COMSOL CONFERENCE BOSTON 2013

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Modeling of Transport Phenomena in Gas Tungsten Arc Welding of Ni to 304 Stainless Steel

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COMSOL Conference

10/10/2013

Excerpt from the Proceedings of the 2013 COMSOL Conference in Boston

Motivation

•Joining of dissimilar metals / alloys by using arc welding has been a challenge in several industries such as power plants and offshore piping.

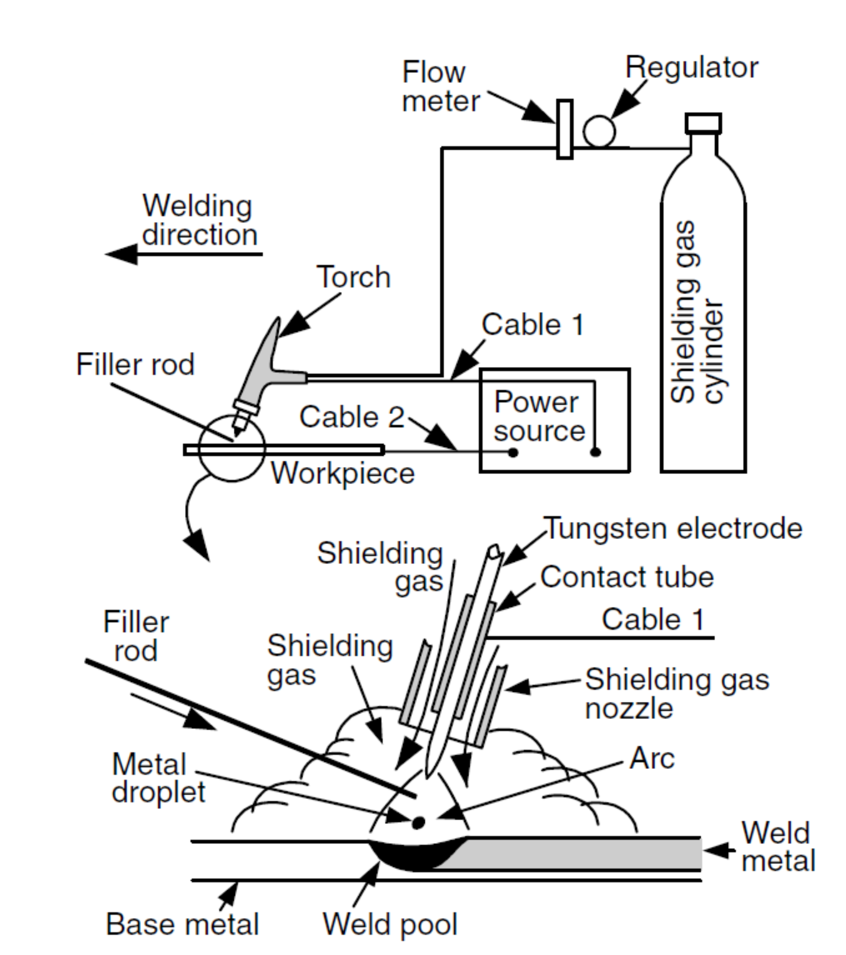
•Challenging physics behind the welding of dissimilar alloys is not yet well understood, because of differences in the thermo-physical, mechanical, and metallurgical properties.

For this reason to produce quality dissimilar welds, it is necessary to perform mathematical / numerical modeling of transport phenomena in the weld pool during melting & solidification.

Not only does modeling of the dissimilar welds provide a better understanding of the physics behind it, but also is a more cost effective process to produce high quality welds.

Gas Tungsten Arc (GTA) welding

- An arc is established between a tungsten electrode and the base metal.
- Tungsten electrode is not a consumable.
- An inert shielding gas protects the weld from the atmosphere



(Welding Metallurgy; S. Kou; 2003)

Transport phenomena

- Physics involved in the welding process
  - Electromagnetics
  - Fluid flow
  - Heat transfer

- Dissimilar welding
  - Different properties
  - Three dimensional modeling
  - Mass transfer

- **Weld zone shape and penetration**
- **Dilution**
- **Cooling rate (Thermal cycle)**
- Heat affected zone geometry / width
- Thermal stress residues
- Defect formation

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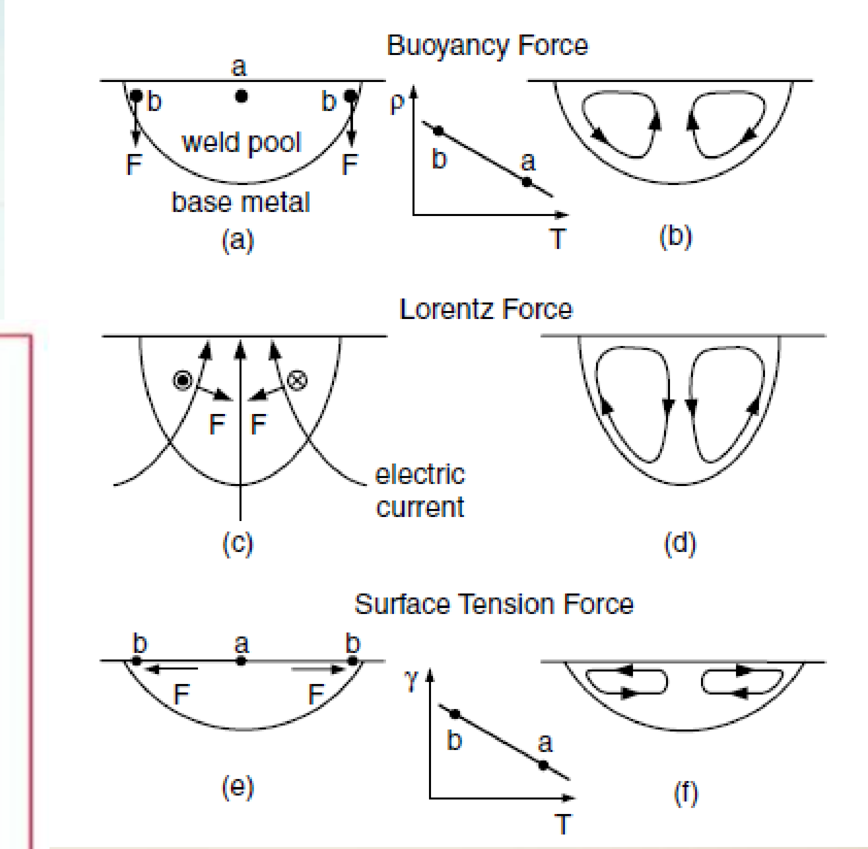
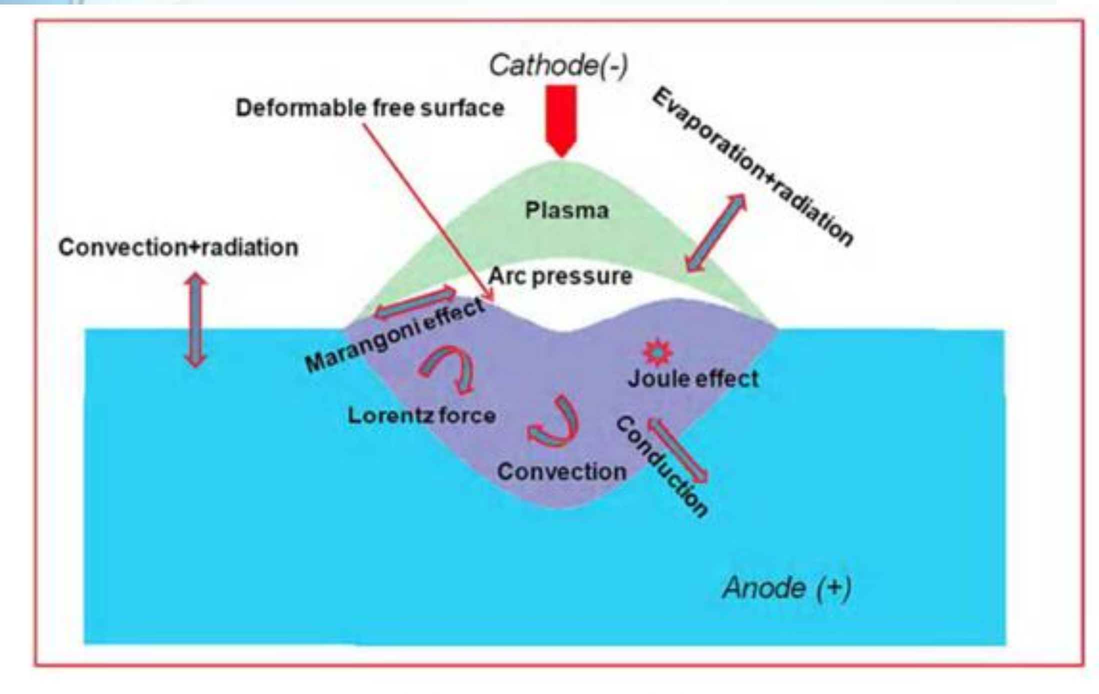
Convective Forces

- Buoyancy force
- Lorentz Force
- Marangoni effect
  depends on dγ/dT





(Welding Metallurgy; S. Kou; 2003)

Mathematical Formulations

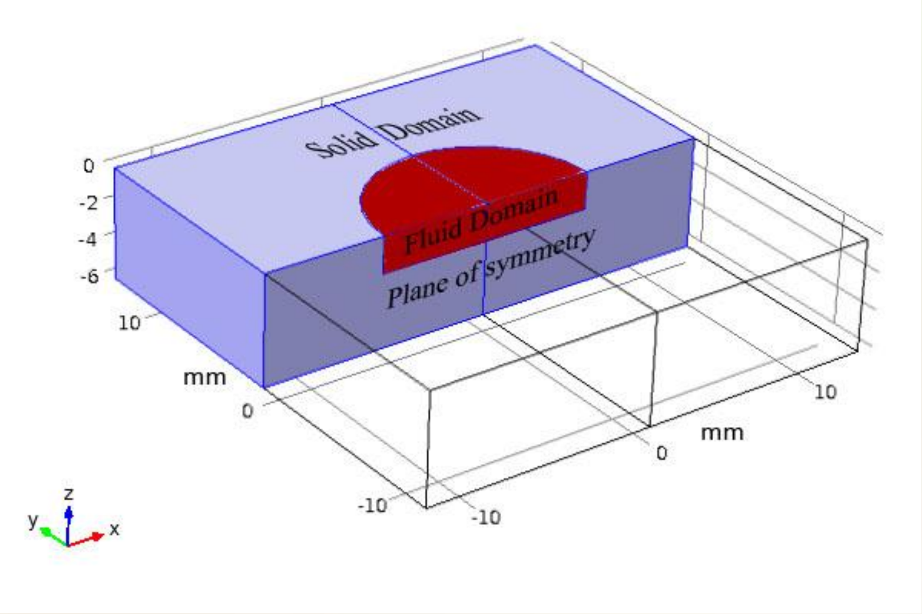
Classic transport equations are solved for the domain

Momentum equation:

$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho \mathbf{u}.\nabla \mathbf{u} = \nabla.\left[-p\mathbf{I} + \mu(\nabla \mathbf{u} + (\nabla \mathbf{u})^T) - \frac{2\mu}{3}(\nabla.\mathbf{u})\mathbf{I} \right] + \mathbf{F_d} + \mathbf{F_b}$$

$$\mathbf{F_b} = \mathbf{J} \times \mathbf{B} + \rho_0 \big(1 - \beta(T - T_s)\big)\mathbf{g}$$

$$\mathbf{F_d} = \frac{(1 - f_l)^2}{{f_l}^3 + \varepsilon} A_{mush}\mathbf{u}$$



Mathematical Formulations

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Marangoni effect:

$$\mu \frac{\partial u}{\partial z} = f_l \frac{d\gamma}{dT} \frac{\partial T}{\partial x}$$

$$\mu \frac{\partial v}{\partial z} = f_l \frac{d\gamma}{dT} \frac{\partial T}{\partial y}$$

Energy equation:

$$\rho C_p' \left(\frac{\partial T}{\partial t} + \mathbf{u}.\nabla T \right) = \nabla.(k\nabla T) + Q_e$$

$$C_p' = C_p + \delta(T)\Delta H_f$$

Material properties

- Solution properties:

$$\bar{A} = \Sigma\, x_i A_i$$

For ρ, μ, β, k, C_p and σ

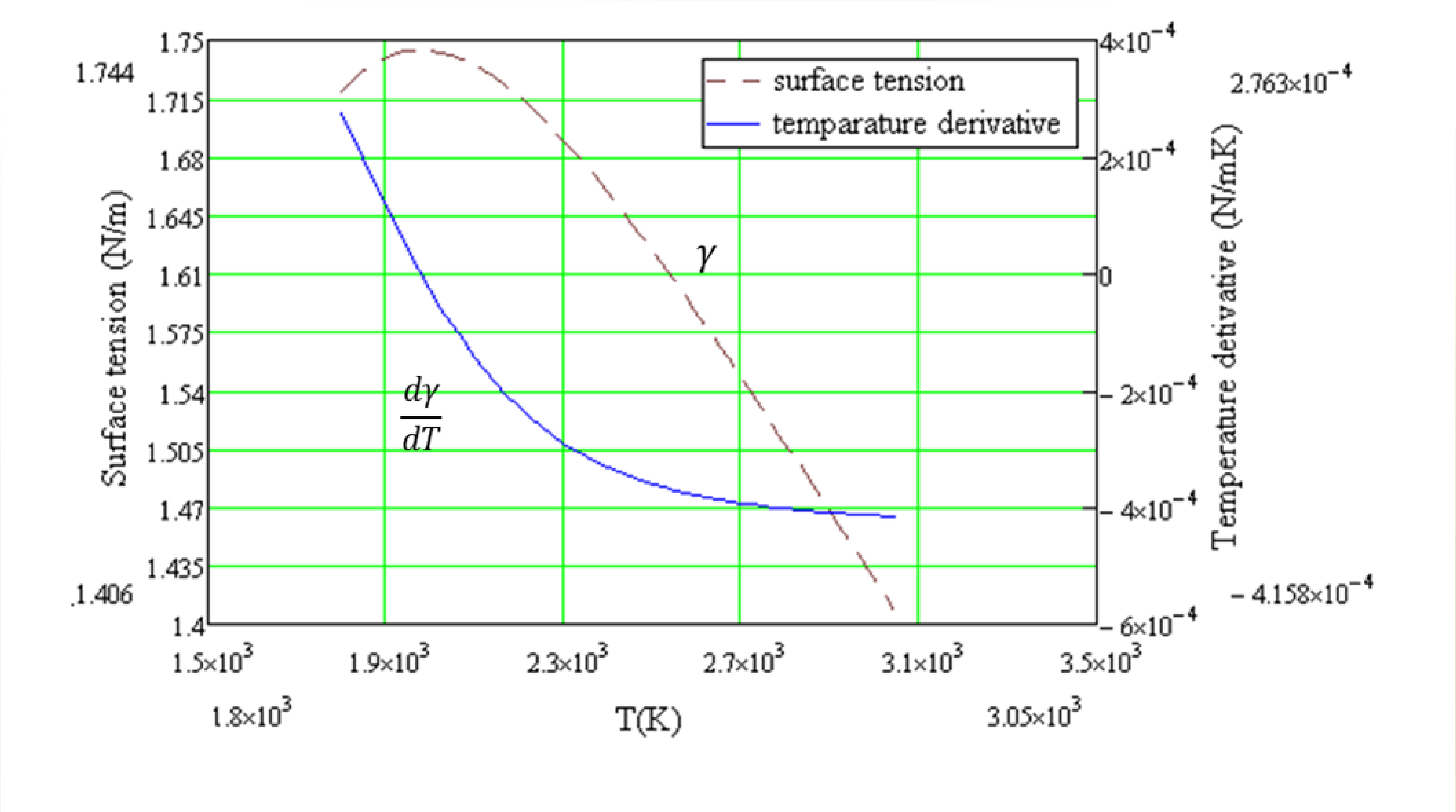
- Surface tension:

$$\gamma = \gamma_m - A_\gamma \left(T - T_l\right) - RT\Gamma_s \ln\left[1 + k_1 a_s \exp\left(\frac{-\Delta H_0}{RT}\right)\right]$$

$$\frac{d\gamma}{dT} = -A_\gamma - R\Gamma_s \ln\left(1 + Ka_s\right) - \frac{Ka_s}{1 + Ka_s}\frac{\Gamma_s \Delta H_0}{T}$$

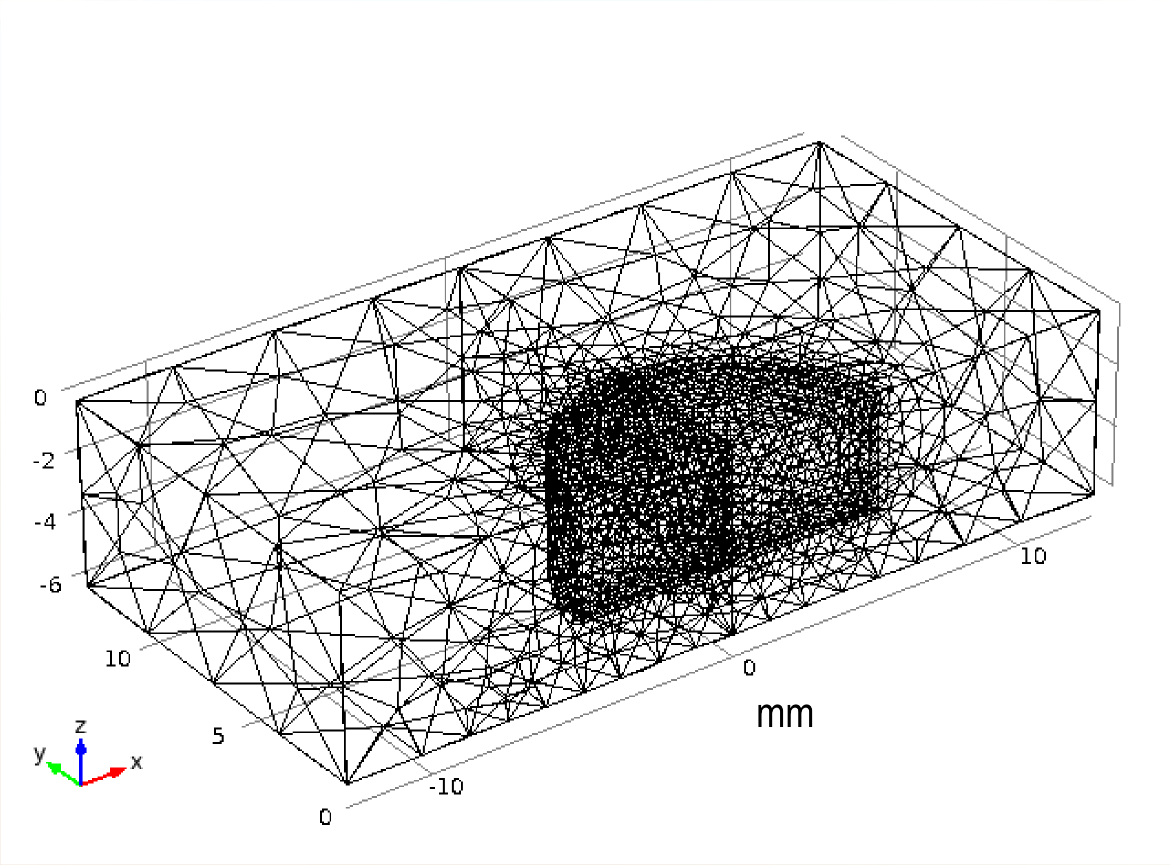
$$K = k_1 \exp\left(\frac{-\Delta H_0}{RT}\right)$$

For a_s =0.012 wt%

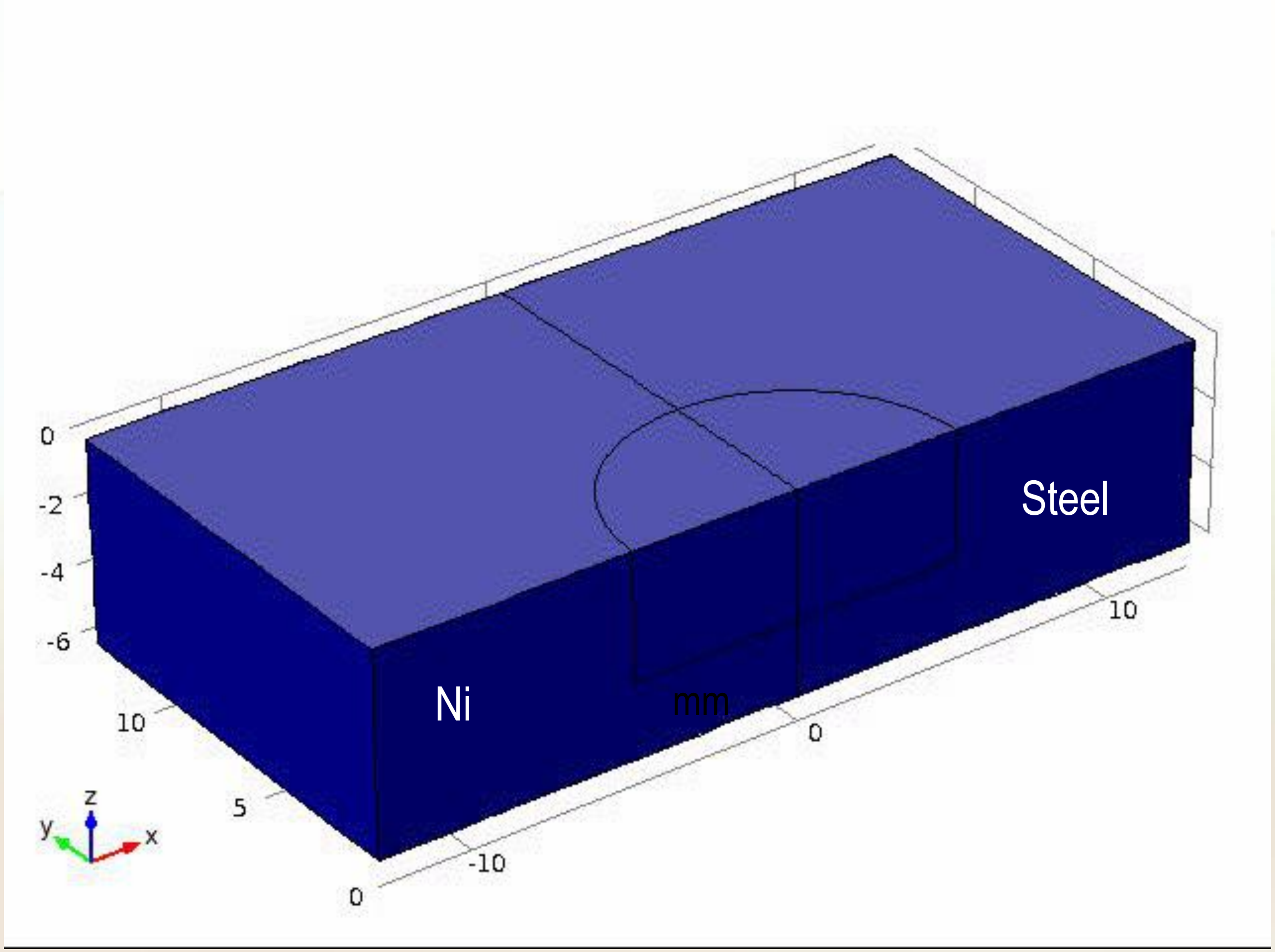


Numerical Method

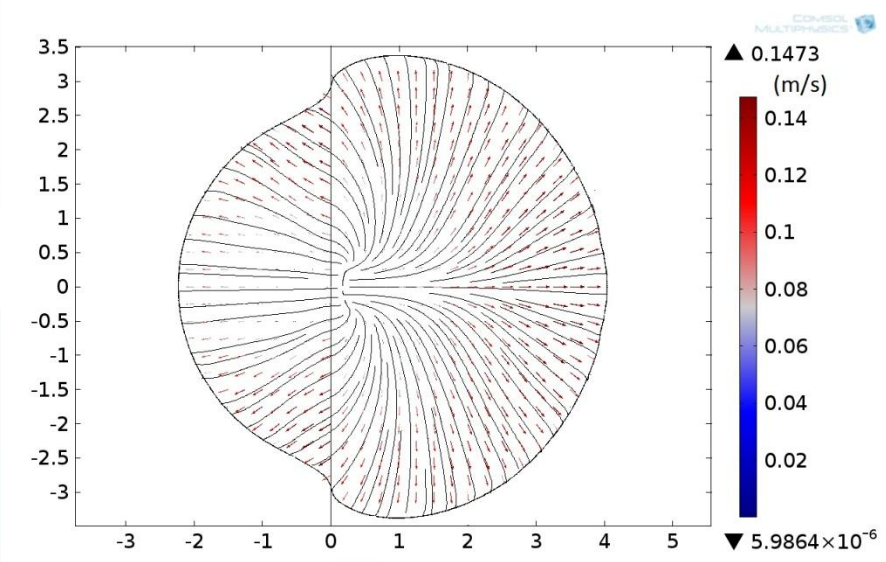
- Software: COMSOL Multi-Physics
- Physics :Electromagnetic Field, Fluid Flow and Heat transfer
- Mesh: Tetrahedral, 0.08 mm at Fluid and 1 mm at Solid Domain

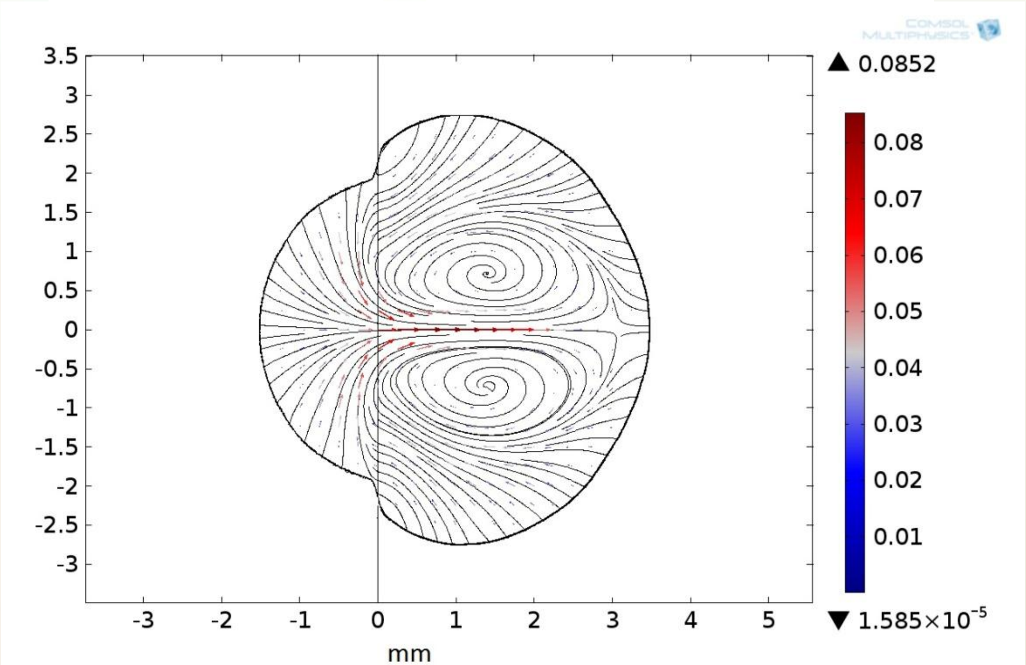


Numerical vs Experimental Results



Top View of the FZ





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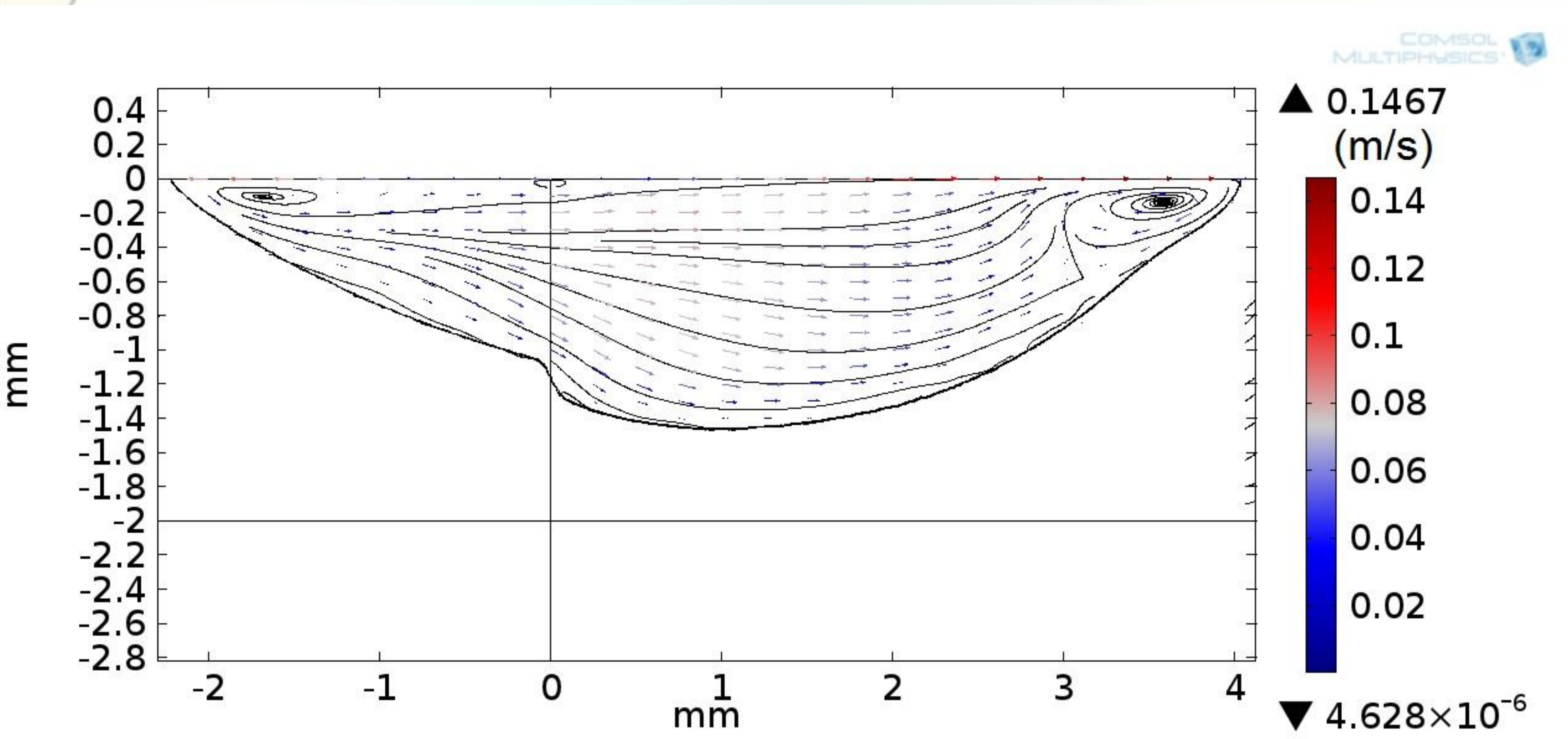
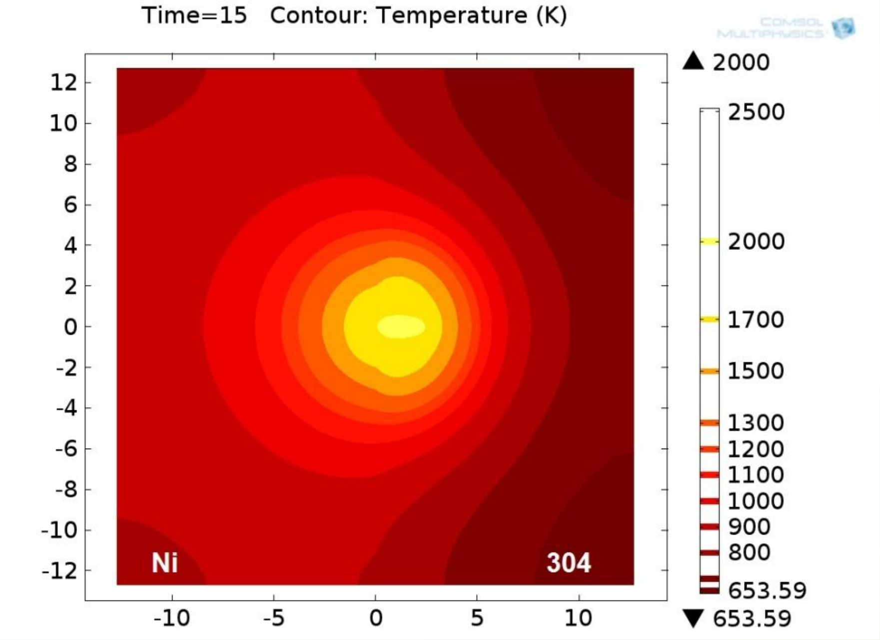
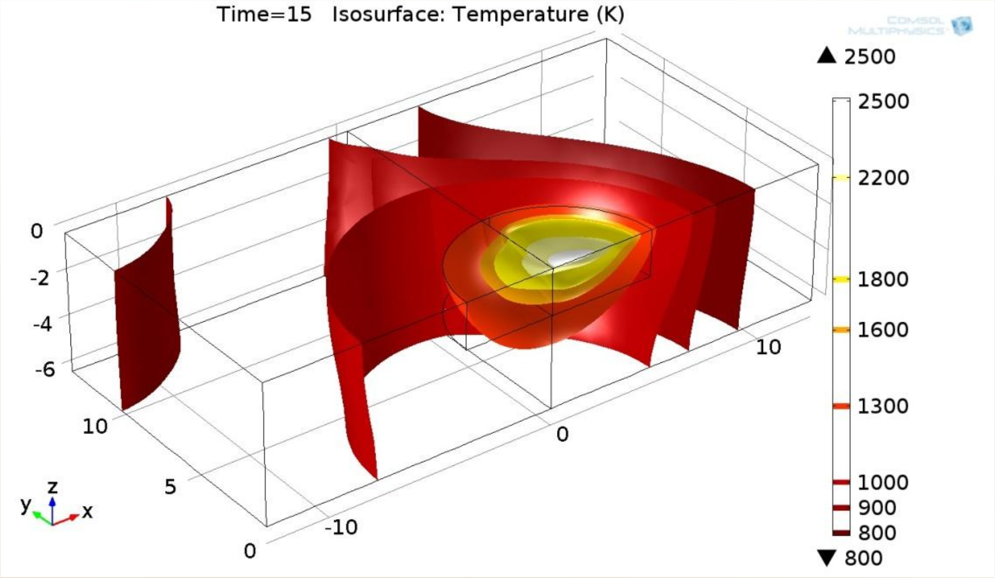
Side View of the FZ



1018 BM   2205 BM

Temperature Distribution





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Conclusion

- Weld profile is asymmetric due to different melting points.
- Higher Lorentz force in the Ni side pushes the fluid towards the steel side.
- At the top surface flow is under Marangoni effect.
- Conductive heat transfer is higher in the Ni side; therefore its temperature grows higher.

Thank You