Easy Teaching of Numerical Simulation of Welding with COMSOL®

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INTRODUCTION:

The initiation in numerical modeling of welding with COMSOL Multiphysics® is proposed to the 2nd year students of the Professional Master Program «Processes, Controls, Metallic Materials: Nuclear Industry» (PC2M) of University of Burgundy, France since 2016 within the module «Simulation of welding physics». This training follows transversal aims such as easy comprehension of the influence of operational parameters on weld properties, learning different kinds of physical phenomena of welding and getting hands-on experience in creation of multiphysical models.

PRACTICAL WORK 1: main principles of heat-transfer simulation in welding

- Quasi-steady approach

$$Q_{surf} = \frac{\eta \cdot P}{\pi \cdot R^2} \exp\left(-0.5\frac{(x^2+y^2)}{R^2}\right)$$

$$\rho C_p \cdot \begin{bmatrix}0\\ V\\ 0\end{bmatrix} \cdot \nabla T = \nabla \cdot (k \nabla T)$$

- Time-dependent approach

$$Q_{surf} = \frac{\eta \cdot P}{\pi \cdot R^2} \exp\left(-0.5\frac{(x^2+(y+V\cdot t)^2)}{R^2}\right)$$

$$\rho C_p \frac{\partial T}{\partial t} + \rho \cdot C_p \cdot \begin{bmatrix}0\\ 0\\ 0\end{bmatrix} \cdot \nabla T = \nabla \cdot (k \nabla T)$$

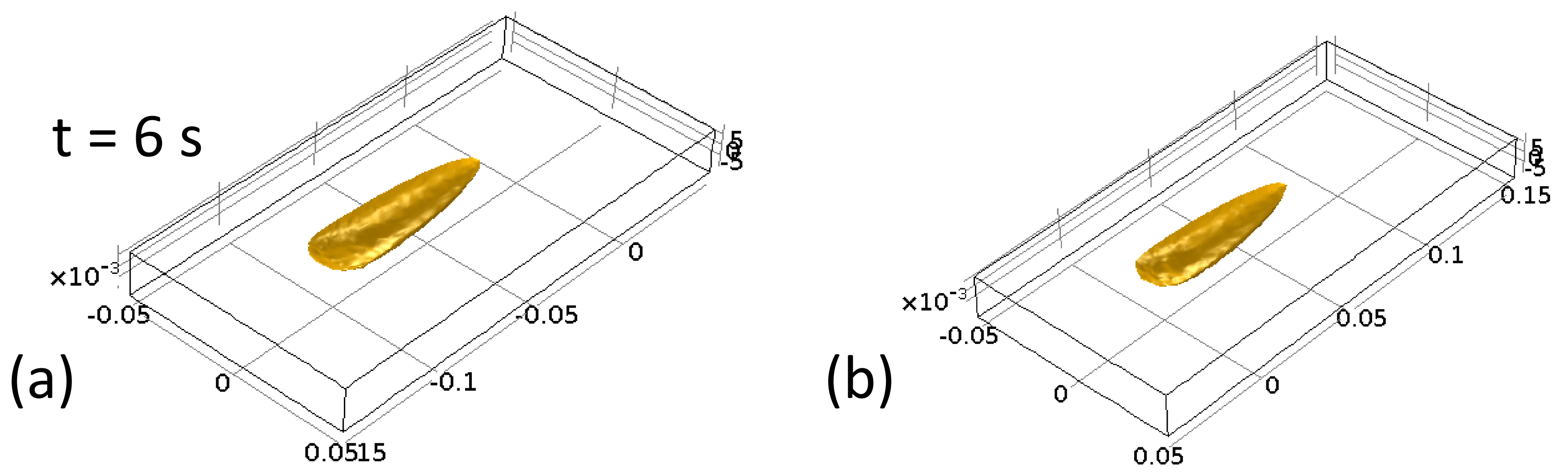


Figure 1. The comparison of 1673 K (solidus of AISI 304L) isotherm for time-dependent (a) and quasi-steady (b) models of heat source

PRACTICAL WORK 2 : role of materials properties and parametric study of input parameters

- Comparison of different materials
- The effect of constant and temperature-dependent material properties (+ latent heat of fusion)
- Parametric studies on welding parameters

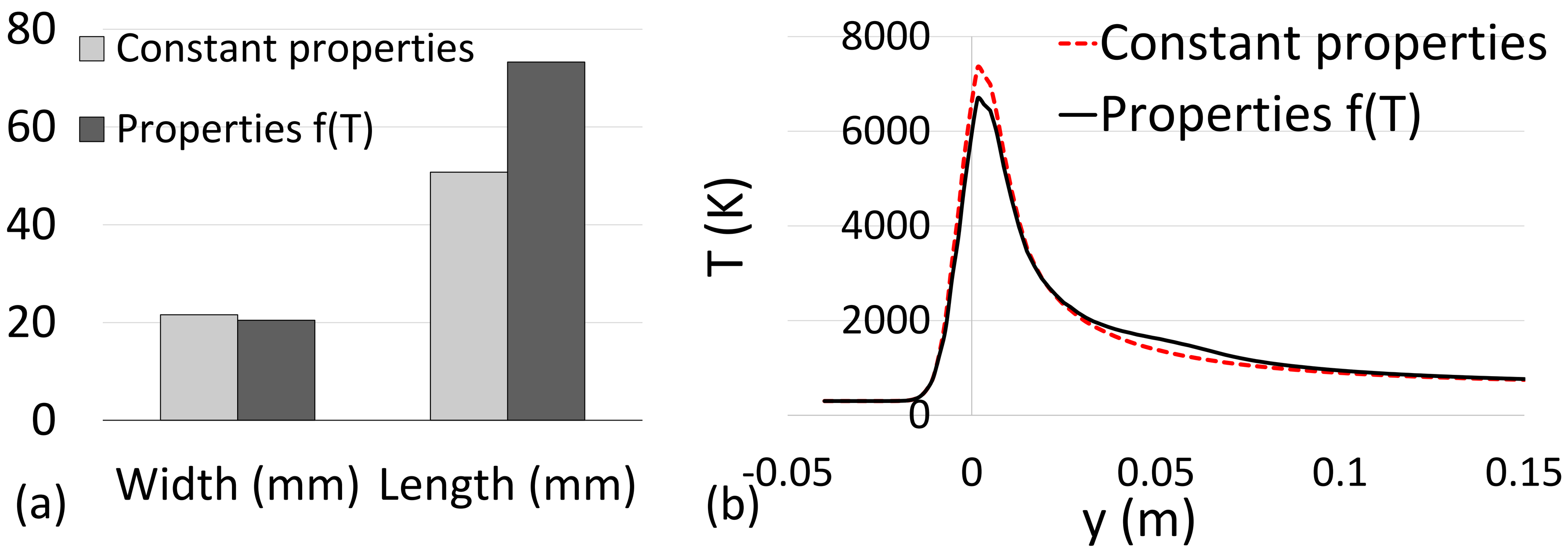
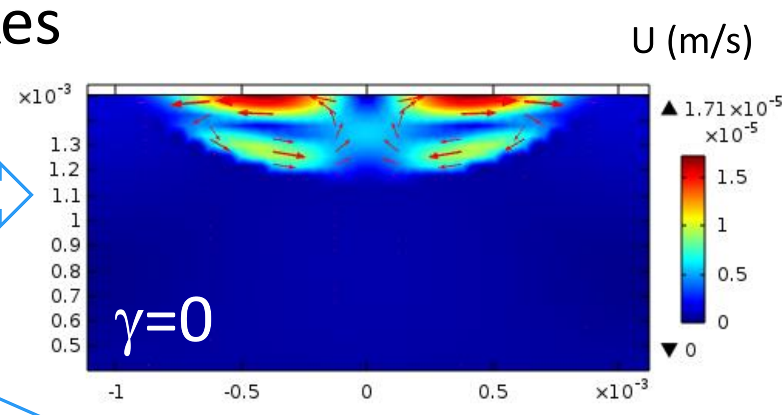


Figure 2. The dimensions of melted zone (a) and thermal history at the top of the joint line (b) compared for constant and temperature-dependent material properties of 16MnNiMo 5

PRACTICAL WORK 3: convective forces in welding

- Incompressible Navier-Stokes
- Newtonian liquid
- Natural convection
- Marangoni convection



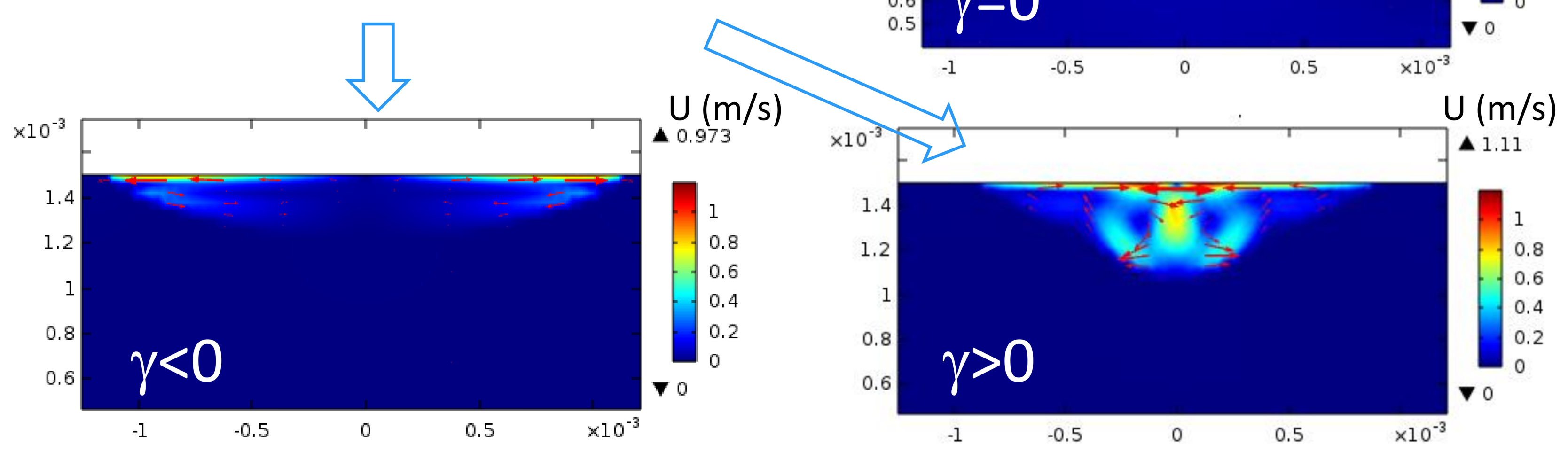


Figure 3. Velocity field of the melt (m/s)

Table 1. The effect of different convective forces on melting of metal plate with defocused laser (P = 1 kW, Ø = 0.2 cm)

Calculation	T_{max} (K)	Width (mm)	Height (mm)	U_{max} (m/s)
Heat transfer only	1249	2.27	0.43	0
Natural convection	1249	2.27	0.43	$1.71\cdot10^{-5}$
Marangoni effect, $\gamma = -4\cdot10^{-4}$ N/m/K	1209	2.50	0.39	0.97
Marangoni effect, $\gamma = 4\cdot10^{-4}$ N/m/K	1254	2.10	0.49	1.11

PRACTICAL WORK 4: simulating the elements transport in multimaterial welding

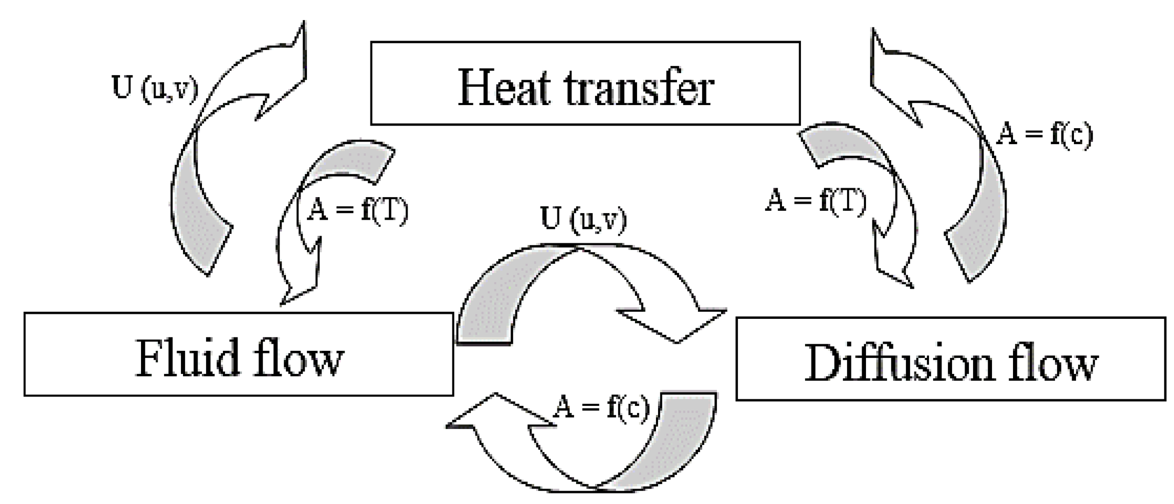


Figure 4. Triple multiphysics scheme

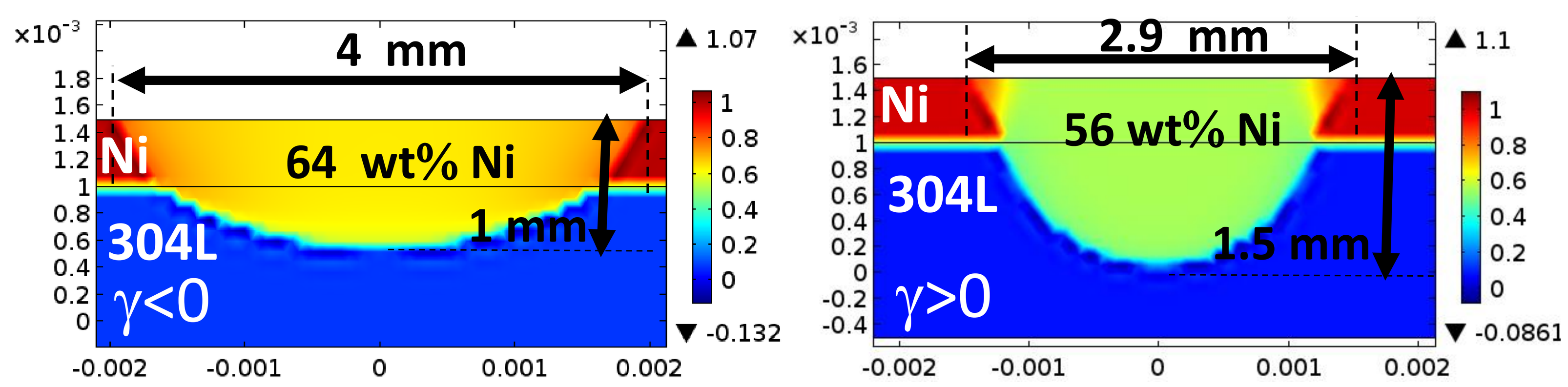


Figure 5. Final composition of the welds (wt% Ni)

CONCLUSIONS:

The use of COMSOL Multiphysics® allows easily apprehend the main principles of phenomenological simulation of welding process within rather short practical module of 12 h. The gradual increase in complexity allows the students to start with simple heat-transfer models and quickly progress up to double and triple multiphysics cases.