A Transient Unified Model of Arc Weld Pool Couplings during Spot GTA Welding

A. TRAIDIA, and F. Roger

ENSTA-Paristech & AREVA NP, FRANCE

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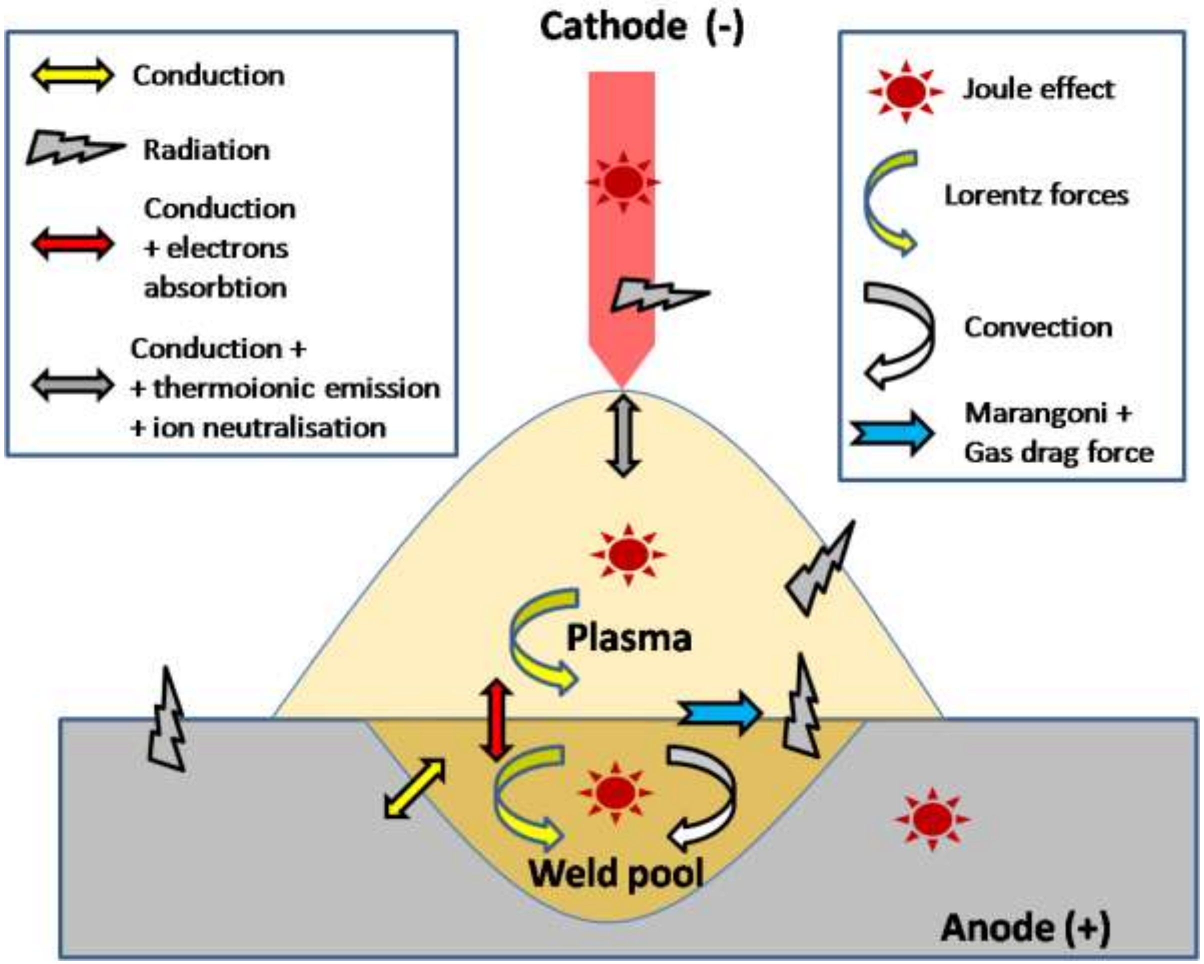
traidia@ensta-paristech.fr

Introduction

Gas Tungsten Arc Welding – Tungsten Inert Gas

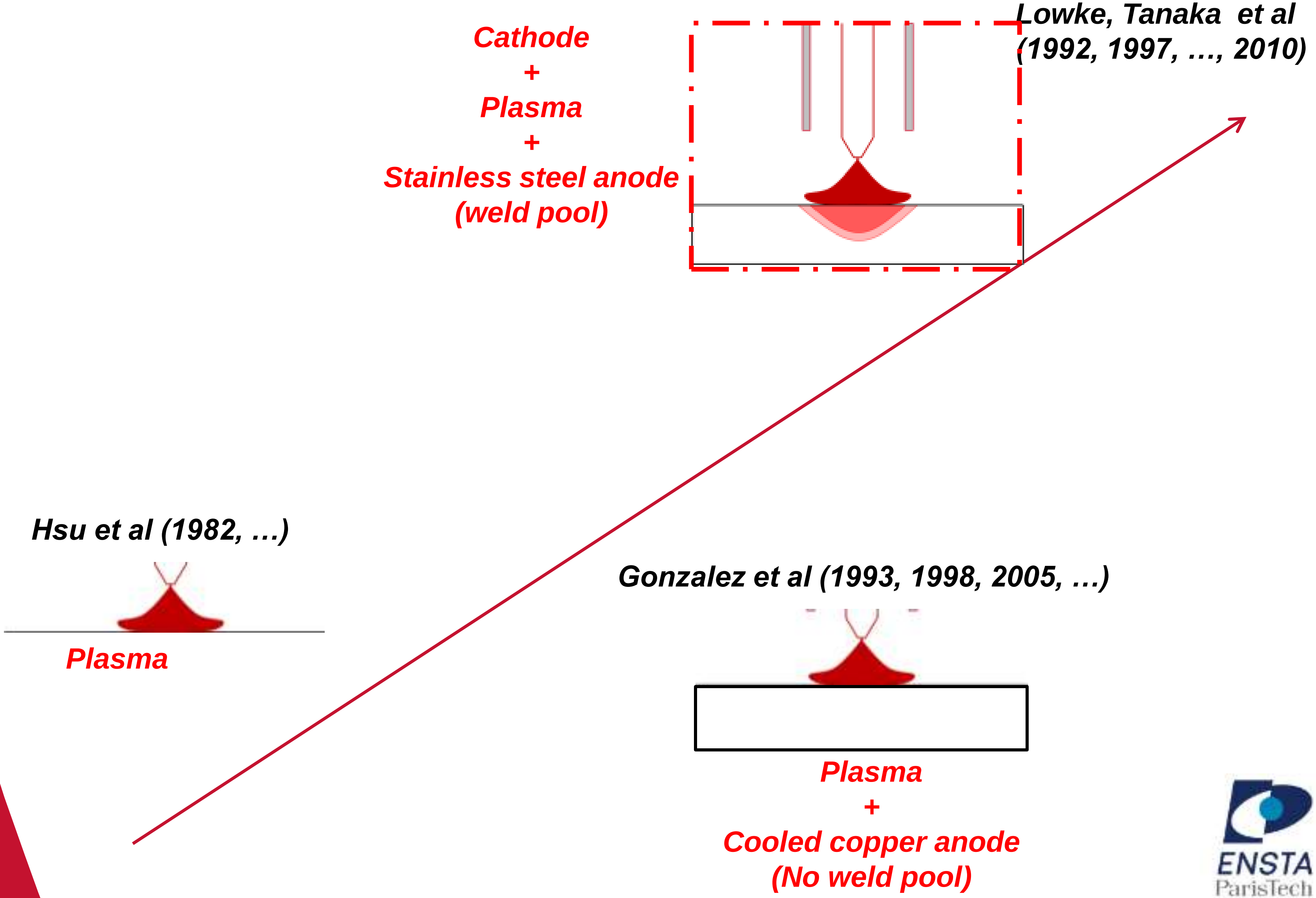


A highly coupled multiphysics problem

traidia@ensta-paristech.fr

Numerical modeling of pulsed GTA welding

State of art – Towards a unified formulation



Lowke, Tanaka et al (1992, 1997, …, 2010)

Cathode
+
Plasma
+
Stainless steel anode
(weld pool)

Gonzalez et al (1993, 1998, 2005, …)

Plasma
+
Cooled copper anode
(No weld pool)

Hsu et al (1982, …)

Plasma

Numerical modeling of pulsed GTA welding

Toward a unified model

Mathematical formulation

Inside the cathode, plasma, and anode

$$\nabla \cdot \left(\sigma \nabla V + \sigma \frac{\partial \overrightarrow{A}}{\partial t} \right) = 0$$

$$\sigma \frac{\partial \overrightarrow{A}}{\partial t} + \nabla \times \left(\frac{1}{\mu_0} \nabla \times \overrightarrow{A} \right) + \sigma \nabla V = \vec{0}$$

$$\nabla \cdot \vec{v} = 0$$

$$\rho \left(\frac{\partial \vec{v}}{\partial t} + \vec{v} \cdot \nabla \vec{v} \right) = - \nabla p + \mu \nabla \cdot (\nabla \vec{v} +^t \nabla \vec{v}) + \overrightarrow{j} \times \overrightarrow{B} + \rho_0 \overrightarrow{g} + w_p \rho_0 \beta (T - T_{ref}) \overrightarrow{g}$$

$$\rho C_p^{eq} \left(\frac{\partial T}{\partial t} + \vec{v} \cdot \nabla T \right) = \nabla \cdot (\lambda \nabla T) + \overrightarrow{j} \cdot \overrightarrow{E} + \frac{5 k_B}{2e} \overrightarrow{j} \cdot \nabla T - (1 - w_p) \cdot 4 \pi \epsilon_N$$

$$P_a - \lambda - \rho g \varphi = -\gamma \frac{r \varphi_{rr} + \varphi_r (1 + \varphi_r^2)}{r (1 + \varphi_r^2)^{\frac{3}{2}}}$$

$$\lambda + \rho g (L + \psi) = -\gamma \frac{r \psi_{rr} + \psi_r (1 + \psi_r^2)}{r (1 + \psi_r^2)^{\frac{3}{2}}}$$

Main boundary conditions

Plasma-cathode interface

$$\left[-k \nabla T \cdot (-\vec{n}) \right]_{cathode} - \left[-k \nabla T \cdot (-\vec{n}) \right]_{plasma} = j_i V_i - j_e \phi_c - \varepsilon \sigma_B T^4$$

Plasma-anode interface

$$\left[-k \nabla T \cdot (-\vec{n}) \right]_{anode} - \left[-k \nabla T \cdot (-\vec{n}) \right]_{plasma} = \left| \vec{j} \cdot \vec{n} \right| \phi_a - \varepsilon \sigma_B T^4$$

$$\mu \frac{\partial (\vec{v} \cdot \vec{s})}{\partial \vec{n}} = \vec{\tau}_a + f_L \frac{\partial \gamma}{\partial T} \frac{\partial T}{\partial \vec{s}}$$

$$\frac{\partial \gamma}{\partial T} = -A_\gamma - R_g \Gamma_s \ln \left(1 + K a_s \right) - \frac{K a_s}{1 + K a_s} \Gamma_s \frac{\Delta H_0}{T}$$

$$K(T) = k_1 \exp \left(- \frac{\Delta H_0}{R_g T} \right)$$

Free surfaces of the weld pool

$$\vec{\tau} = \mu \frac{\partial (\vec{v} \cdot \vec{s})}{\partial \vec{n}} = f_L \frac{\partial \gamma}{\partial T} \frac{\partial T}{\partial \vec{s}}$$

$$\vec{q} \cdot \vec{n} = h (T - T_0)$$

$$\int_0^{rt} 2 \pi \varphi(r) \mathrm{d}r = \int_0^{rb} 2 \pi \psi(r) \mathrm{d}r$$

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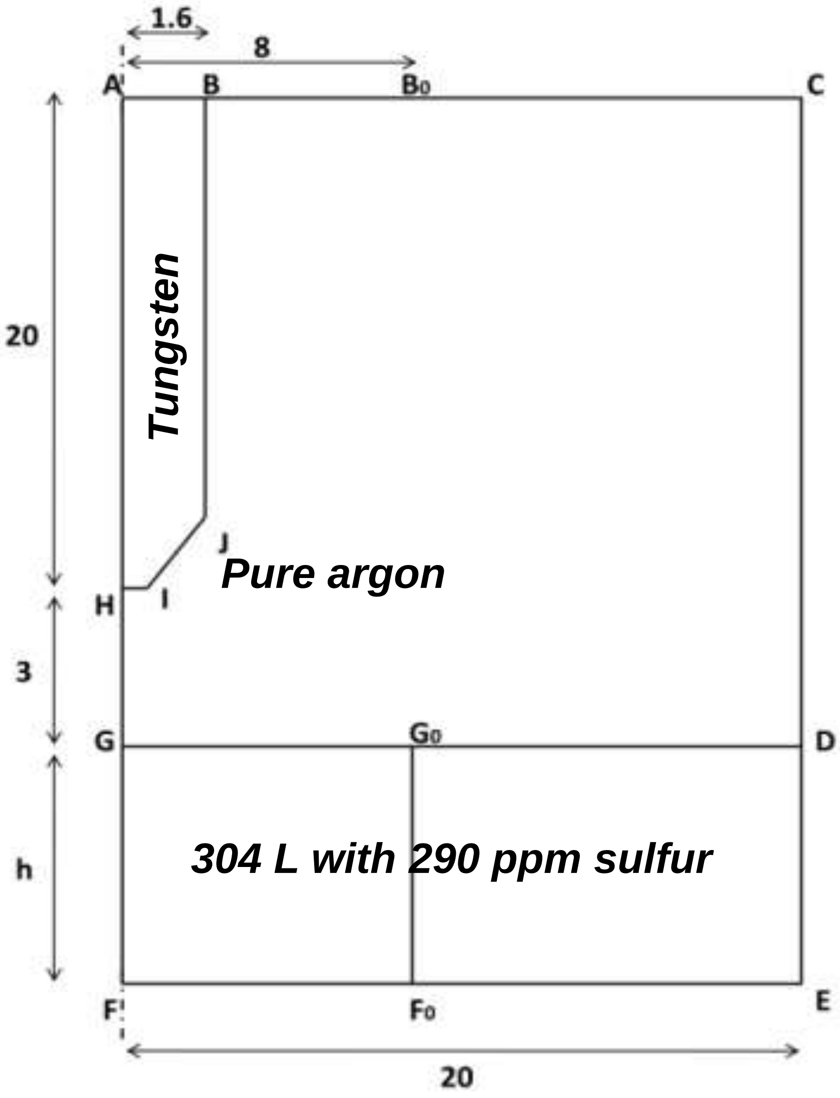
Numerical modeling of pulsed GTA welding

Application to pulsed current welding



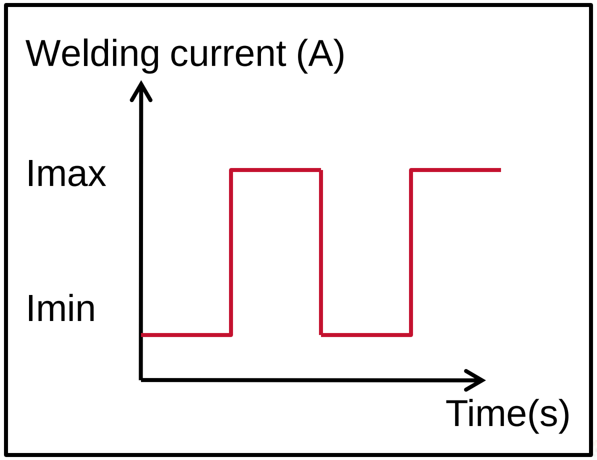
80/160 A

1 Hz

α 60°

Arc length 3 mm

Heating time: 15 s



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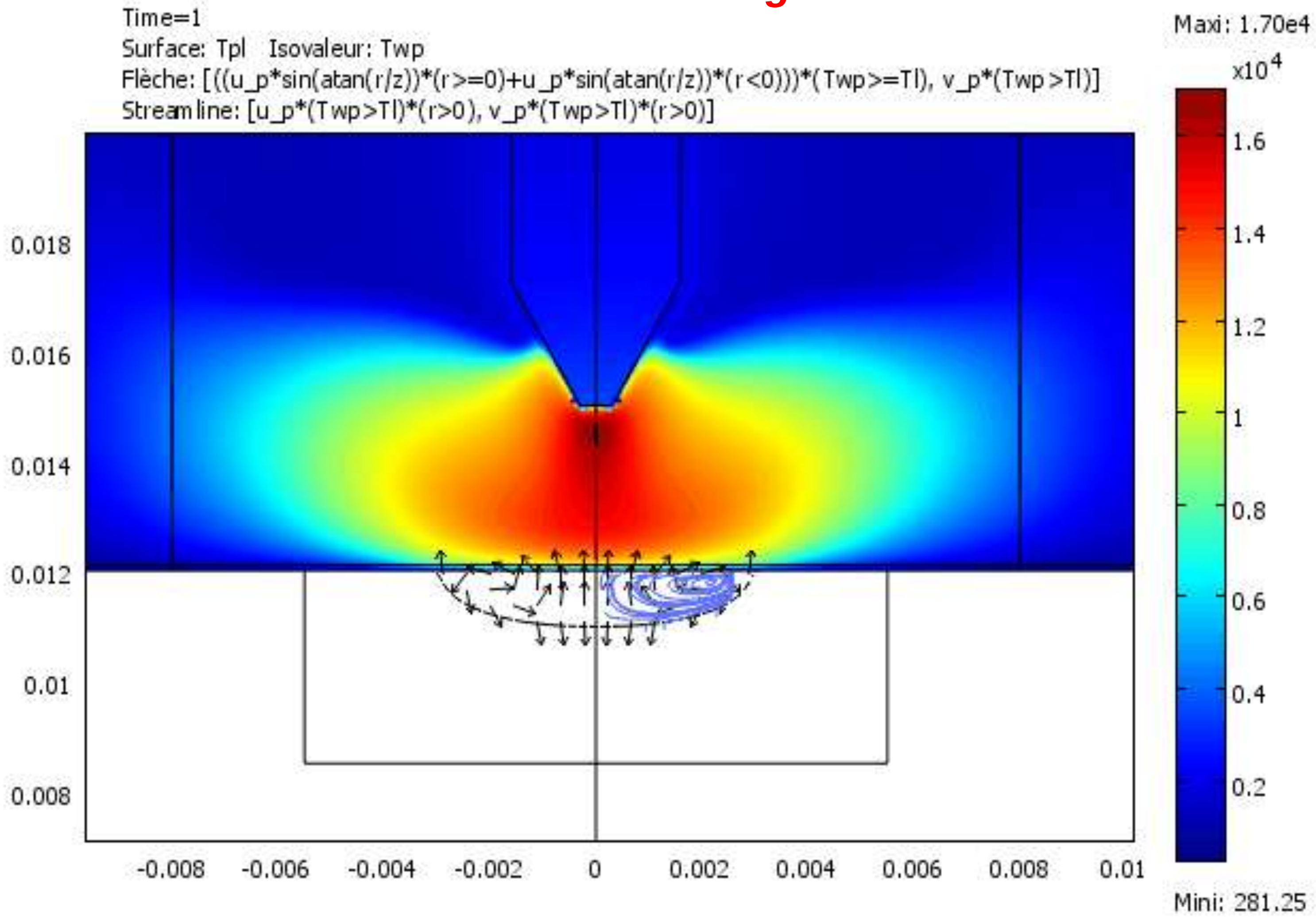
Numerical modeling of pulsed GTA welding

- **Results**

Application to pulsed current welding

80/160 A- 1 Hz
α 60°- h 3 mm



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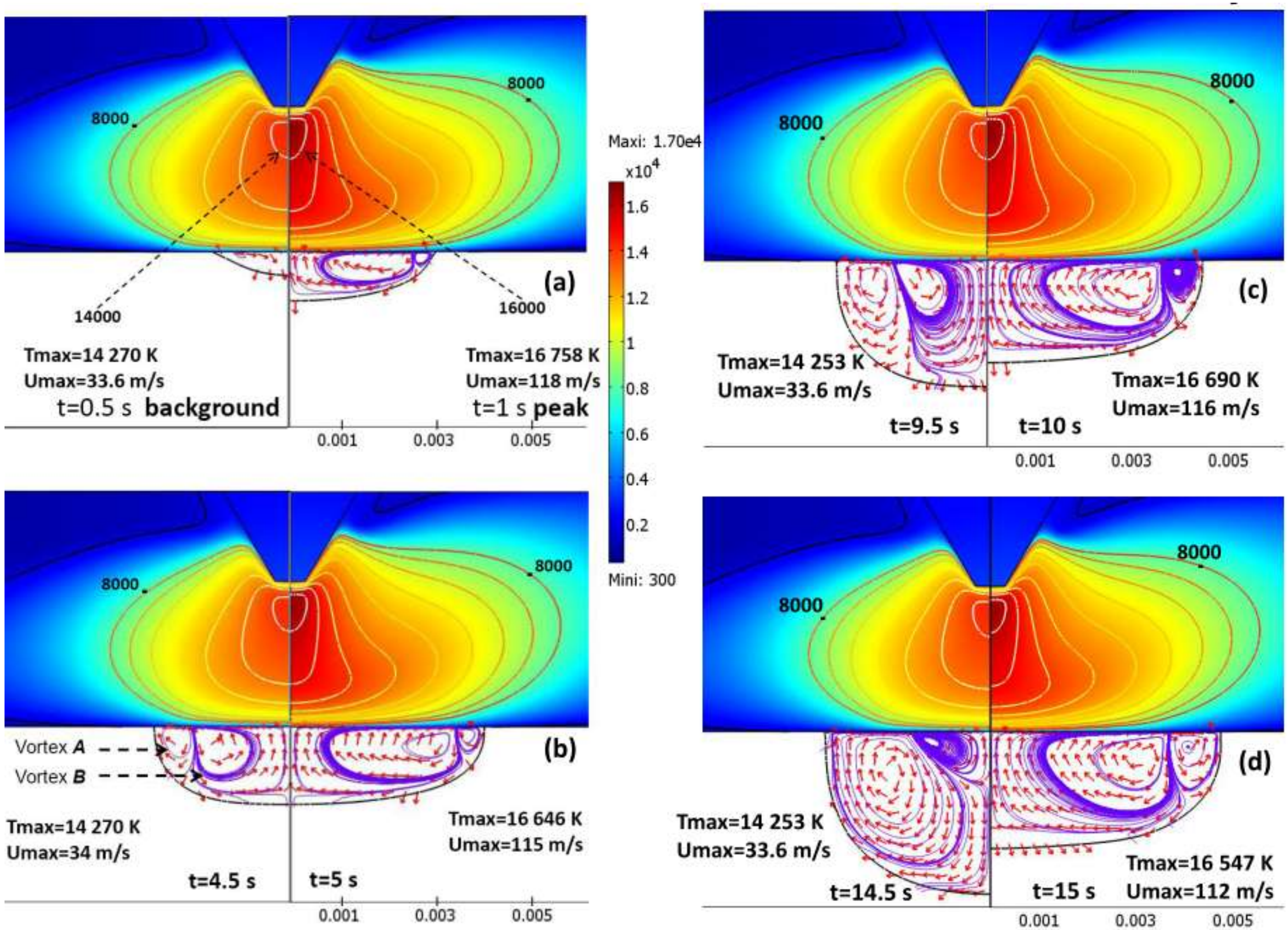
Numerical modeling of GTA welding

▶ Results

Application to pulsed current welding

80/160 A- 1 Hz
α 60°- h 3 mm



Details about the weld pool evolution in: *A. Traidia, F. Roger, E. Guyot.* “Optimal parameters for pulsed gas tungsten arc welding in partially and fully penetrated weld pools”. **IJTS** 2010.

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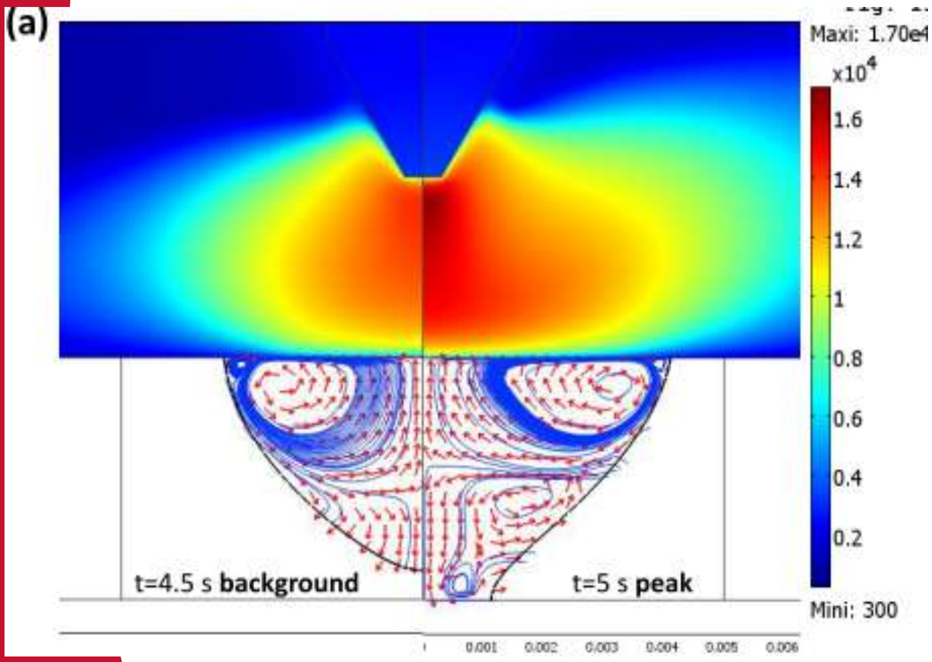
Numerical modeling of pulsed GTA welding

▶ Results

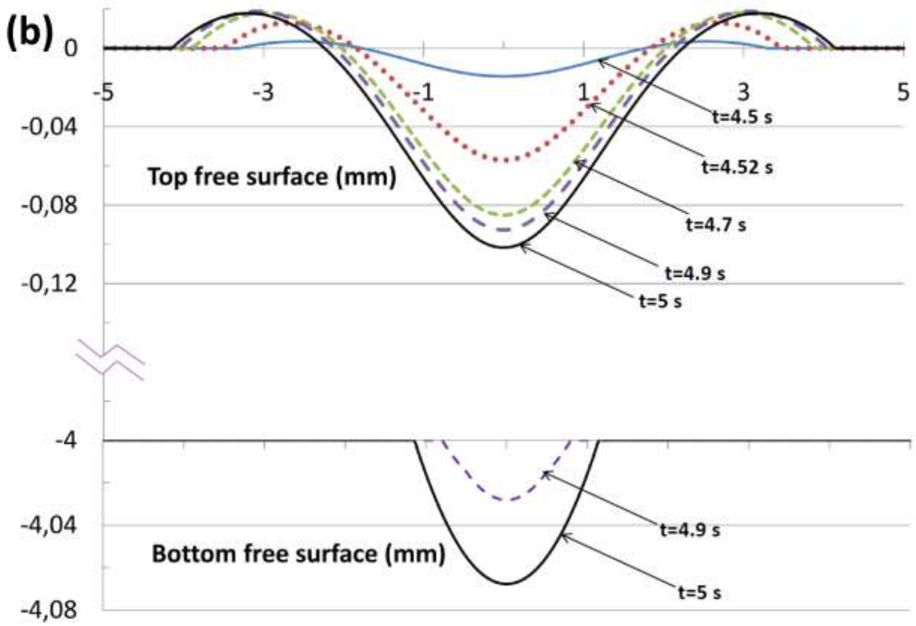
Application to pulsed current welding

80/160 A- 1 Hz
α 60°- h 3 mm

➡*Fully penetrated weld pool*



Solutions at t=4.5 s and t=5 s



Free surfaces shape at different times

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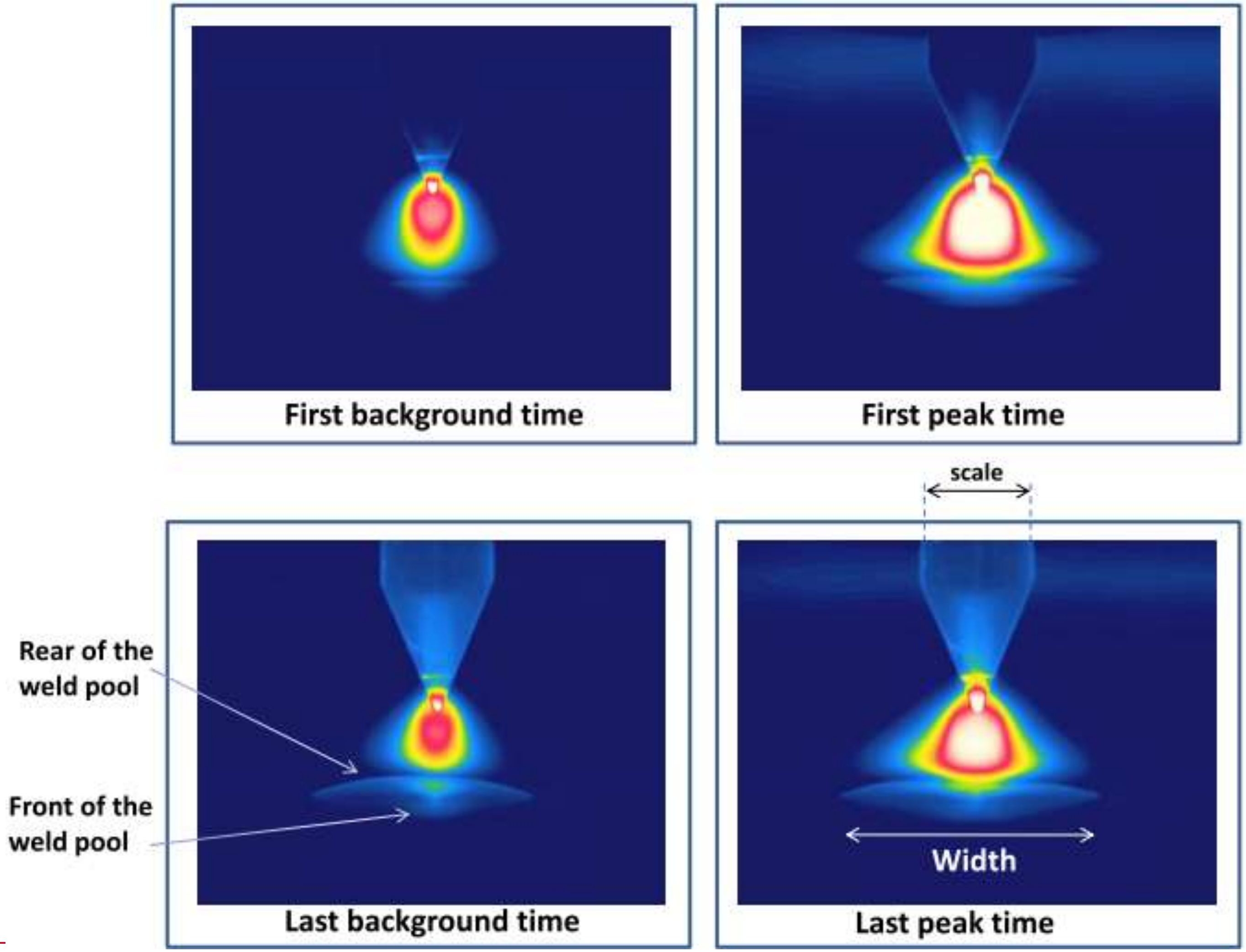
Experimental validation

Experimental procedure

- *Observation of the weld pool using an IR camera*



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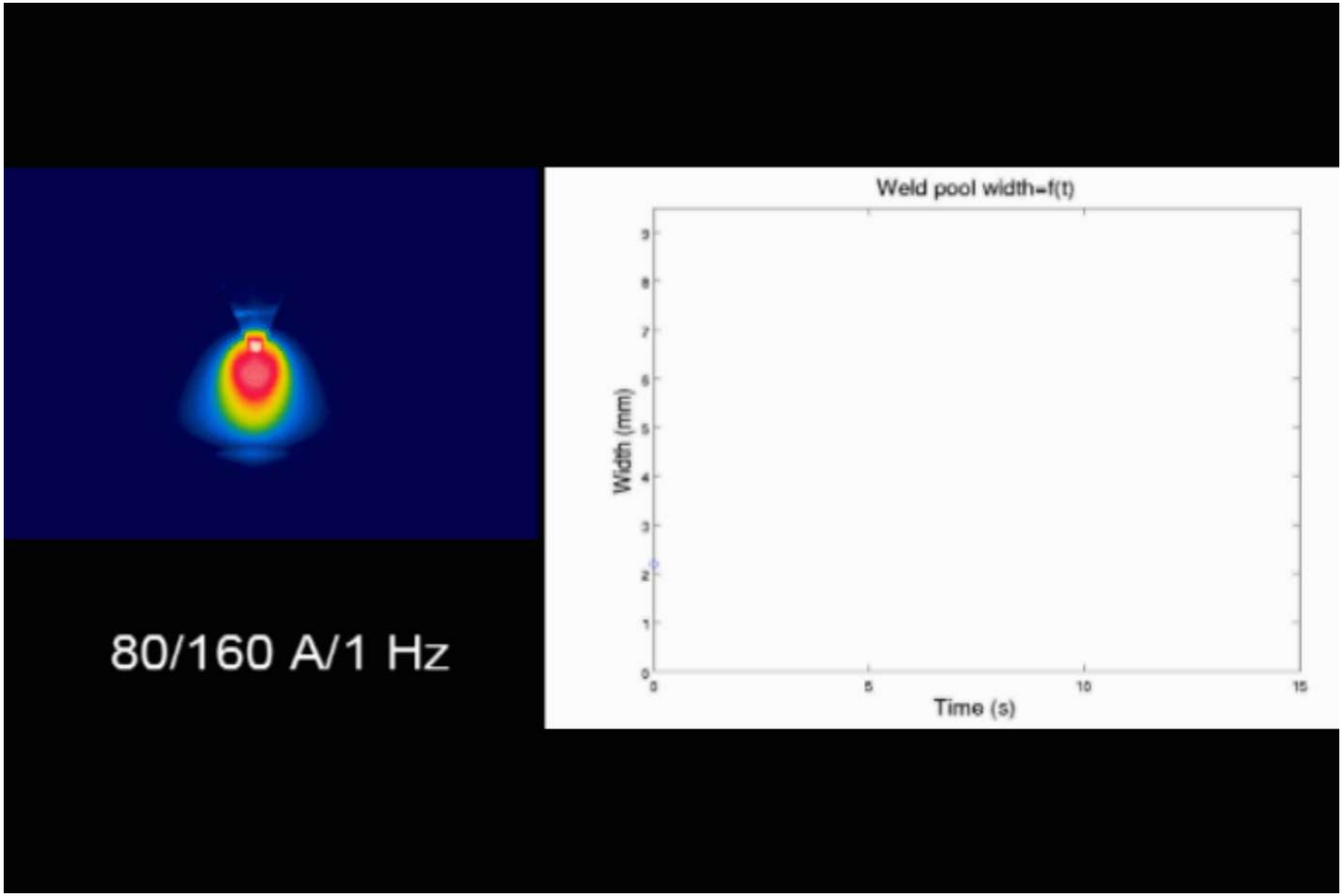
Experimental validation

Validation

- *Experimenal width of the weld pool* *Matlab image processing algorithm*



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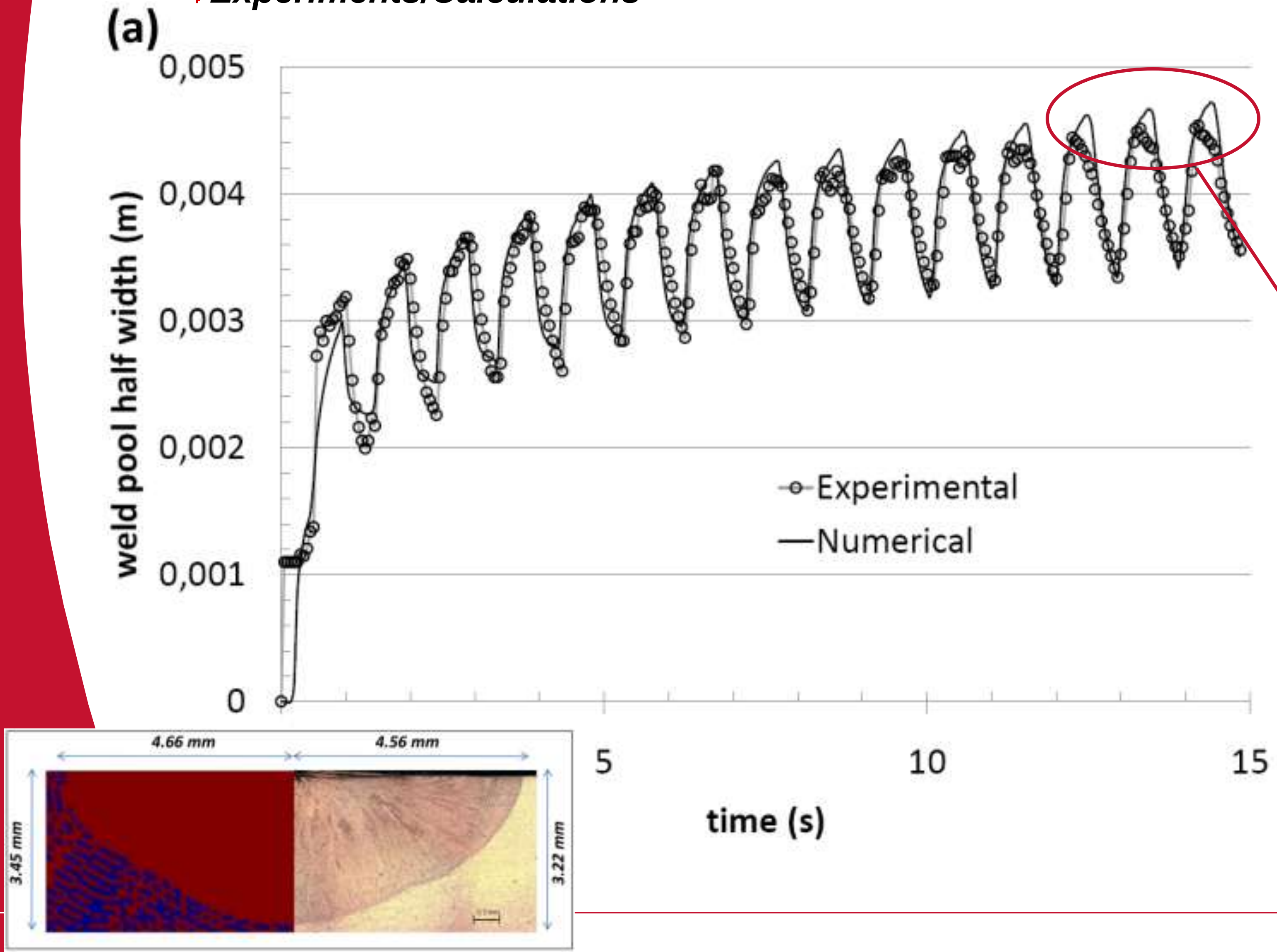
Experimental validation

Validation

Experiments/Calculations



Accumulation of metal vapors in the arc plasma

Thank you for your attention,

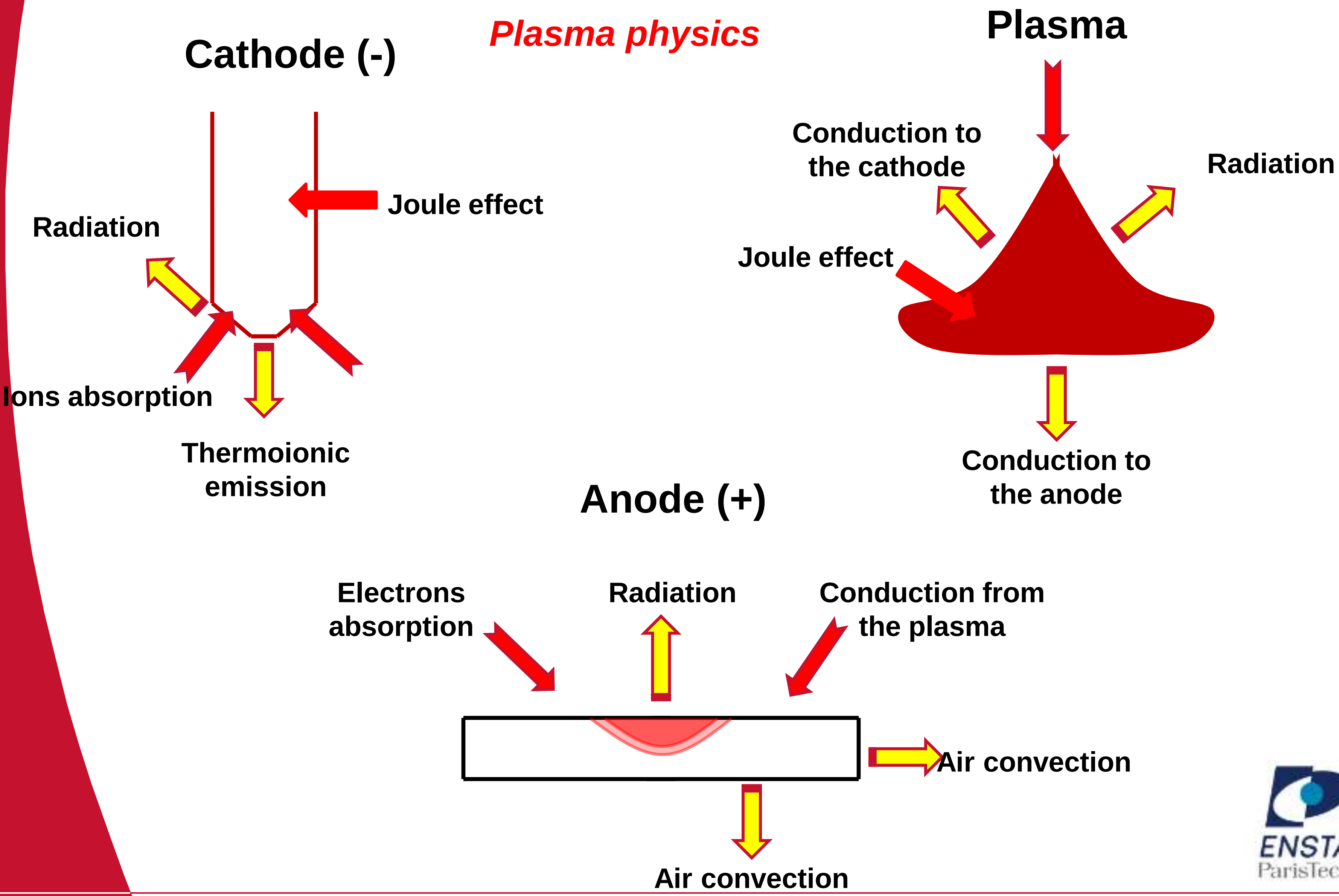
Any questions ?

traidia@ensta-paristech.fr

Numerical modeling of GTA welding

Appendix A

Plasma physics



Cathode (-)

Joule effect

Radiation

Ions absorption

Thermoionic emission

Plasma

Conduction to the cathode

Radiation

Joule effect

Conduction to the anode

Anode (+)

Electrons absorption

Radiation

Conduction from the plasma

Air convection

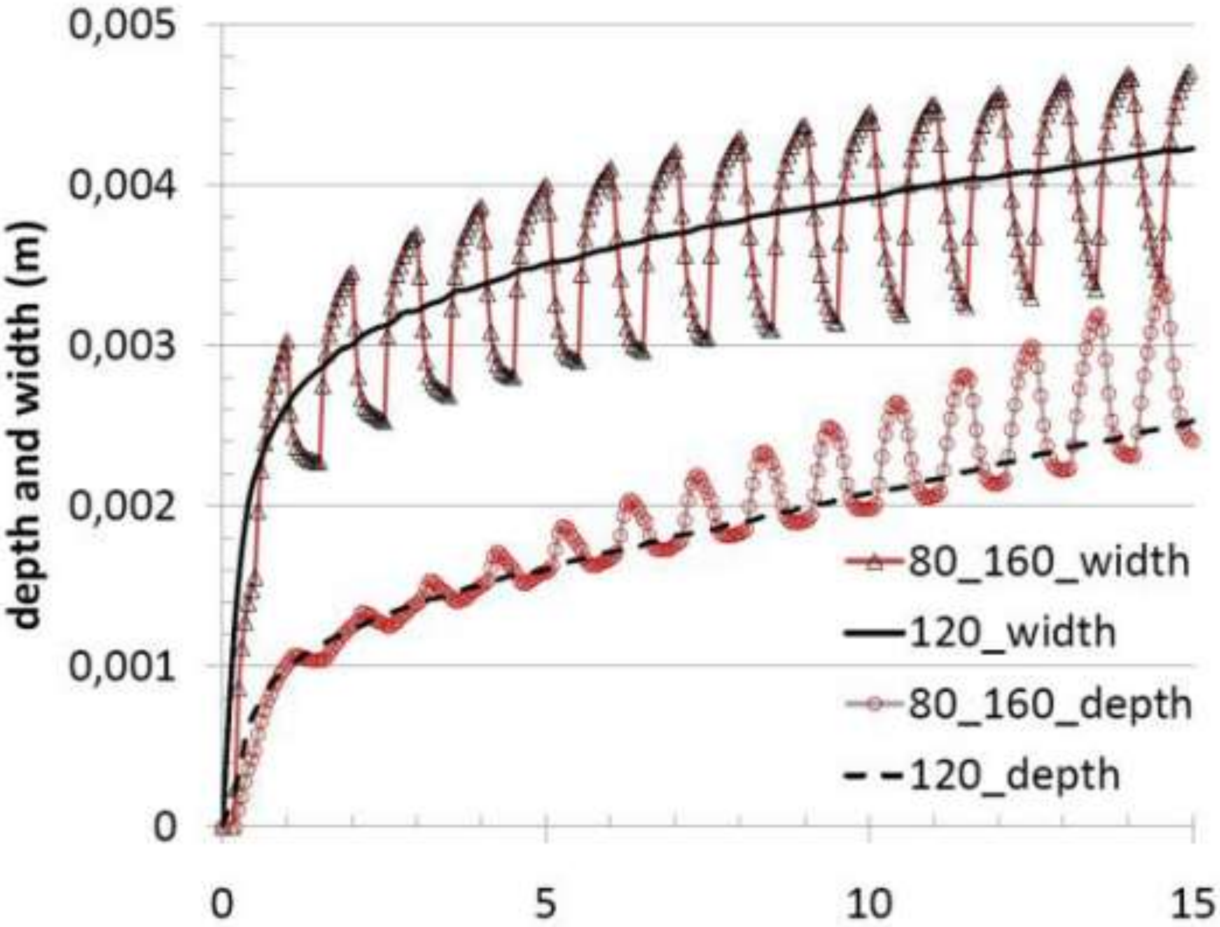
Air convection

traidia@ensta-paristech.fr

Numerical modeling of pulsed GTA welding

Appendix B *Application to pulsed current welding*

80/160 A- 1 Hz
α 60°- h 3 mm



Weld pool dimensions for a pulsed current welding and its constant mean current

traidia@ensta-paristech.fr