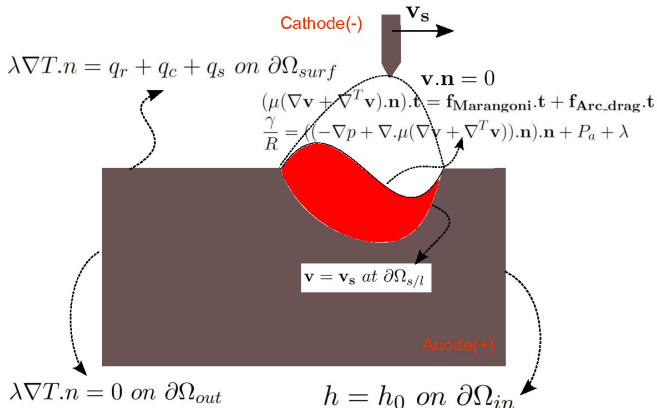
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Conservation equations and boundary conditions

- Continuity : $\nabla \cdot \mathbf{v} = 0$
- Momentum : $\rho(\nabla \mathbf{v}) \cdot (\mathbf{v} - \mathbf{v}_s) + \nabla p - \nabla \cdot \mu(\nabla \mathbf{v} + \nabla^T \mathbf{v}) = \mathbf{f}_{\text{Buoyancy}} + \mathbf{f}_{\text{Extinction}}$
- Energy : $\rho c_p(\nabla h) \cdot (\mathbf{v} - \mathbf{v}_s) = \nabla \cdot \lambda \nabla T$



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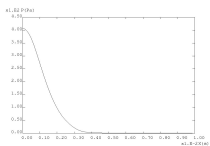
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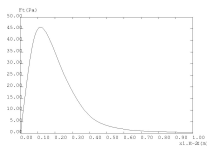
Conclusion and perspectives

Hybrid approach 2D axisymmetric arc model + 3D weld pool model

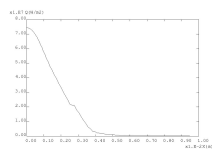
2D arc model provides the arc source



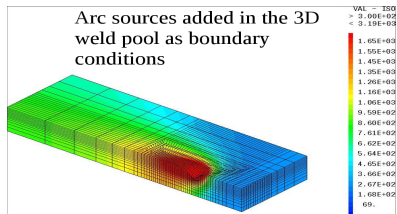
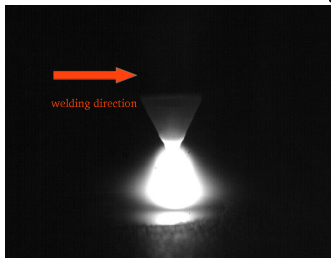
Radial evolution of the pressure of the arc



Radial evolution of the arc force



Radial evolution of the heat source



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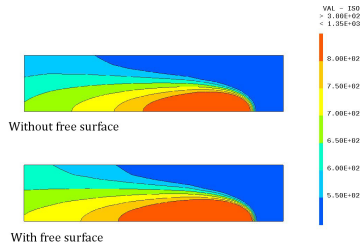
Results and analyses

Influence of the free surface

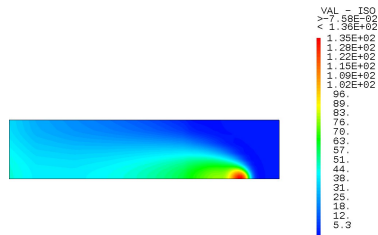
Numerical sensitivity

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Influence of the free surface on the temperature field of the bottom surface



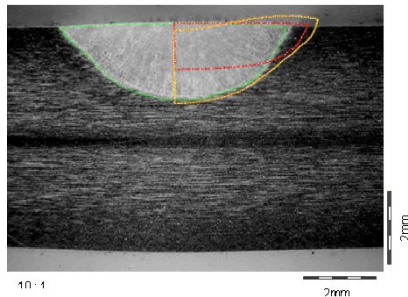
Temperature field with and without free surface



Difference of the temperature field on the bottom surface

- $\Delta T_{max} = 135 \text{ } ^\circ\text{C}$
- The weld pool length is larger in the model with free surface

Comparison between the simulation and the experiment



Current (A)	Voltage (V)	Arc length (mm)	Welding speed (mm/s)
150	10	2	2.5

- The calculated penetration and weld shape in the model with free surface agree well with the experiment.

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Design of numerical experiments

Tests	Pressure (Pa)	Heat flux (W)	Welding speed (mm/s)
1	326	1021	2
2	407	1021	2
3	326	1276	2
4	326	1276	2.5
5	407	1021	2.5
6	407	1276	2
7	407	1276	2.5
8	326	1021	2.5

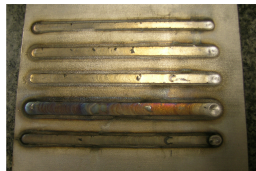
Regression model for the sensitivity analysis

- $y =$
 $a_1 + a_2 X_P + a_3 X_F + a_4 X_V + a_5 X_P X_F + a_6 X_P X_V + a_7 X_F X_V + a_8 X_P X_F X_V$
- y the response, X_P , X_F , X_V the factors (pressure, heat flux and welding speed).

Contributions of the different factors

Factors	Penetration P	Width L	P/L	Volume of the pool
X_P	54.01	0.06	92.62	3.80
X_F	42.00	79.26	2.7	64.91
X_V	2.41	20.49	2.7	8.79
$X_P X_F$	0,13	0,06	0.06	6.00
$X_P X_V$	0.02	0.06	0.06	6.30
$X_F X_V$	0,33	0,00	0.50	2.50
$X_P X_F X_V$	1.11	0,06	1.38	7.69

- Trends consistent with those of the literature,
- In progress : validation of the model by correlations with the corresponding experimental tests.



Conclusions and perspectives

Conclusions :

- The model taking into account the free surface predicts better the weld pool shape than the model without the free surface,
- Numerical sensitivity analysis of the influence of the free surface, the welding speed, the heat flux and the quantity of sulfur composition.

Perspectives :

- Simulation of the metal evaporation,
- Simulation of the filler metal.

Thank you for your attention !