Free Surface Deformation of the Weld Pool in Orbital Narrow Groove GTA Welding

October 23, 2018

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COMSOL CONFERENCE 2018 LAUSANNE

Contents

- Presentation of SIMTEC
- Case of application : **G**as **T**ungsten **A**rc **W**elding
- Physical phenomena & Modeling
- Results
- Summary & Future Work

Working with SIMTEC

Industry Challenges

- R&D sections: experts in their field
  → Expertise in numerical modelling?
- Lack of time
- FE modelling performed by a small group of people

SIMTEC's Solutions

- Numerical modelling project
  → SIMTEC's member as your colleague
  → Help improve your modelling knowledge!
  → Cost-effective outsourcing

Our team & Our clients

COMSOL Certified Consultant

Numerical Modelling Consultants

6 Members all EngD + PhD

- Extensive research background
- Complex problems
- Various fields of expertise

Successful Track Record:

- Big international compagnies
- Government laboratories

Involved in Research Consortia

- EU funded projects (REEcover / SHARK)
- PhD projects supervision.

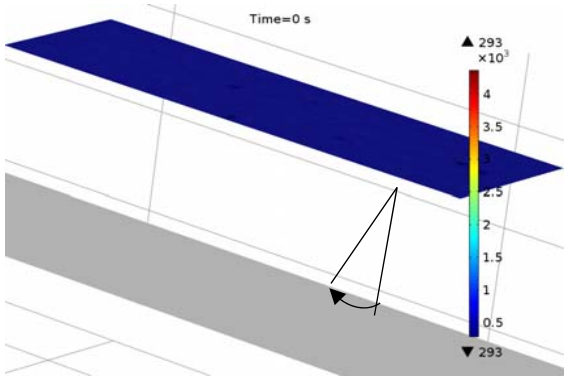
EUROPEAN COMMISSION
SEVENTH FRAMEWORK PROGRAMME
REEcover
SHARK
INDUSTRIALISING LASER FUNCTIONAL TEXTURING

→ Discover more about our successful modelling work with clients!
www.simtecsolution.fr

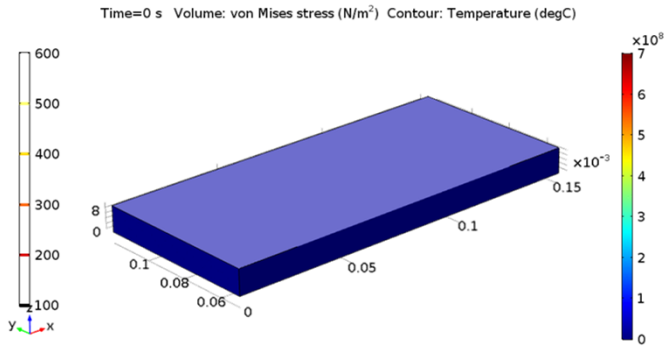
Assembly Process Modelling

cea framatome SHARK INDUSTRIALISING LASER FUNCTIONAL TEXTURING

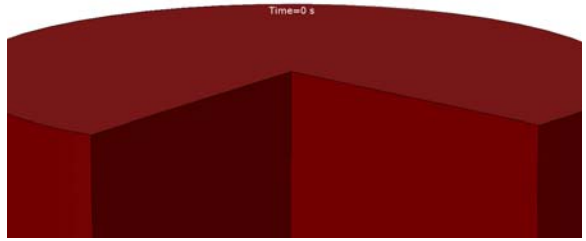
Continuous Laser Welding



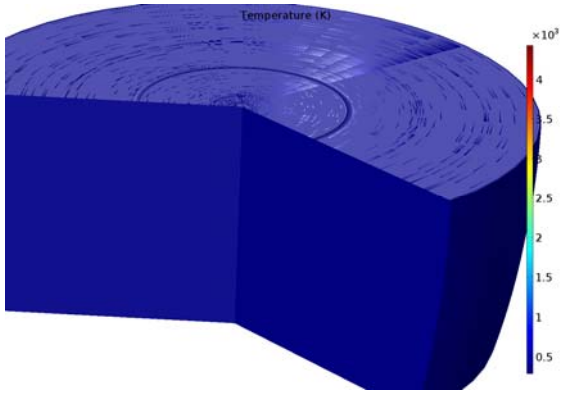
Additive Manufacturing



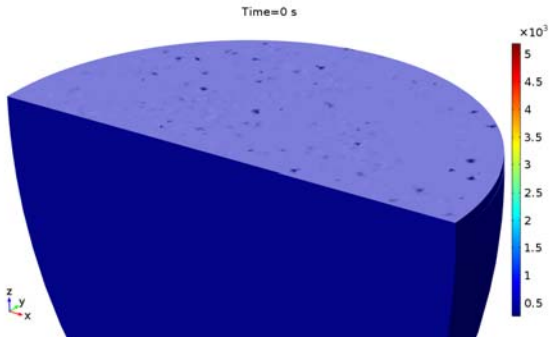
Laser Surface Texturing



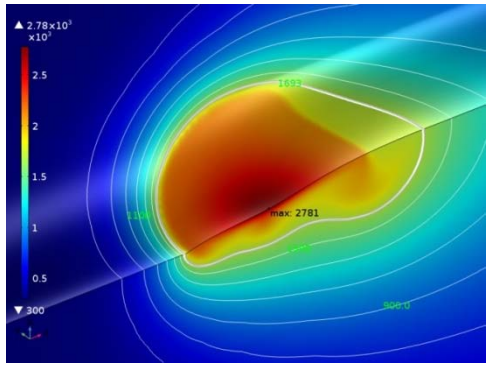
Laser Drilling



Heterogeneous Laser Welding

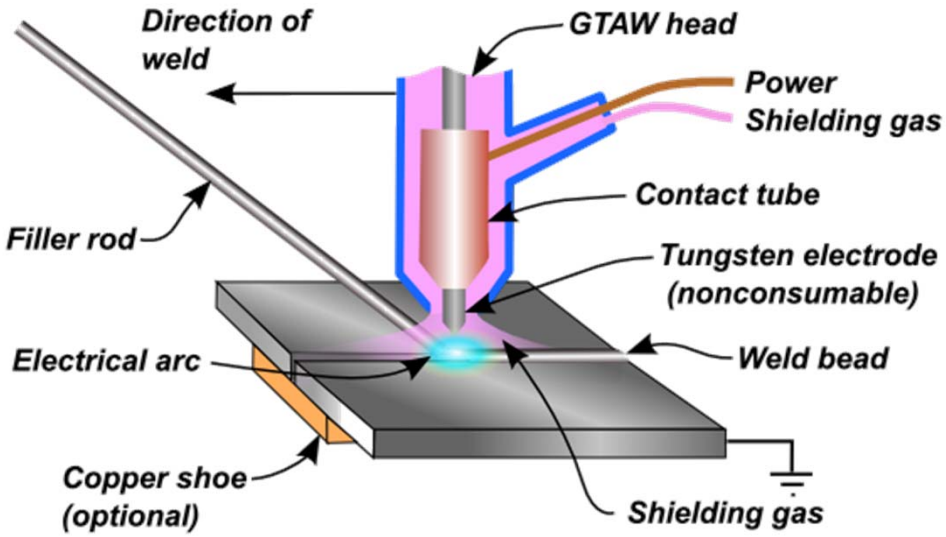


GTA Welding



Process Description and Objectives

Gas Tungsten Arc Welding (GTAW)



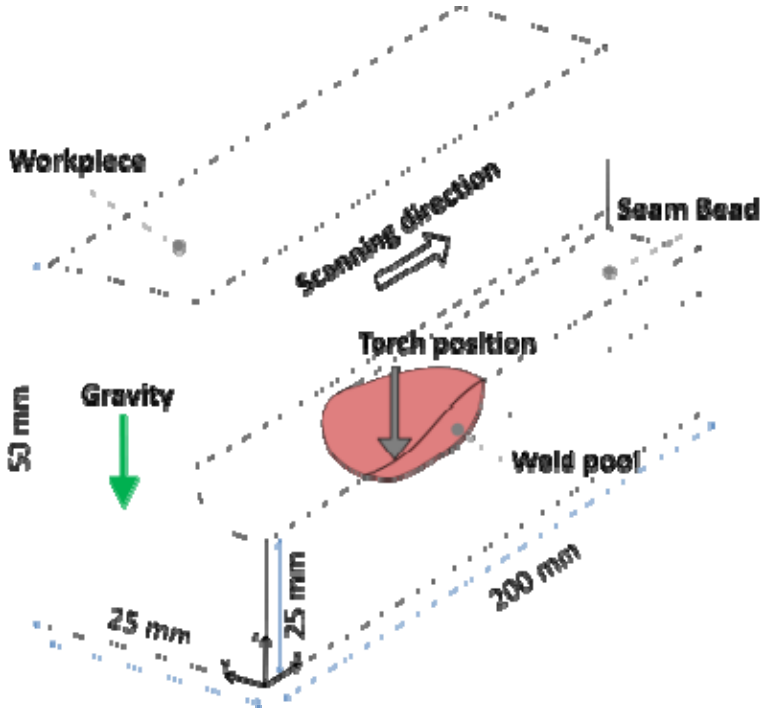
https://en.wikipedia.org/wiki/Gas_tungsten_arc_welding

- To **understand** the welding process behavior and the influence of all the process parameters
- To **predict** the dimensions of the Melted Zone, the Heat Affected Zone and the Weld Bead
- To **improve** the robustness of a welding application

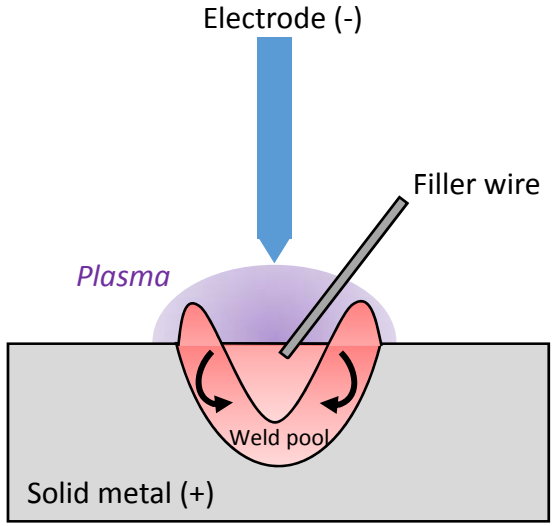
Geometry and Materials

- Narrow Groove Welding
- 3D model
- One symmetry plane
- Material: 316L stainless steel

IAEA report, "Thermophysical properties of materials for nuclear engineering: a tutorial and collection of data" (2008)



Physical Phenomena & Modelling



Electro-Magnetism

$$\nabla \cdot (\sigma \nabla V) = 0$$

$$\nabla \times \left(\frac{1}{\mu_0} \nabla \times \mathbf{A}\right) + \sigma \nabla V = 0$$

Energy Balance

$$\rho C_p (\mathbf{u} - \mathbf{u_{weld}}) \cdot \nabla T = \nabla \cdot (k \nabla T) + Q_{EM}$$

Mass and Momentum Balances

$$\nabla \cdot (\boldsymbol{u}) = 0$$

$$\rho_L (\mathbf{u} \cdot \nabla)\mathbf{u} = \nabla \cdot \left(-p\mathbf{I} + \mu\left(\nabla \mathbf{u} + (\nabla \mathbf{u})^T\right)\right) + \mathbf{F_{Darcy}} + \mathbf{F_{EM}} + \mathbf{F_{Buoyancy}}$$

Free Surface Description [1]

$$-\nabla \cdot \left(\frac{\gamma}{\sqrt{1 + \phi_x^2 + \phi_y^2}} \nabla \phi\right) = P_{arc} + \rho g + \lambda$$

Moving Mesh (Hyperelastic)

$$W = \int_\Omega \frac{\eta}{2}(I_1 - 3) + \frac{\kappa}{2}(J - 1)^2 dV$$

Mechanisms

Joule Heating
Lorentz Force

Liquid/solid transition
Evaporation
Buoyancy
Marangoni effects

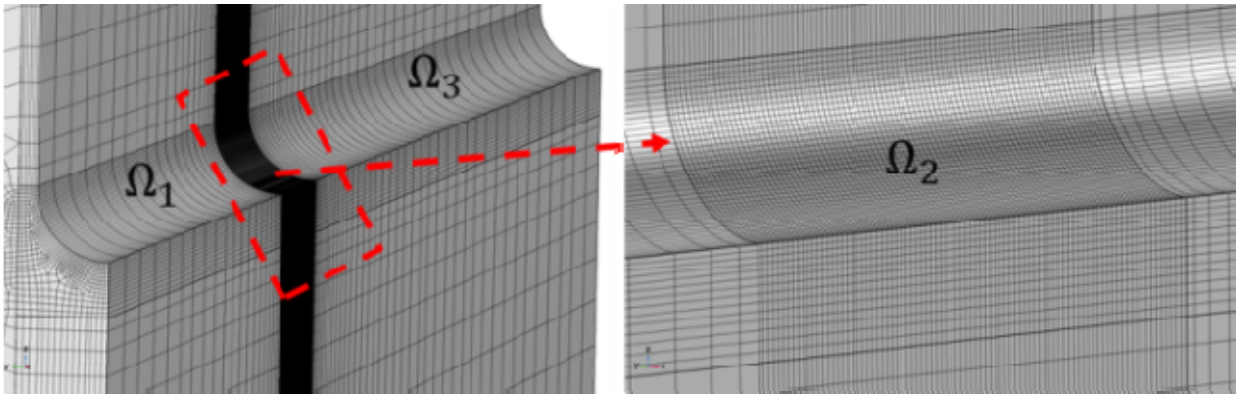
Gravity
Surface tension
Arc pressure

Filler Metal

[1] Wu et al., Numerical analysis of both front-and back-side deformation of fully penetrated GTAW weld pool surfaces, *Computational Materials Science*, **39**, 635-642 (2007)

Numerical Aspects

- Fine and mapped mesh



- Strong couplings (multi-physics) and highly non-linear problem

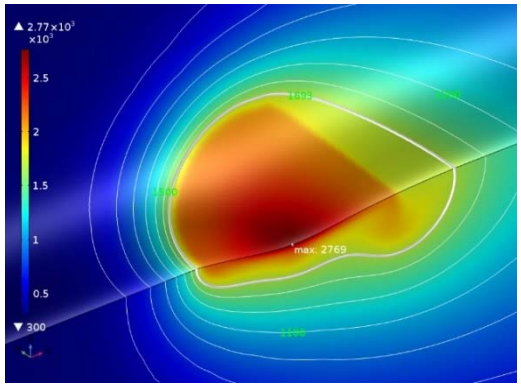
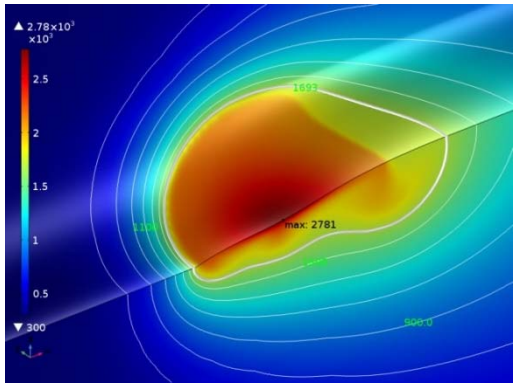
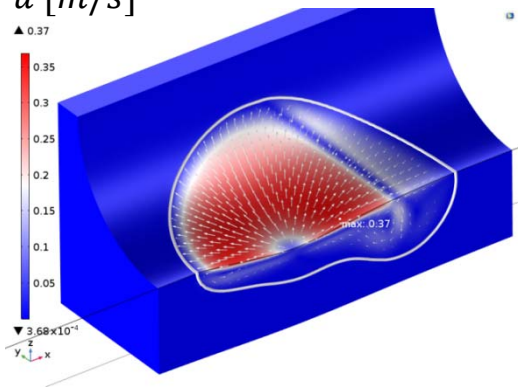
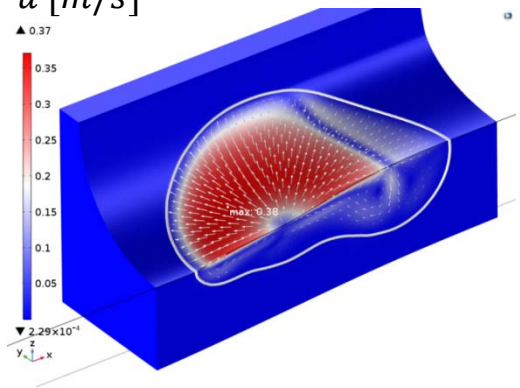
  → **Adapted solving strategy**

  - Each equation is firstly solved separately
  - Thermo-hydraulic problem is then solved in the new configuration
  - The segregated solver is lastly used to solve the whole problem

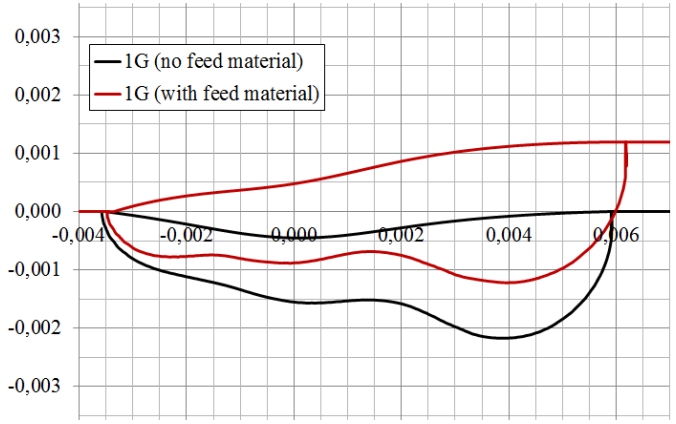
- ≅ 1 million of DoF → 10 hours with 6 cores and 192 Go RAM

Results

Influence of the filler metal

without filler metal	with filler metal
$T\ [K]$	$T\ [K]$
	
$u\ [m/s]$	$u\ [m/s]$
	

Comparison of cross-sections

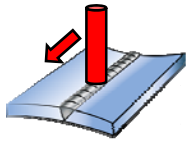


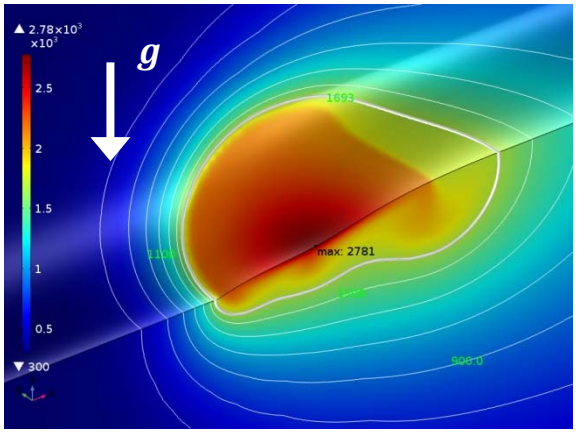
- **Convective cells** with contrary rotation making the **melt pool deeper at the rear** than under the welding torch
- **Little impact** of the filler metal on **the velocities and Temperature maximum**
- **Melt pool volume** remains the same for both configurations
- **Penetration depth decreases** for the case **with filler metal** and **creation of a weld bead**

Results

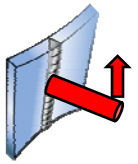
Influence of the welding position

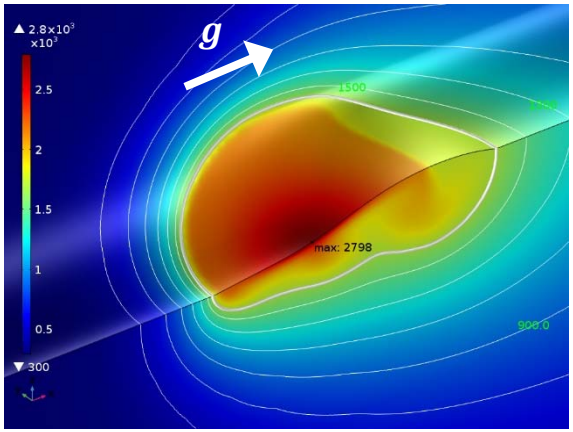
1G (flat) *g*



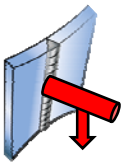


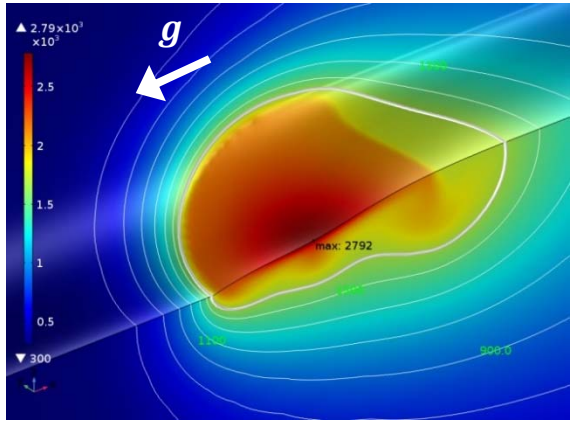
3GU (vertical up) *g*

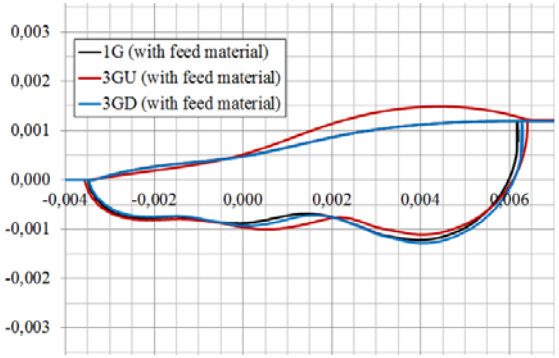




3GD (vertical down) *g*







- 1G and 3GD show little difference
- 3GU shows a larger deformation at the back of the pool → **effect of the heavy liquid metal**
- **Limited sensitivity to the welding position**

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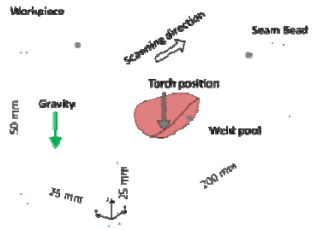
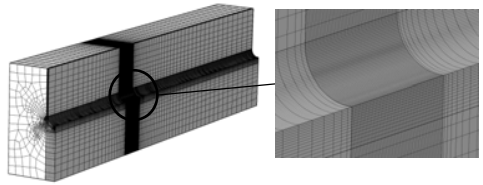
Summary & Future Work

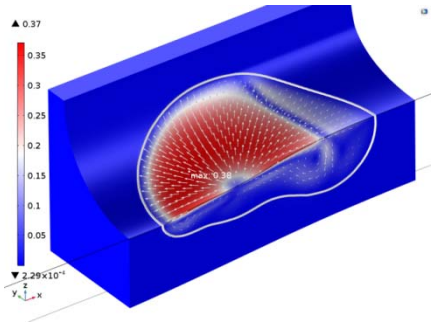
- **3D Multiphysics** Model applied to GTA Welding and taking into account several physical phenomena on **an industrial application geometry**



- **Numerical aspects** carefully managed to obtain stationary state convergence



- **Numerical trends in agreement with literature data**



- Comparison in progress with **experimental data**

Thanks for your attention .. and your questions!

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Results

Influence of the filler metal