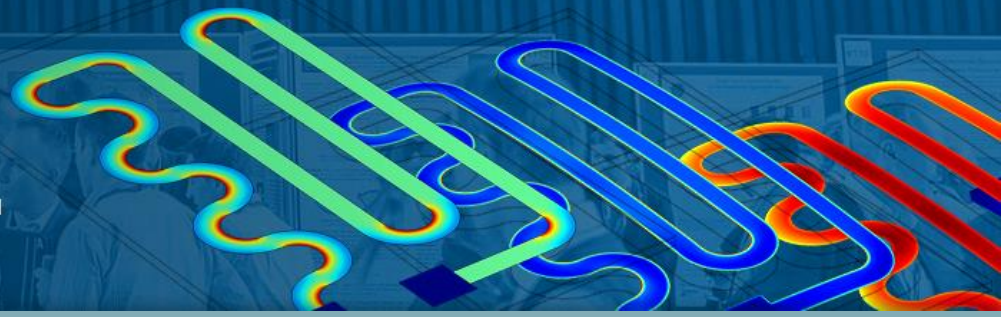
COMSOL CONFERENCE 2016 MUNICH
October 12-14
THE WESTIN GRAND MÜNCHEN



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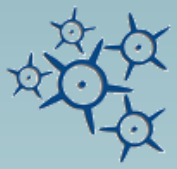

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LASER RHONE ALPES

Multiphysical modelling of keyhole formation during dissimilar laser welding

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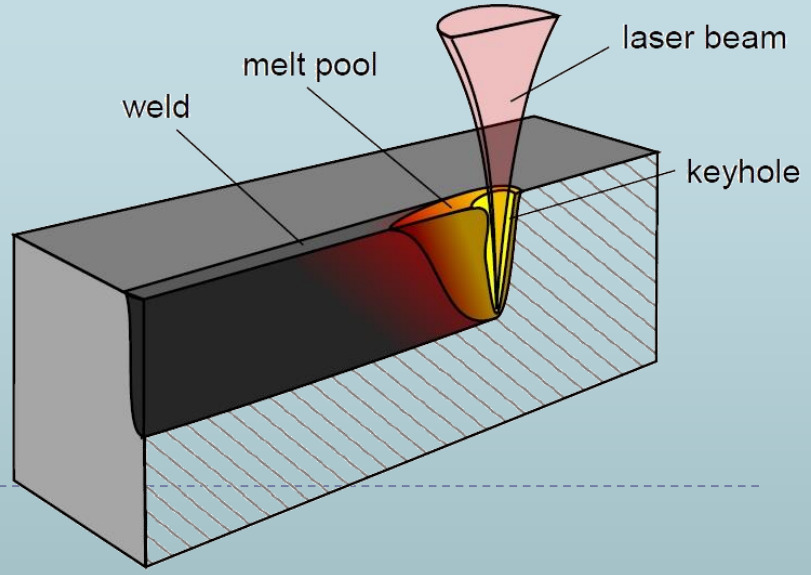
Motivations

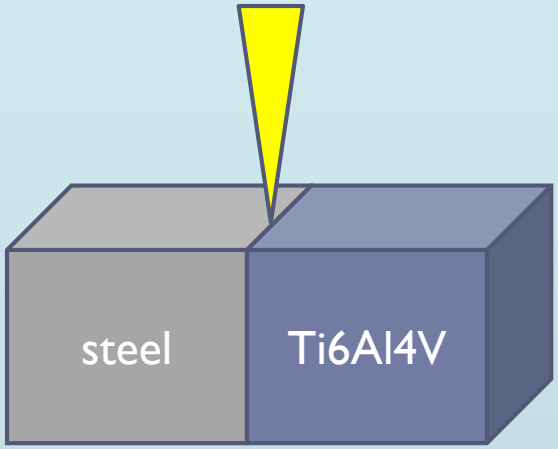
- Estimate the shape and dimension of a keyhole created during laser welding of dissimilar metallic couples
- Experiments on dissimilar welding show:
  - Melted zones are often asymmetrical
  - Keyhole position to joint line defines global composition
  - Question arises : is a keyhole also asymmetrical to joint line?



Follow the development of the keyhole and the melted zone

Model description

- Butt joint configuration
  - Pulsed welding (single pulse)
  - Continuous welding



	316L SS	Ti6Al4V
Tm (K)	1720	1928
Abs coef	0.3	0.4
$\alpha \cdot 10^6$ (m²/s)	5.58	7.86

- Strong coupling between
  - Heat Transfer
  - Laminar fluid flow
  - ALE
- Materials properties as functions of temperature

Model description : heat transfer

- Heat equation $\rho c_p^{eq}\left(\frac{\partial T}{\partial t}+\vec{u}.\vec{\nabla}T\right)=\vec{\nabla}.\left(\lambda\vec{\nabla}T\right)$

- Pulsed beam

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

- Continuous beam

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

- Energy absorption

$$A = A_{solid} + (A_{liquid} - A_{solid}) \cdot flc2hs(T-T_m, \Delta T)$$
$$A_{liquid} = A_{surf} + (A_{kh} - A_{surf}) \cdot flc2hs(z-z_c, \Delta z).$$

A	316L SS	Ti6Al4V
Solid	0.3	0.4
Melted	0.15	0.25
Keyhole	0.6	0.7

- Phase change

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

Model description : fluid flow

- Navier-Stokes equation

$$\rho_l\left[\frac{\partial \vec{u}}{\partial t}+\left(\vec{u}.\vec{\nabla}\right)\vec{u}\right]=\vec{\nabla}.\left[-pI+\mu(T)\left(\vec{u}.\vec{\nabla}+\left(\vec{u}.\vec{\nabla}\right)^t\right)\right]+\vec{F}$$

$$\vec{\nabla}.\vec{u}=0$$

$\vec{u}$ ⟺ ALE

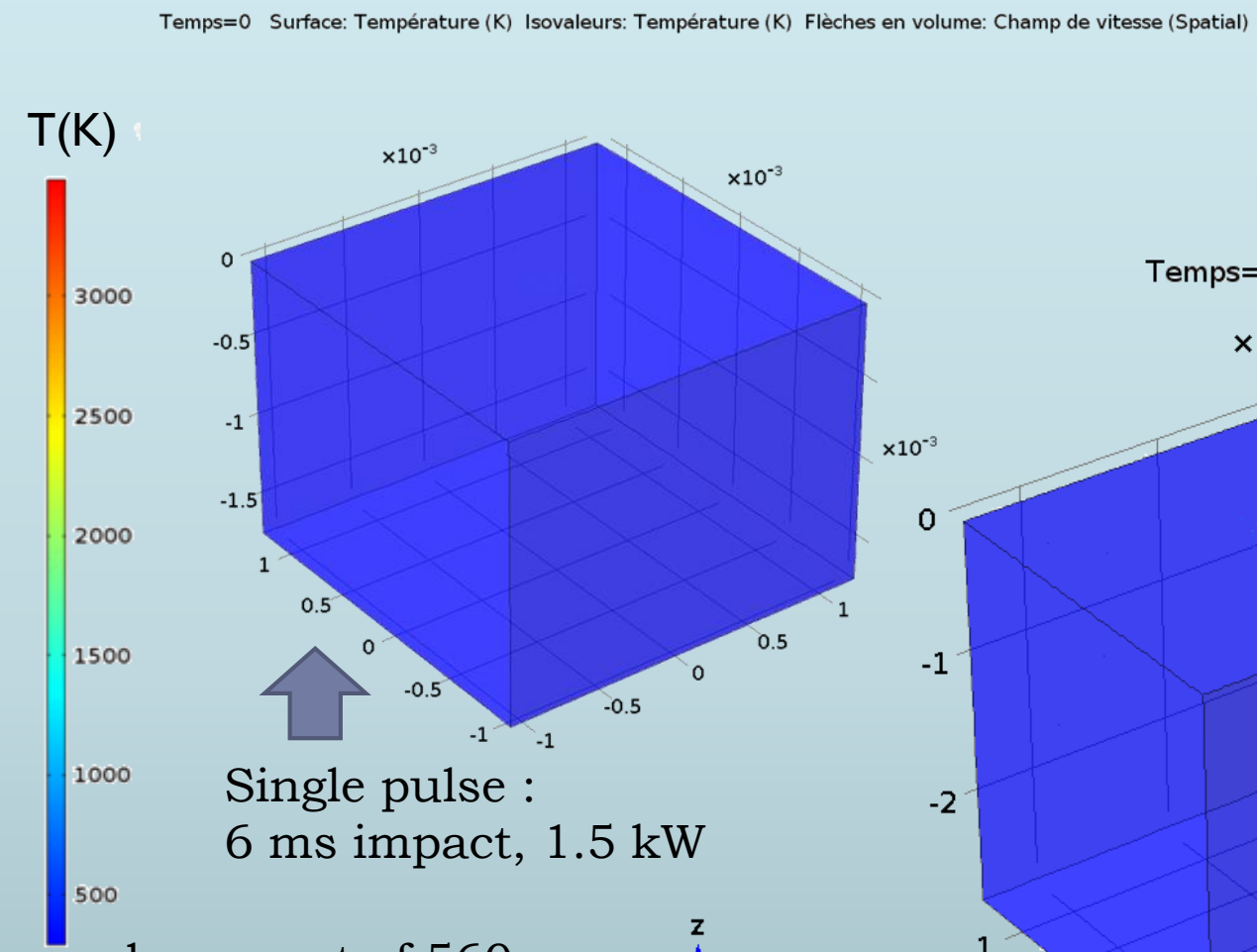
- Equivalent viscosity

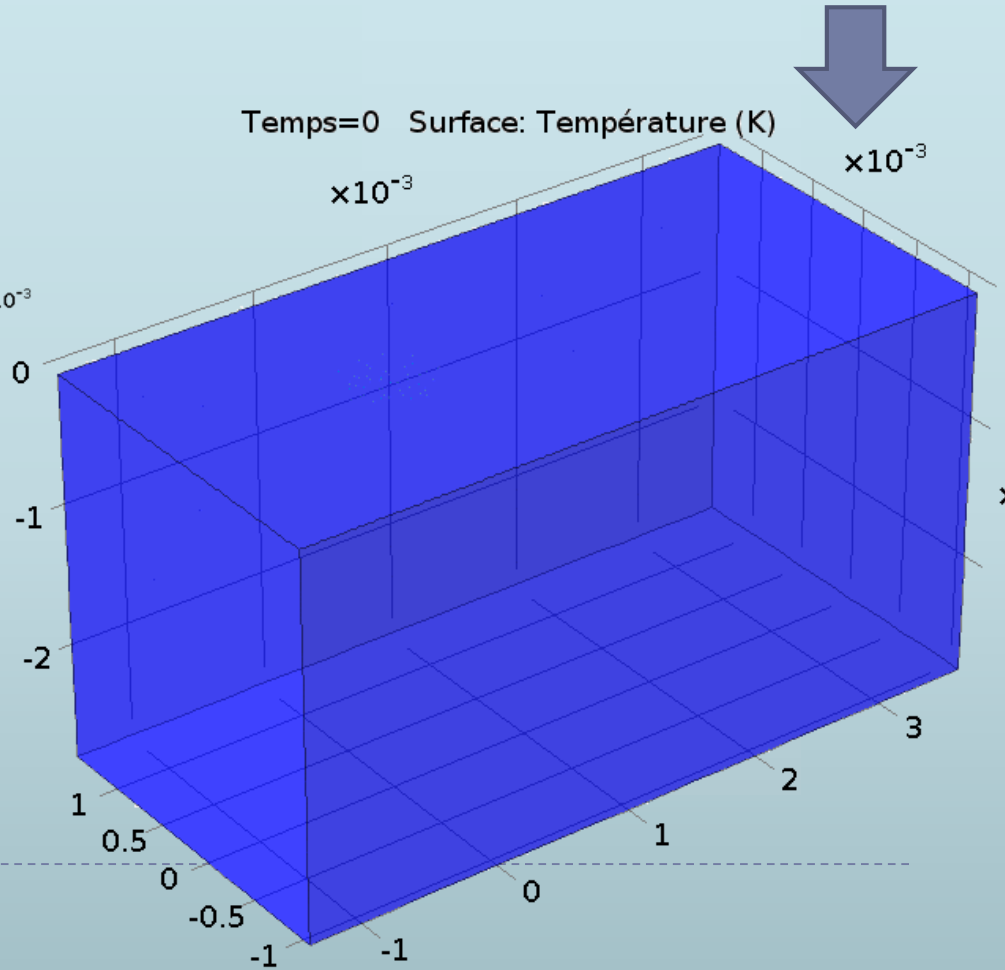
$$\eta = \eta_{solid} + (\eta_{liquid} - \eta_{solid})\, flc2hs(T-T_m, \Delta T)$$

- Convection forces
  - Natural convection
  - Marangoni effect
  - Surface tension
- Recoil pressure

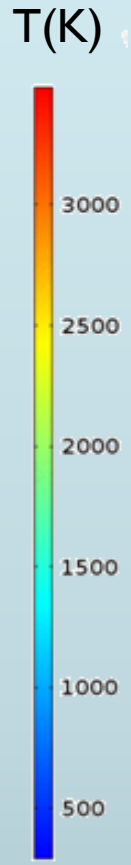
$$p_r = a \cdot e^{-\frac{b}{T}+c}$$

Homogenous welding : Ti6Al4V

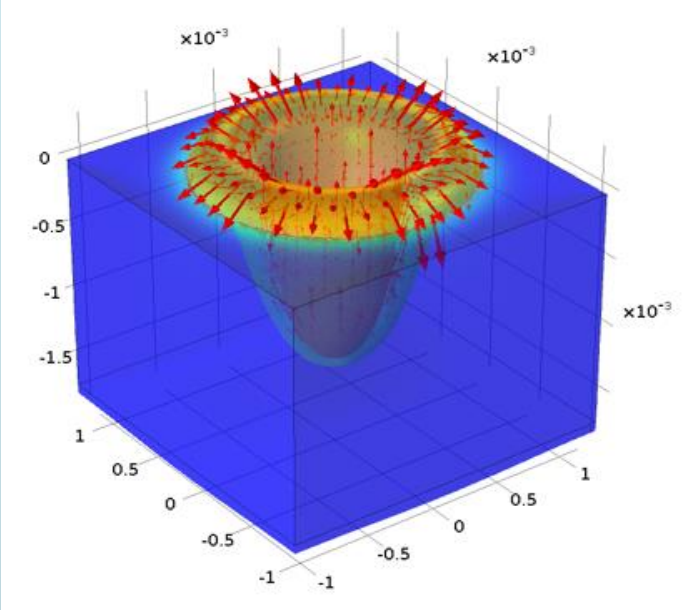




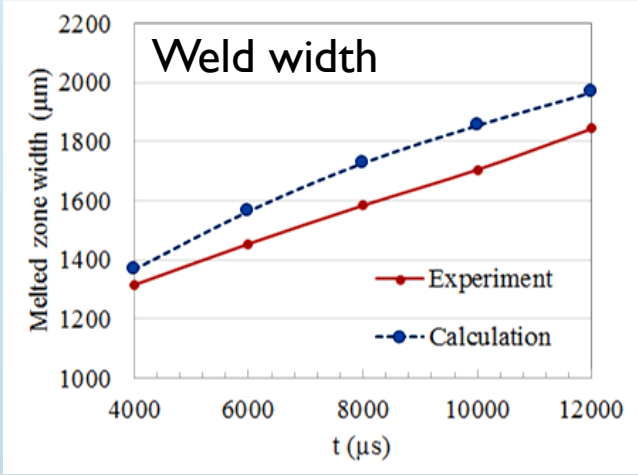
Homogenous welding : Ti6Al4V

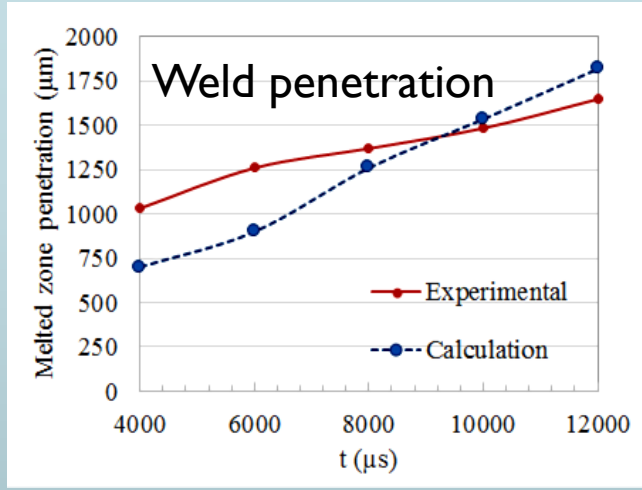


Single pulse



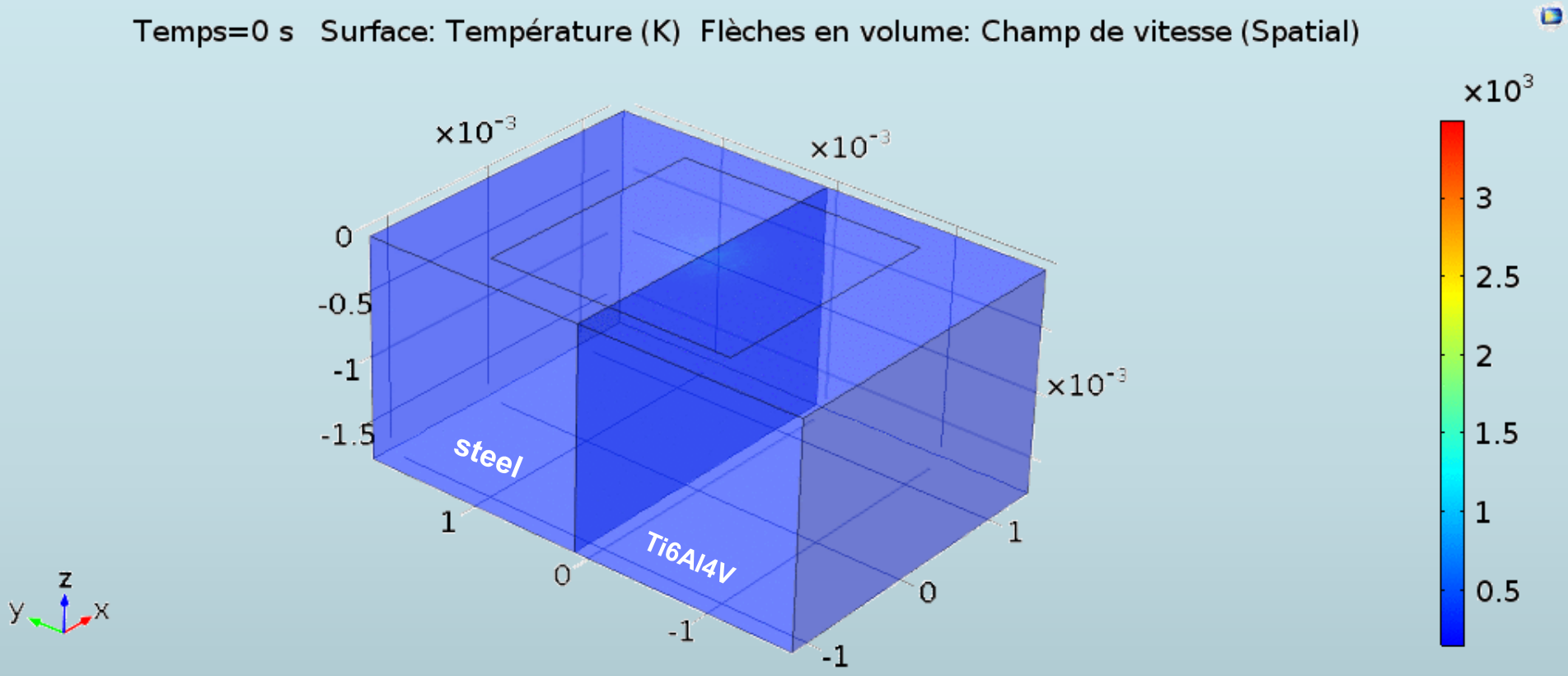
6 ms impact of 1.5 kW laser power, laser spot diameter 560 µm





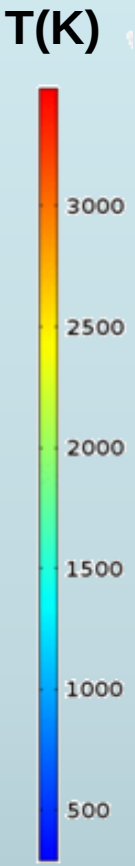
Dissimilar welding : Ti6Al4V/316L

Single pulse

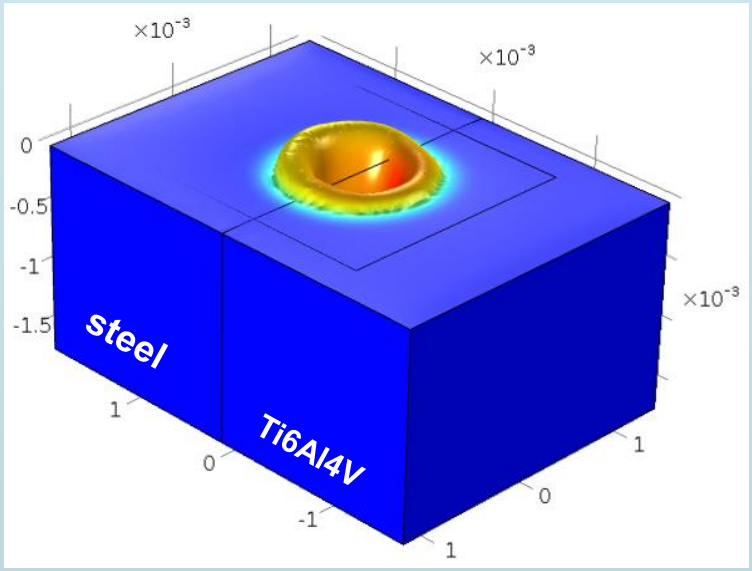


Calculation for 3 ms impact with laser power of 1.5 kW.

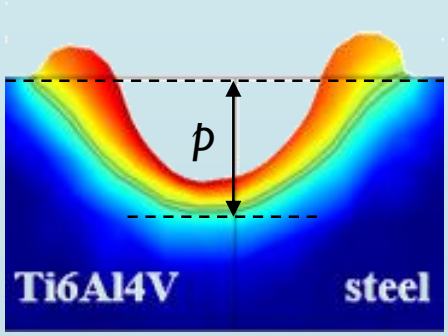
Dissimilar welding : Ti6Al4V/316L



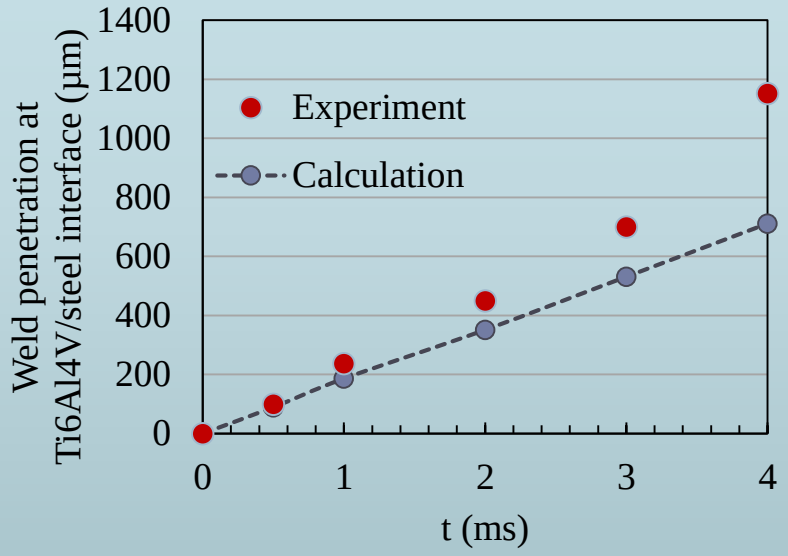
Single pulse



More complex function needed for absorption coefficient ?



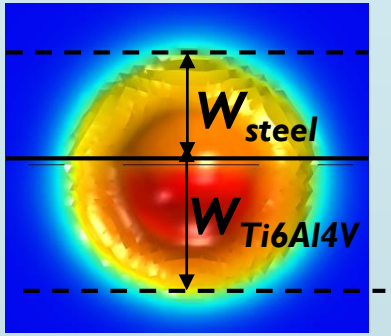
Weld penetration at joint line



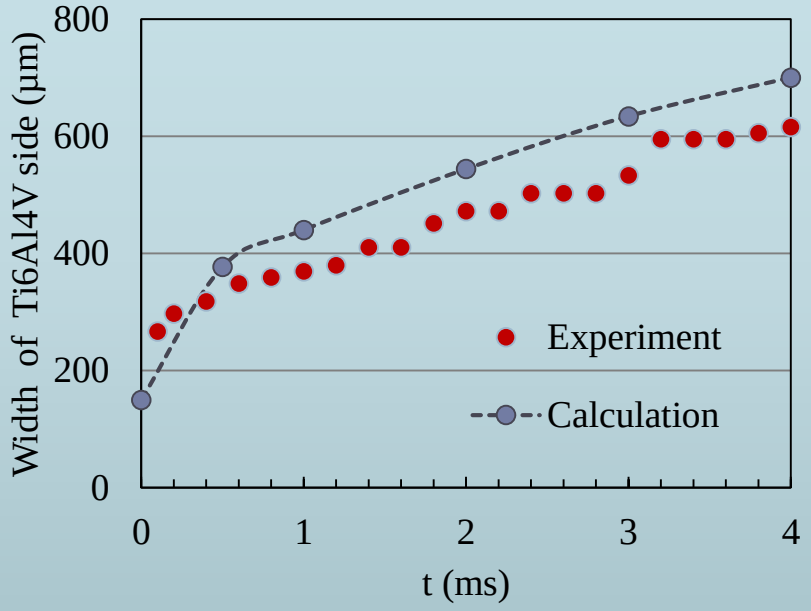
Dissimilar welding : Ti6Al4V/316L

Single pulse

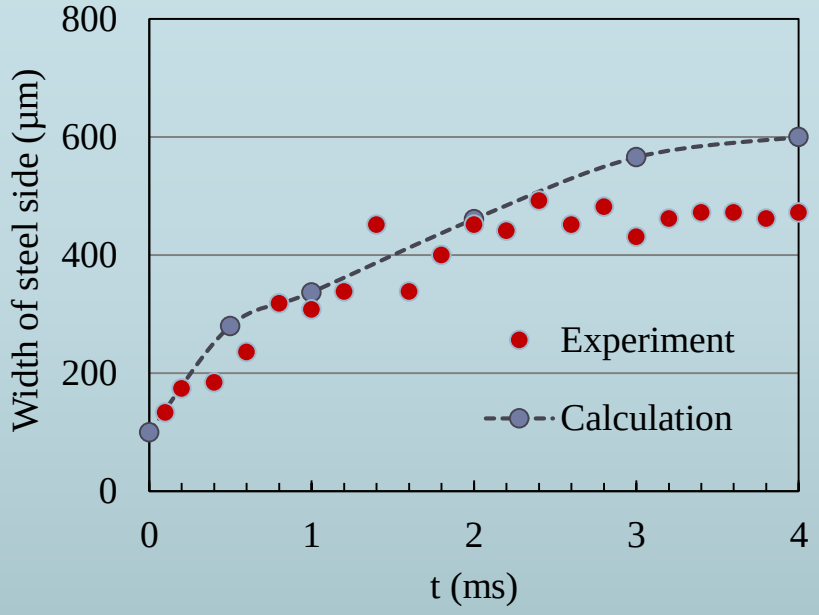
- More rapid melting in Ti6Al4V
- Equilibrium melting after several ms



Melted width at Ti6Al6V side

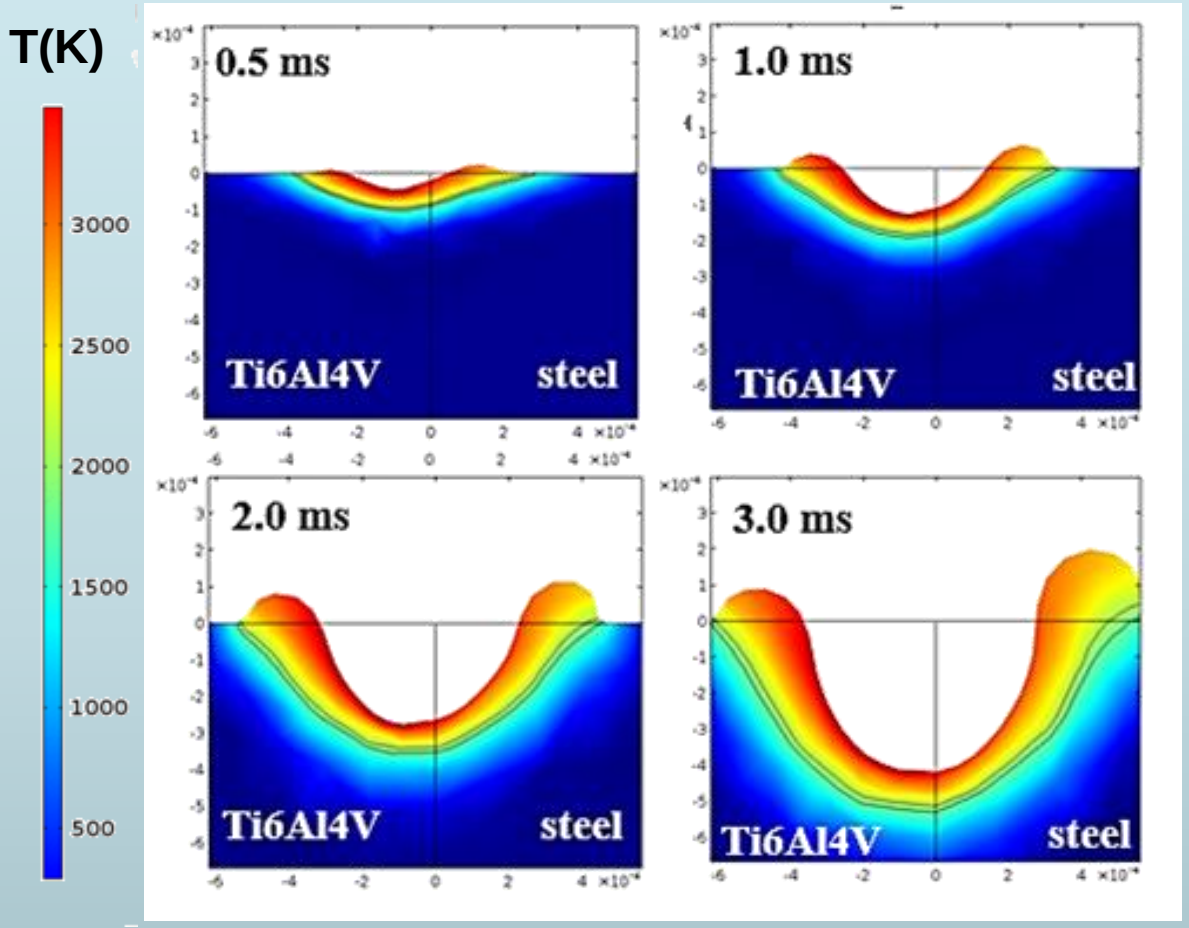


Melted width at steel side



Dissimilar welding : Ti6Al4V/316L

Single pulse : take a look at the keyhole

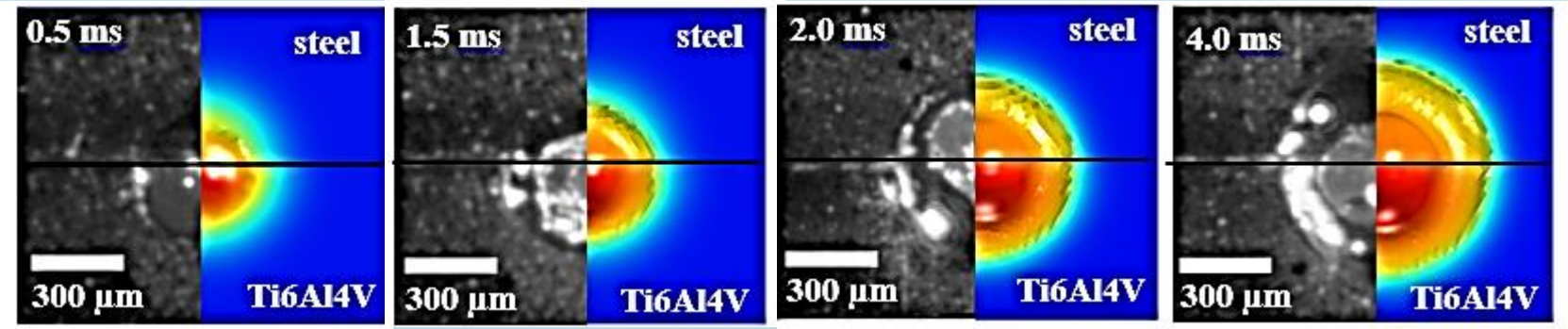


- Keyhole is shifted at Ti6Al4V side
- Keyhole diameter close to laser beam diameter.
- After several ms this asymmetry disappears.

- Conclusions to be made case by case!

Dissimilar welding : Ti6Al4V/316L

Single pulse :
comparison with high speed camera imaging



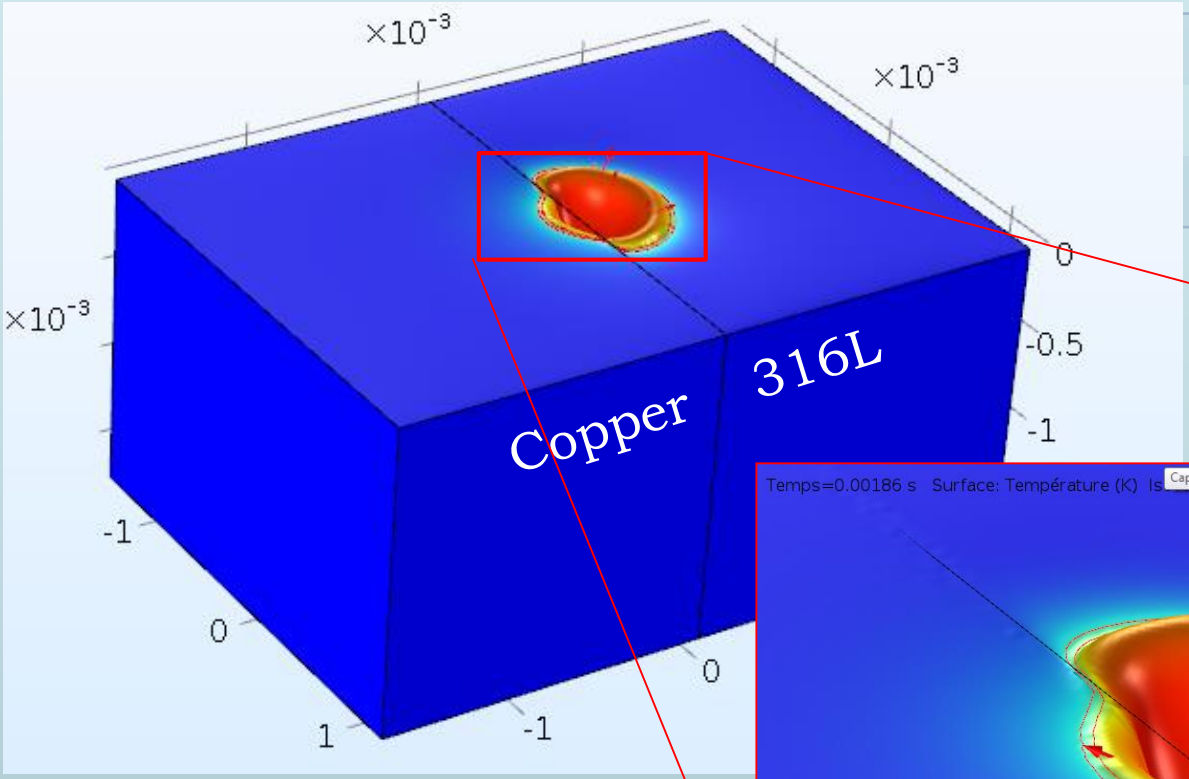
- Good global representation of matter ejection
- Melted zone forms first on material with higher A_{solid}, but final melt is almost symmetrical

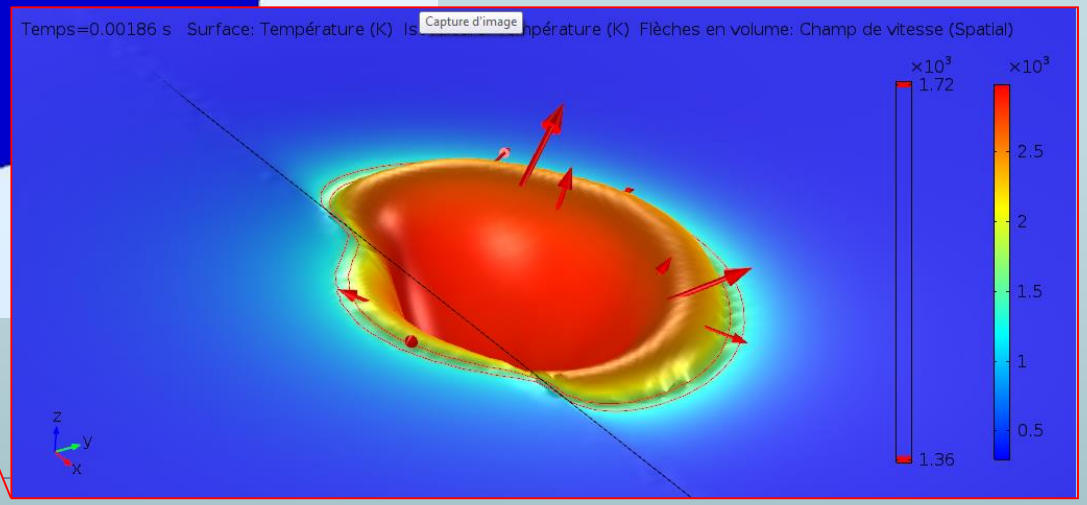
Dissimilar welding : copper/steel

Single pulse

Coef abs	316L SS	Copper Cu
Solid	0.3	0.05
Melted	0.15	0.03
Keyhole	0.6	0.6

	316L SS	Cu
Tm (K)	1720	1356
Abs coef	0.3	0.05
$\alpha \cdot 10^6$ (m²/s)	5.58	110

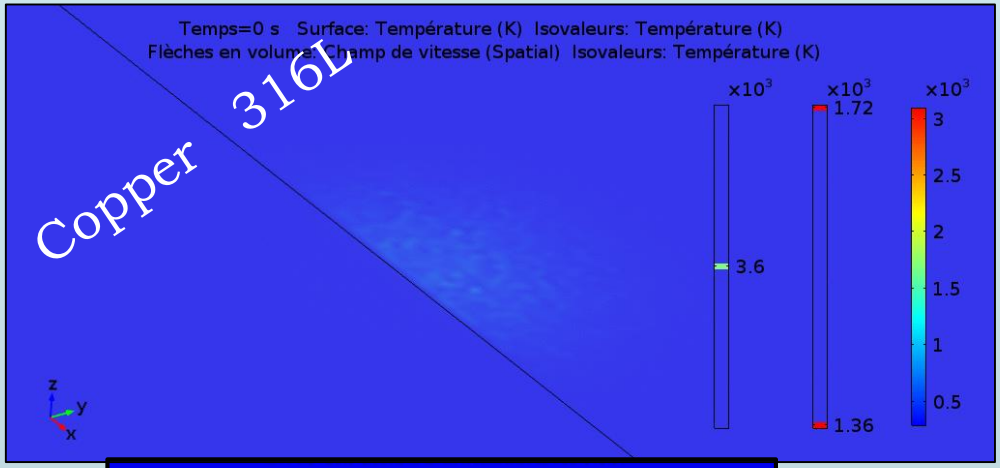




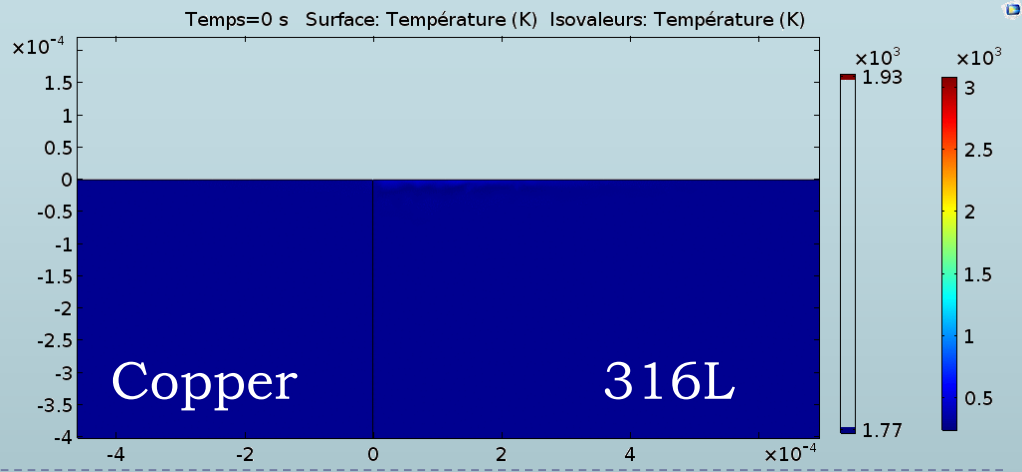
1 kW, 2 ms

Dissimilar welding : copper/steel

Single pulse 1 kW, 2 ms

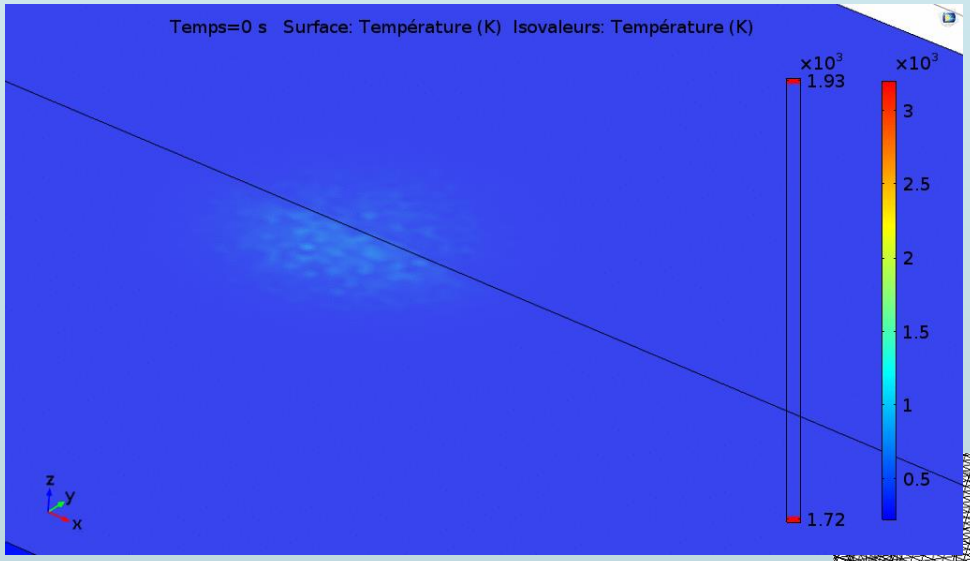


- Keyhole is quasi-totally shifted on steel side!
- Copper melts by conduction and not by laser absorption.

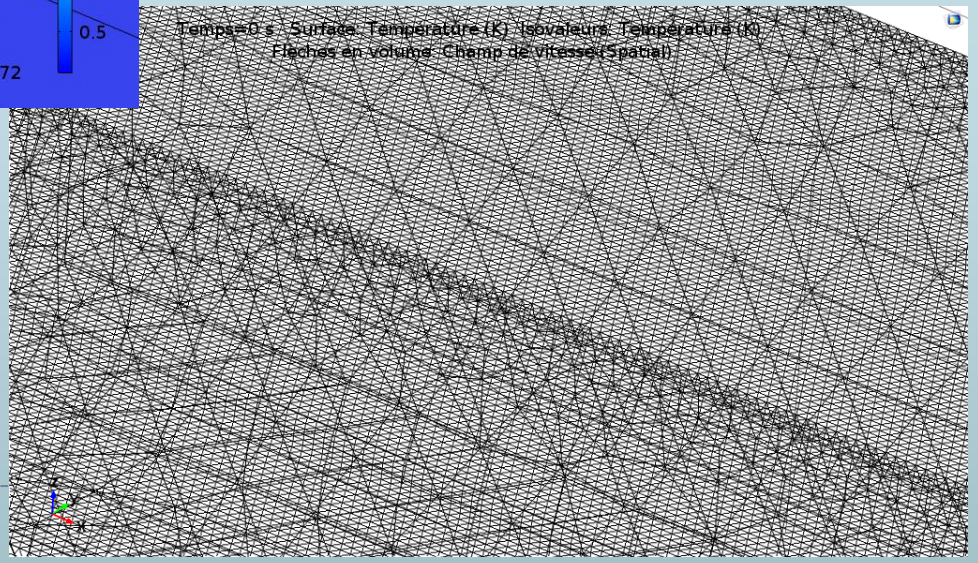


Dissimilar welding : Ti6Al4V/316L

Continuous welding



1.5 kW laser power,
8 m/min welding speed,
laser spot diameter 560 µm



Conclusions

- ALE-based multiphysical model of keyhole formation in case of pulsed and continuous welding between dissimilar materials is proposed.
- First results for pulsed welding were validated for Ti6Al4V/steel couple of materials.
- Dissymmetry of keyhole to joint line is observed only during first seconds of laser-matter interaction.
- Close result for continuous laser welding.
- Lack of data about absorption coefficient!
- Perspective :
  - test on another dissimilar couples
  - interdiffusion of species during melting and solidification

Acknowledgements

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- Our colleagues : Dr Aléxandre Mathieu, Ing Mélanie Duband, ICB, Université Bourgogne-Franche Comté, France

Laboratoire Interdisciplinaire Carnot de Bourgogne

Thank you for your attention!

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