Keyhole Behavior during Spot Laser Welding

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Objectives: To understand the physical phenomena governing the keyhole behavior during spot laser welding in order to improve the process and predict its effect on structures.

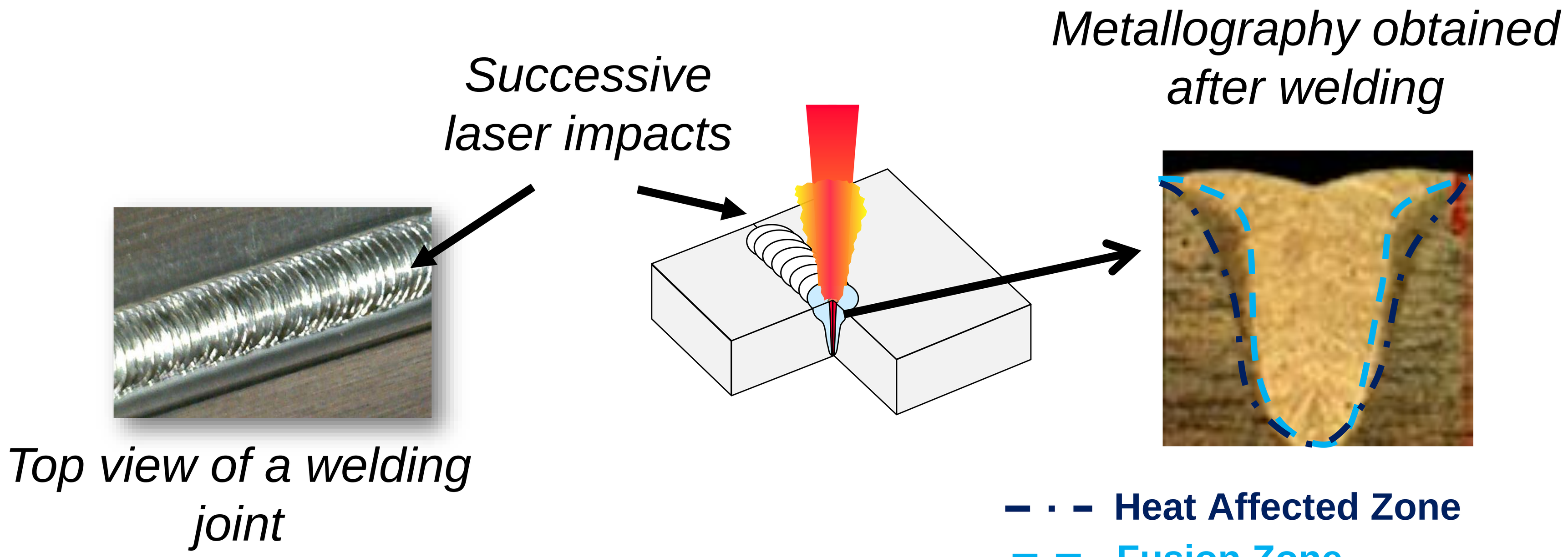

Figure 1. Spot laser welding

Physical Phenomena:

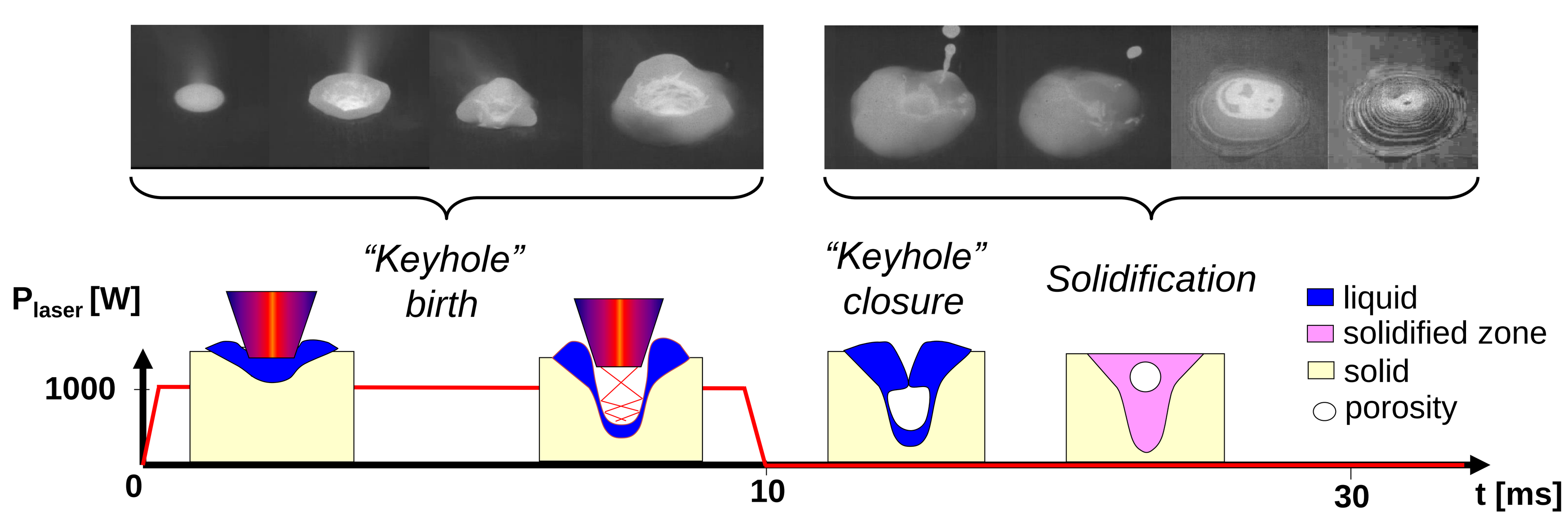

Figure 2. "Keyhole" life

- Multiple reflections of the beam
- Intense vaporization
- Recoil pressure
- Capillary effects
- Solidification

Computational Methods: A 2D-axisymmetric thermo-hydraulic model is built to describe this three-phase flow problem. Two "physics" are solved in a fully coupled way:

- the fluid mechanics, for a laminar and transient free-surface flow,
- the thermal problem, with three thermodynamics states and with phase change.

The strong coupling comes from the interfacial effects happening during the laser/matter interaction:

Recoil pressure — **Capillary effects (LAPLACE and MARANGONI)**

$$\bar{\bar{\sigma}}_{liq/gas}\cdot\boldsymbol{n} = -p_{recoil}(T)\boldsymbol{n} + \gamma(T)(\nabla_s\cdot\boldsymbol{n})\boldsymbol{n} - \nabla_s\gamma(T)$$

To track the liquid/gas interface location, two numerical methods are tested [1]. The "Phase Field" approach is chosen here to treat the different phases of the "keyhole" life in a unique model.

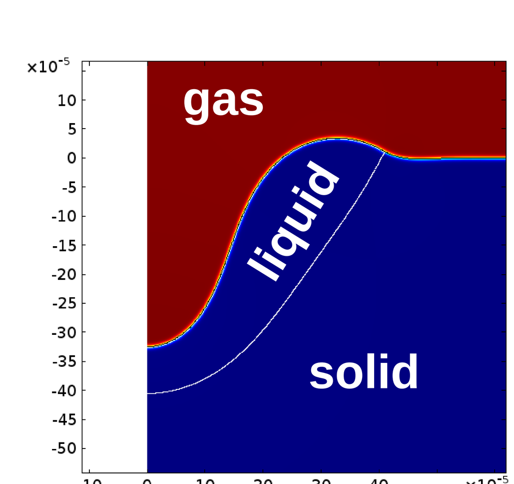

Figure 3. Phase Field Approach

Results: The different phases of the "keyhole" evolution are studied:

Digging phase

- Major influence of the recoil pressure

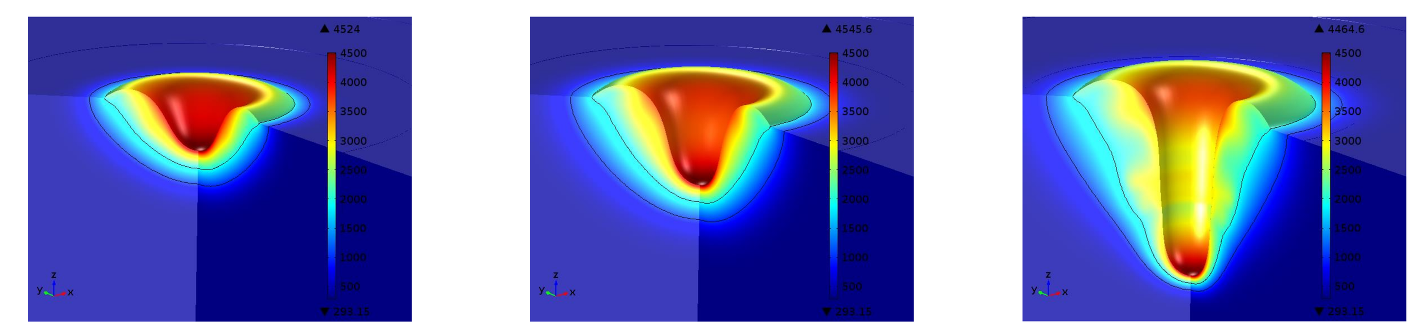

Figure 4. Temperature in liquid and solid phases [K]

- Comparison between experimental fusion zone shapes and numerical digging kinetics

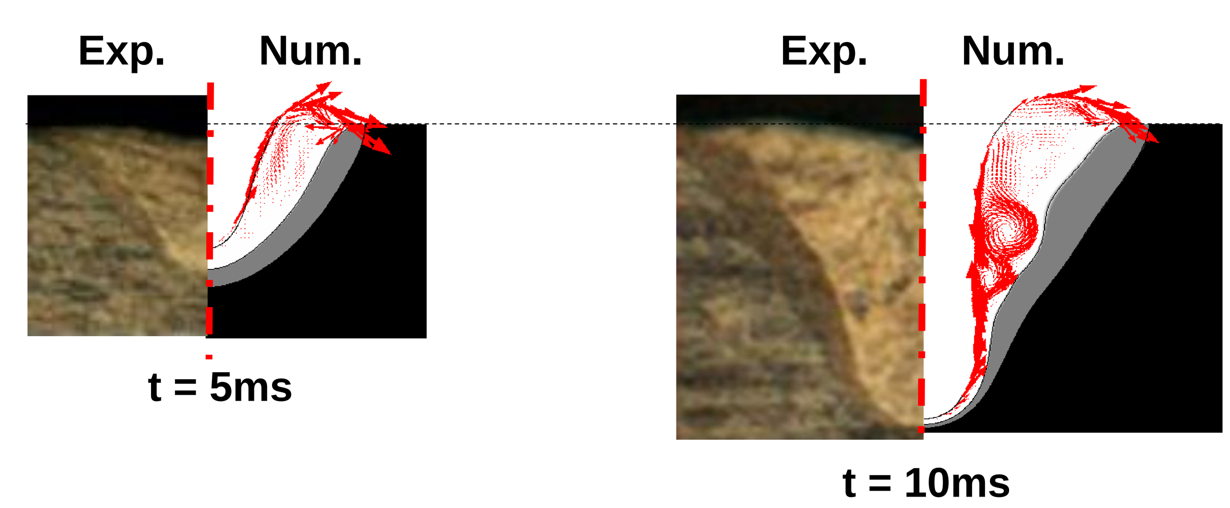

Figure 5. Experimental (left) and numerical (right) comparison for 2 different times

Closure phase

- Identification of mechanisms responsible for the formation of porosities

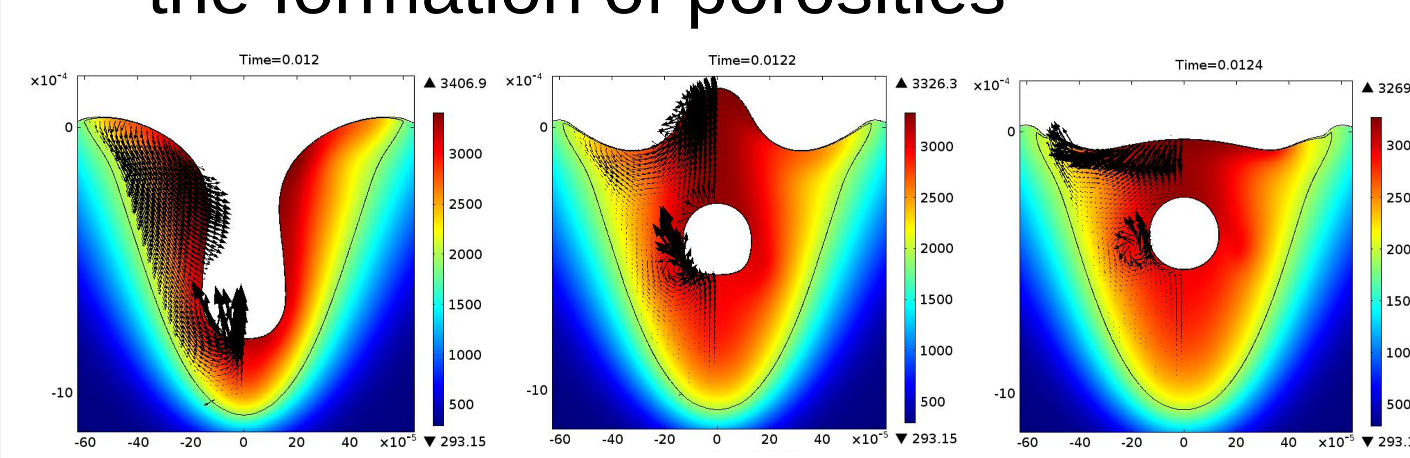

Figure 6. Temperature in liquid and solid phases [K]

- Adaptation of the laser power to optimize the process

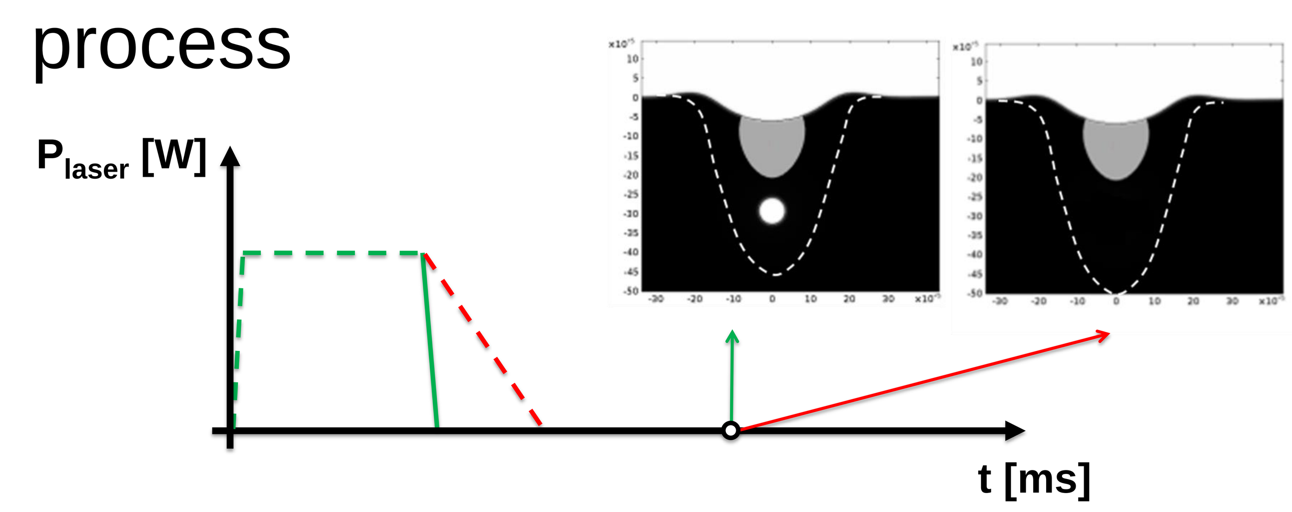

Figure 7. Influence of the laser power control

Conclusions: A thermo-hydraulic model has been validated by comparison with experimental data. It permits to predict the resulting fusion zone shape from operating conditions and material properties knowledge. The process can now be improve by precisely control the time evolution of the laser power.

References:

1. V.Bruyere et al., Comparison between Phase Field and ALE Methods to model the Keyhole Digging during Spot Laser Welding, *Proceedings of the 2013 Comsol Conference*, Rotterdam.