The Numerical Challenges in Multiphysical Modeling of Laser Welding with ALE

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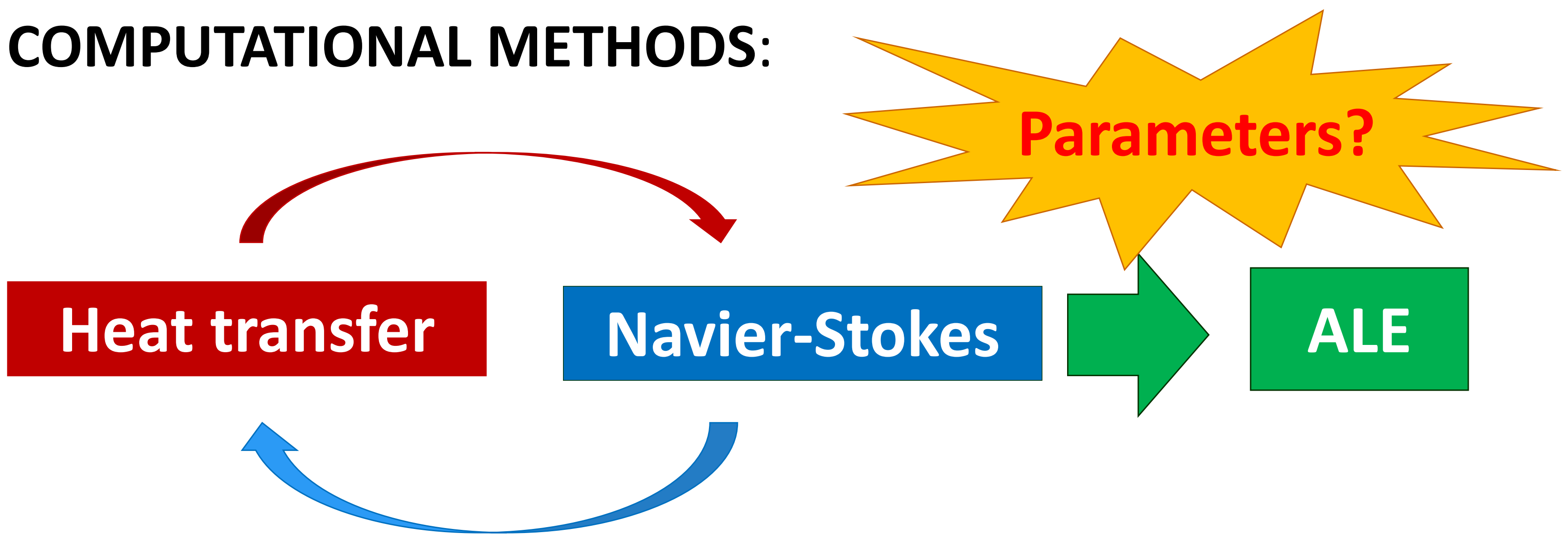
INTRODUCTION: The present work summarizes the numerical challenges in creation and validation of free-surface models using ALE moving mesh coupled with heat transfer equation and Navier-Stokes fluid flow. The influence of a set of numerical parameters as well as physical hypotheses on the dynamics of the keyhole and the characteristics of the melt formed in titanium alloy Ti-6Al-4V is analyzed.

COMPUTATIONAL METHODS:



Parameters?

Heat transfer

Navier-Stokes

ALE

Heat transfer

- time-dependent
- standalone laser pulse
- T-dependent absorption coefficient

$$\rho\, c_p^{\,eq}\left(\frac{\partial T}{\partial t}+\vec{U}\cdot\vec{\nabla}T\right)=\vec{\nabla}\cdot\left(\lambda\vec{\nabla}T\right)$$

$$c_p^{eq}=c_p+D_m.L_m \qquad D_m=\frac{e^{\frac{-(T-T_m)^2}{\Delta T}}}{\sqrt{\pi\Delta T^2}}$$

$$q_L=\frac{P_L A}{\pi r_0^2}e^{\left(-\frac{x^2+y^2}{r_0^2}\right)}\cdot\left(t<t_{pulse}\right)$$

$$A = A_{solid} + (A_{liquid} - A_{solid}) \cdot flc2hs(T-T_m, \Delta T),$$

$$A_{liquid} = A_{surf} + (A_{kh} - A_{surf}) \cdot flc2hs(T-T_v, \Delta T),$$

Navier-Stokes

Newtonian liquid
Mean viscosity in solid phase
Inconsistent stabilization

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

$$\rho\left[\frac{\partial\vec{U}}{\partial t}+\left(\vec{U}\cdot\vec{\nabla}\right)\vec{U}\right]=\vec{\nabla}\cdot\left[-pI+\eta(T)\left(\vec{U}\cdot\vec{\nabla}+\left(\vec{U}\cdot\vec{\nabla}\right)^t\right)\right]+\vec{F}$$

$$\eta(T)= \eta_{solid} + (\eta_{liquid} - \eta_{solid})\, flc2hs(T-T_m, \Delta T).$$

- natural convection (Boussinesq approximation),
- surface tension force /Marangoni convection
- recoil pressure in the keyhole

$$p_r=\frac{(1+\beta)}{2}\cdot a\cdot e^{-\frac{b}{T}+c}$$

ALE

- Hyperelastic smoothing is better
- Deformation driven by velocity field

?

Parametric studies :
- ALE smoothing methods
- Numerical stabilization of N-S equation
- Solid and liquid viscosity
- Adsorption in the keyhole A_{KH}
- Condensation coefficient β
- Incompressible VS weakly compressible N-S

RESULTS: Optimal parameters allow to reproduce the whole lifetime of the keyhole during pulsed welding of Ti6Al4V alloy (temperature field + velocity field).

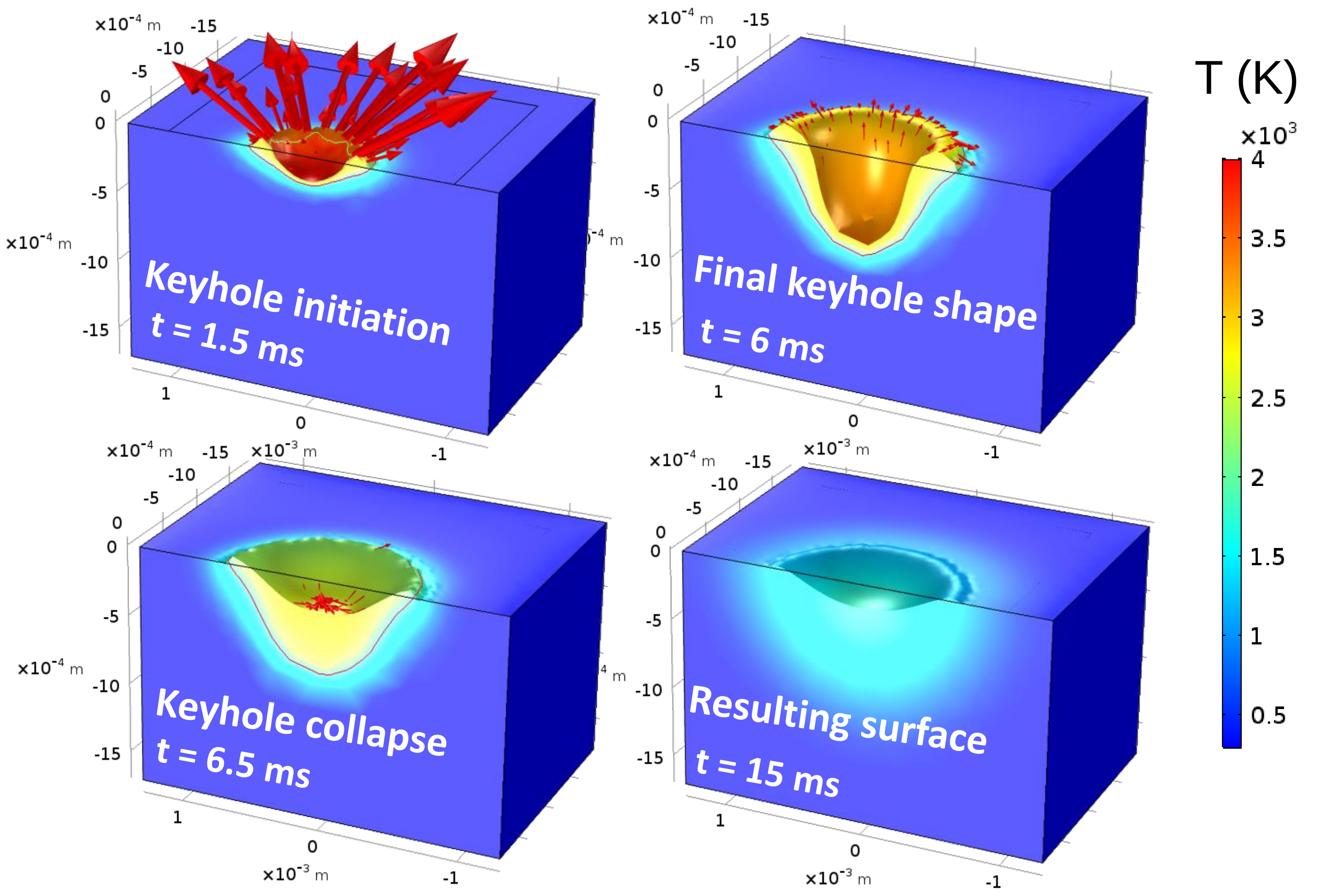


Figure 1. Nd:YAG laser pulse of 6 ms, 1.5 kW, Ø = 560 µm, η_{solid} = 200 Pa·s.

Influence of critical parameters:

Avoid low solid viscosity

- Parasite velocities in solid
- Less profound keyhole
- Unphysical relaxation of solid

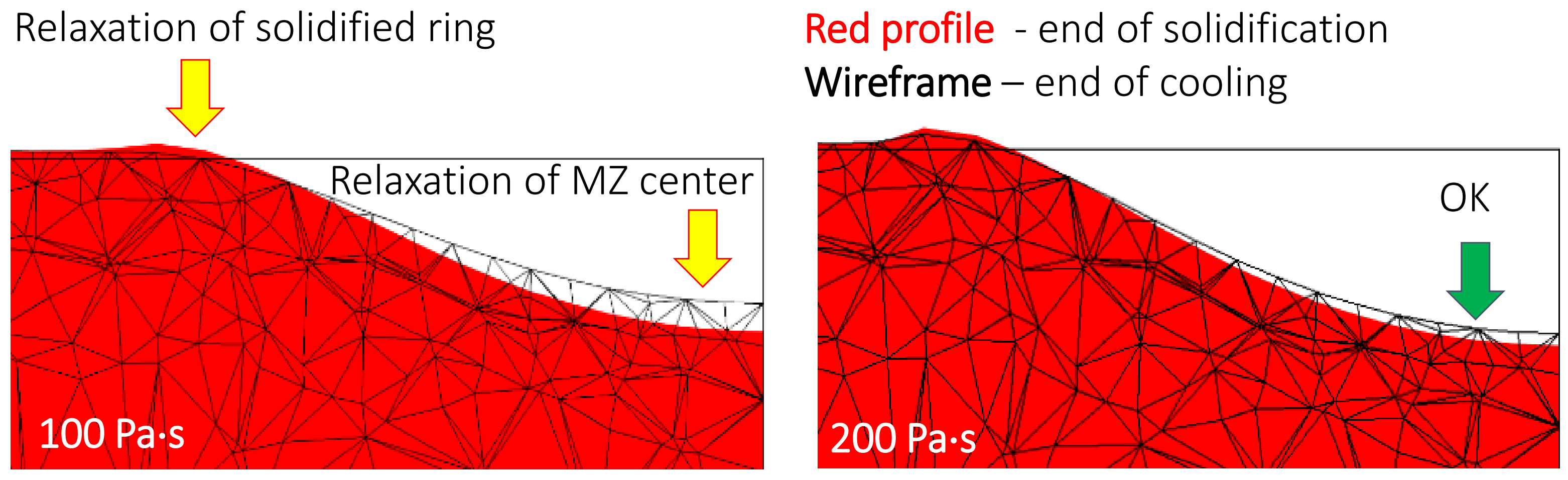


Figure 2. Unphysical relaxation of solidified weld between the end of solidification and the end of cooling for different solid viscosities.

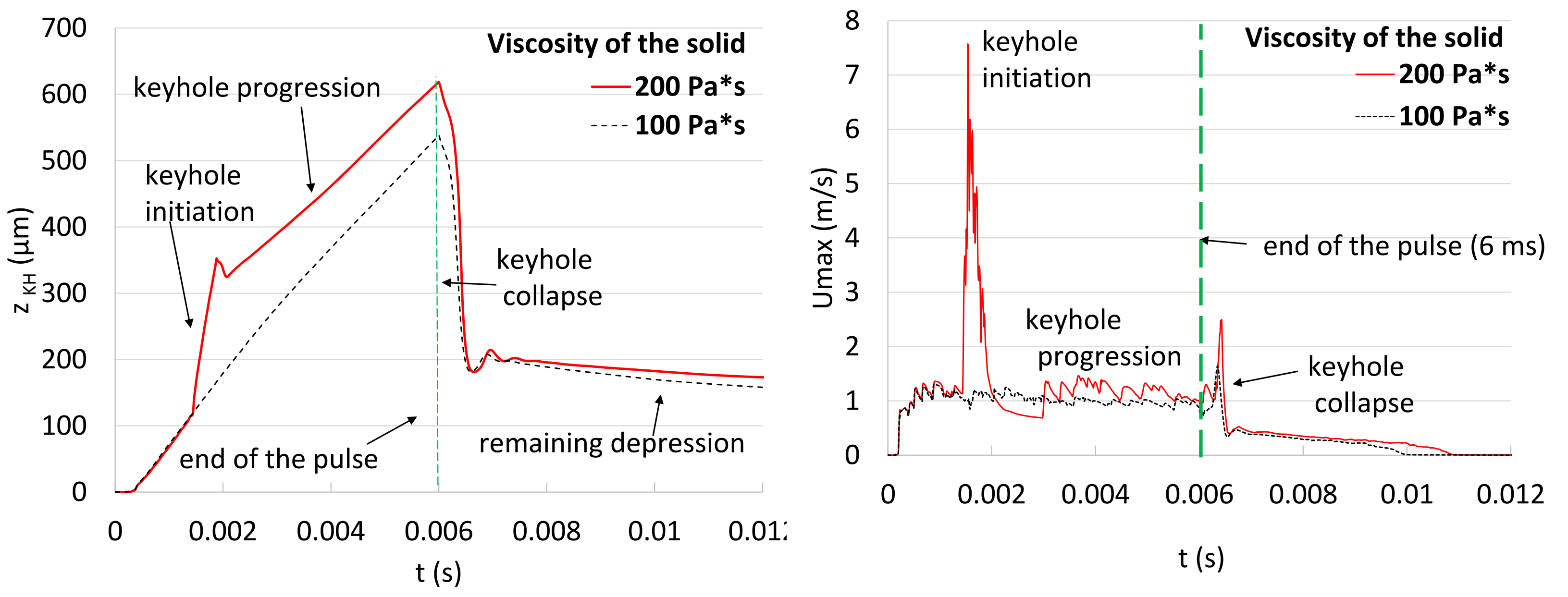


Figure 3. The influence of solid viscosity on the evolution of maximal temperature, melt velocity and keyhole depth for standalone Nd:YAG laser pulse on Ti-6Al-4V plate (6 ms, 1.5 kW, Ø = 560 µm).

A_{KH}>0.8 → Convergence problems

β>0.5 → Important undershoots of pressure and stress accumulation around the impact zone

CONCLUSIONS:

- Convergence problems associated with too important deformation of free surface (**remeshing?**)
- Keyhole depth sensitive to : solid and liquid viscosity, keyhole adsorption coefficient and condensation coefficient
- Acceptable mass conservation

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