Multiphysics Process Simulation of the Electromagnetic-Supported Laser Beam Welding

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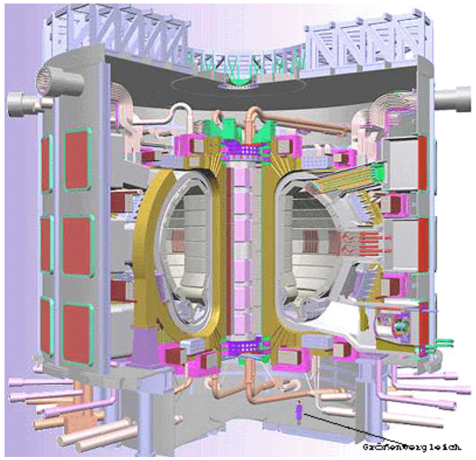
- **Introduction & Motivation**
- **Numerical Modeling & Results**
- **Summary & Outlook**

Applications single-pass laser beam welding

Thick-walled components:

- Ship-building industry
- Reactor vessel welding
- Power plant components

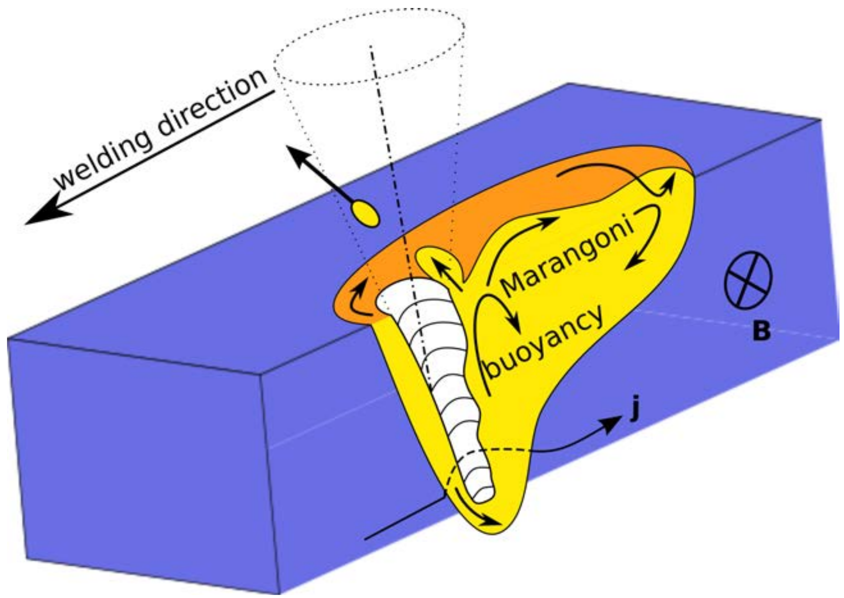
Container ship
www.maerskline.com



ITER reactor
www.bmbf.de

Combined heat and power plant Berlin Mitte
Vattenfall Europe Berlin

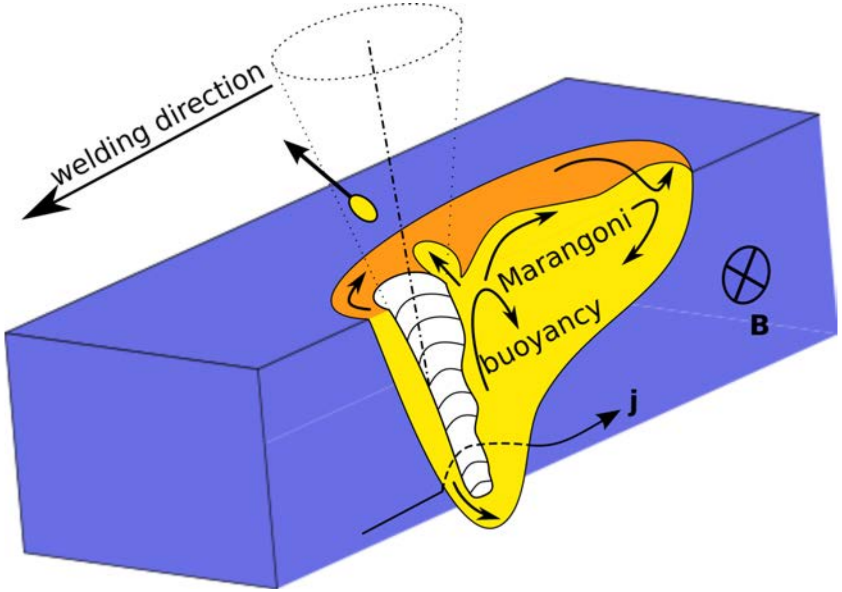
Full penetration laser beam welding of thick plates



Related issues:

- Marangoni
- Natural convection
- Recoil pressure
- Surface stability
- Gravity-induced drop out

Full penetration laser beam welding of thick plates



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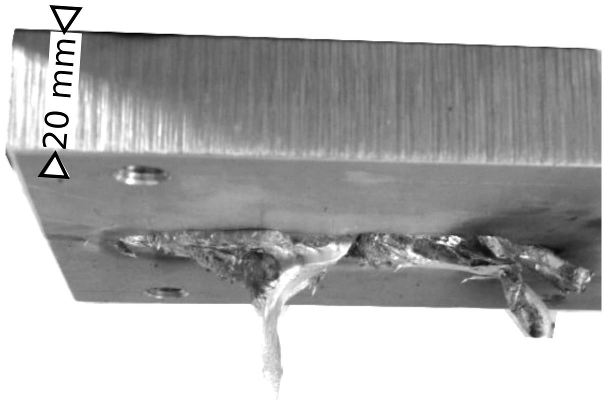
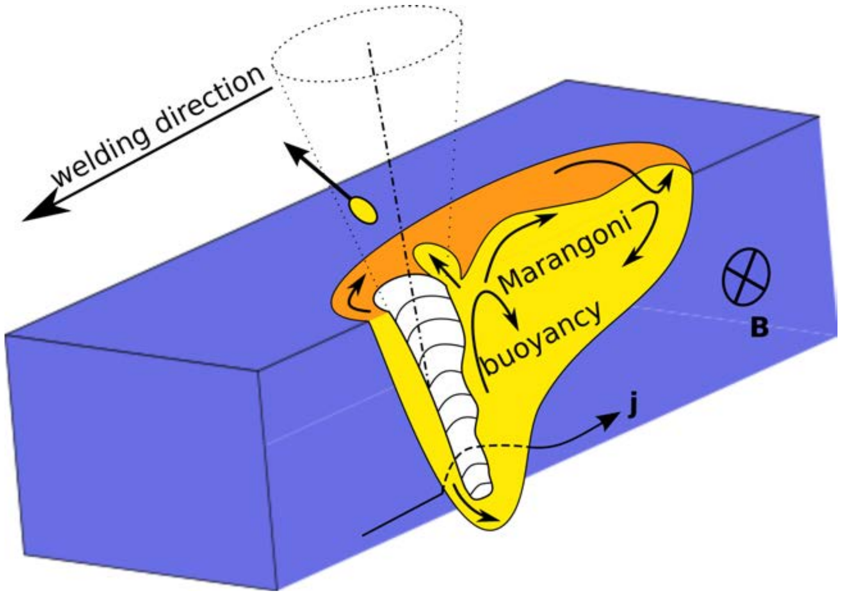


Full penetration laser beam welding of thick plates



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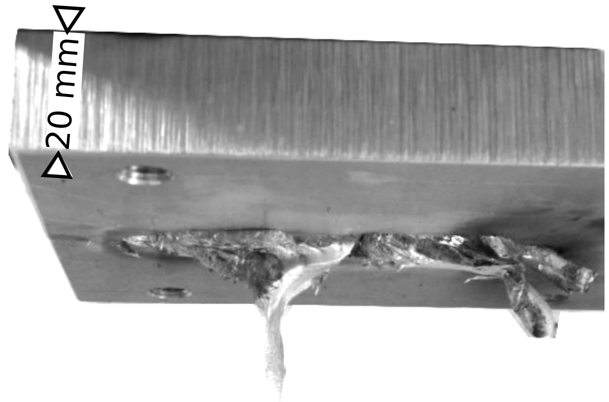
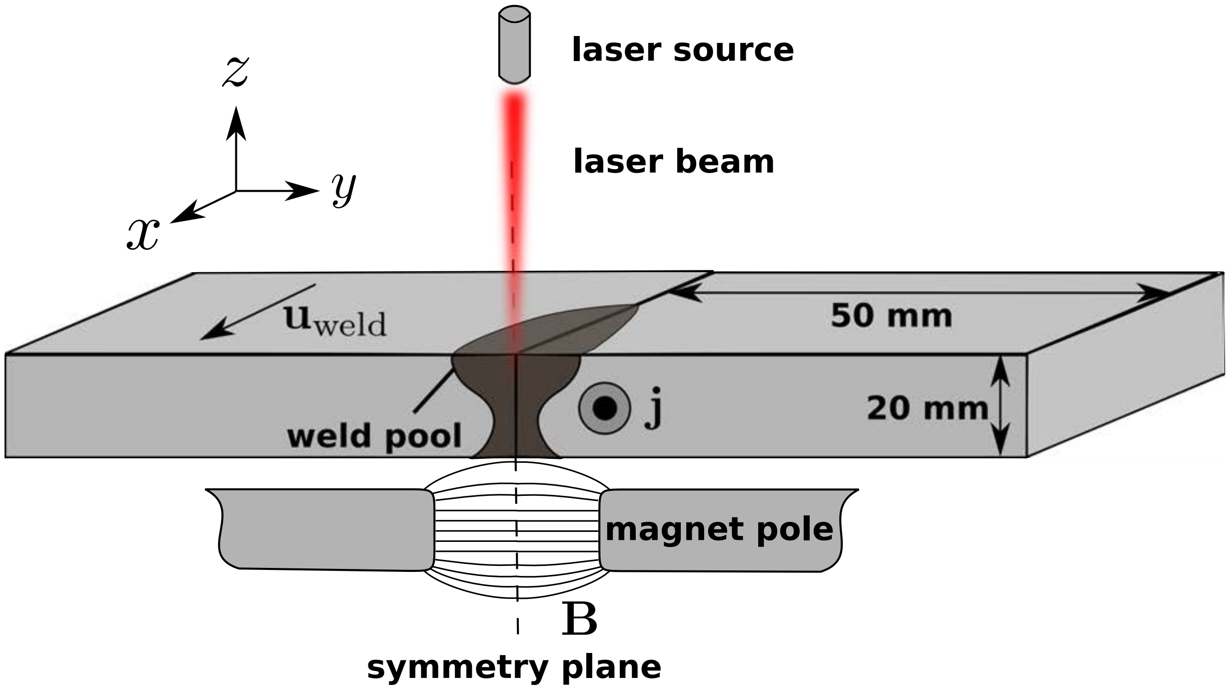


Approach:

- Contactless weld pool support system
- Insertion of Lorentz forces in the melt
- Coupled multiphysics simulation of the process

Weld Support System

- Magnetic field purely diffusive
- Oscillating magnetic field B and induced eddy currents $\mathbf{j}$
- Generalized Ohm's law
- Resulting Lorentz force distribution



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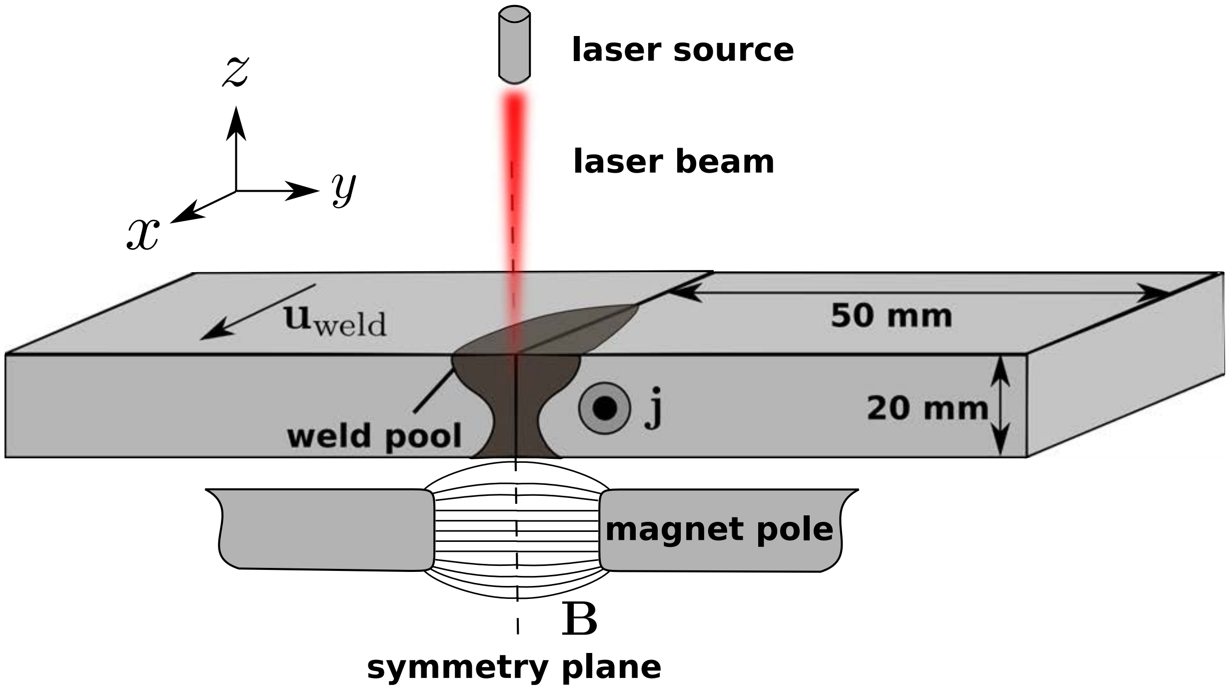


Mechanisms

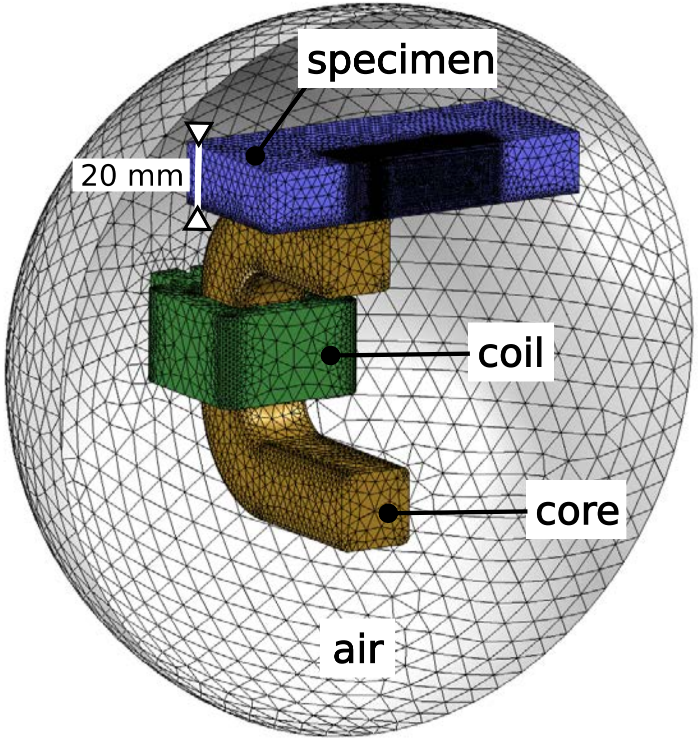
- Magnetic pressure

  $p_{\text{EM}} \propto \mathbf{B}^2$

- Magnetic induced drag

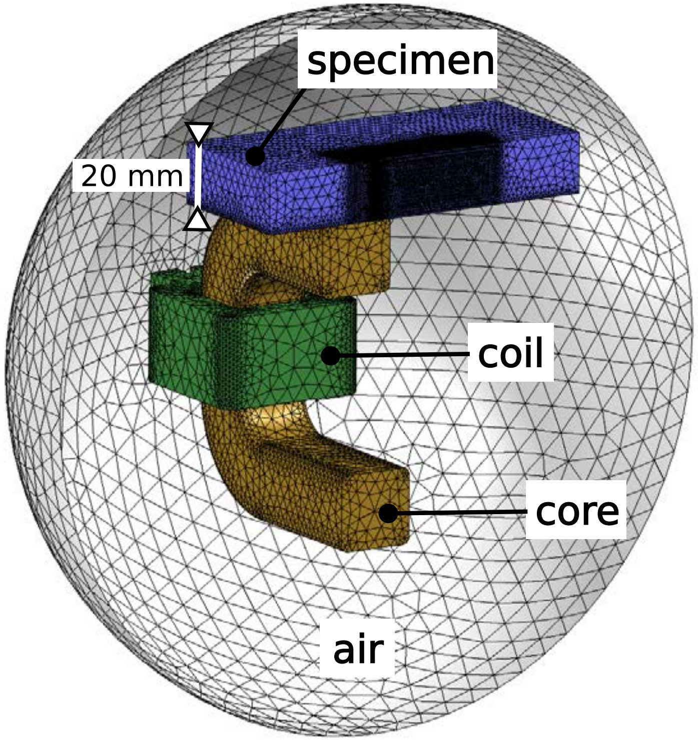
  $\text{Ha}^2 \approx 500$

Numerical Modeling



- Steady state assumed
- Laminar flow
- Fixed geometry
- Temperature-dependent material properties of pure aluminum
- Solidification model
- Magnetic field generation

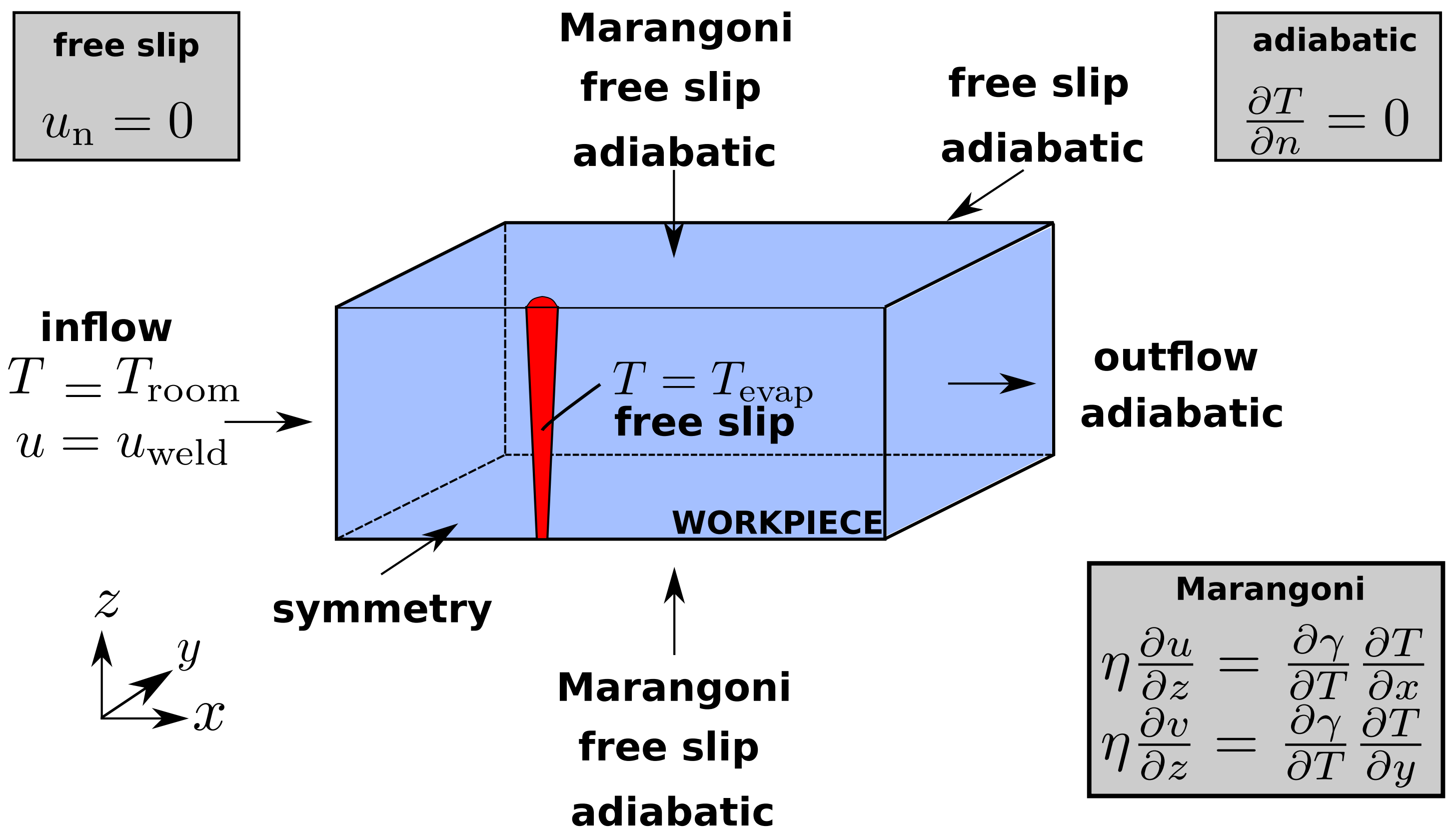
Numerical Modeling



- **Steady state assumed**
- **Laminar flow**
- **Fixed geometry**
- **Temperature-dependent material properties of pure aluminum**
- **Solidification model**
- **Magnetic field generation**

- **2.15 $\times$ 10^6 finite elements**
- **Typical calculation time: $\mathcal{O}$(hours)**

Numerical Modeling

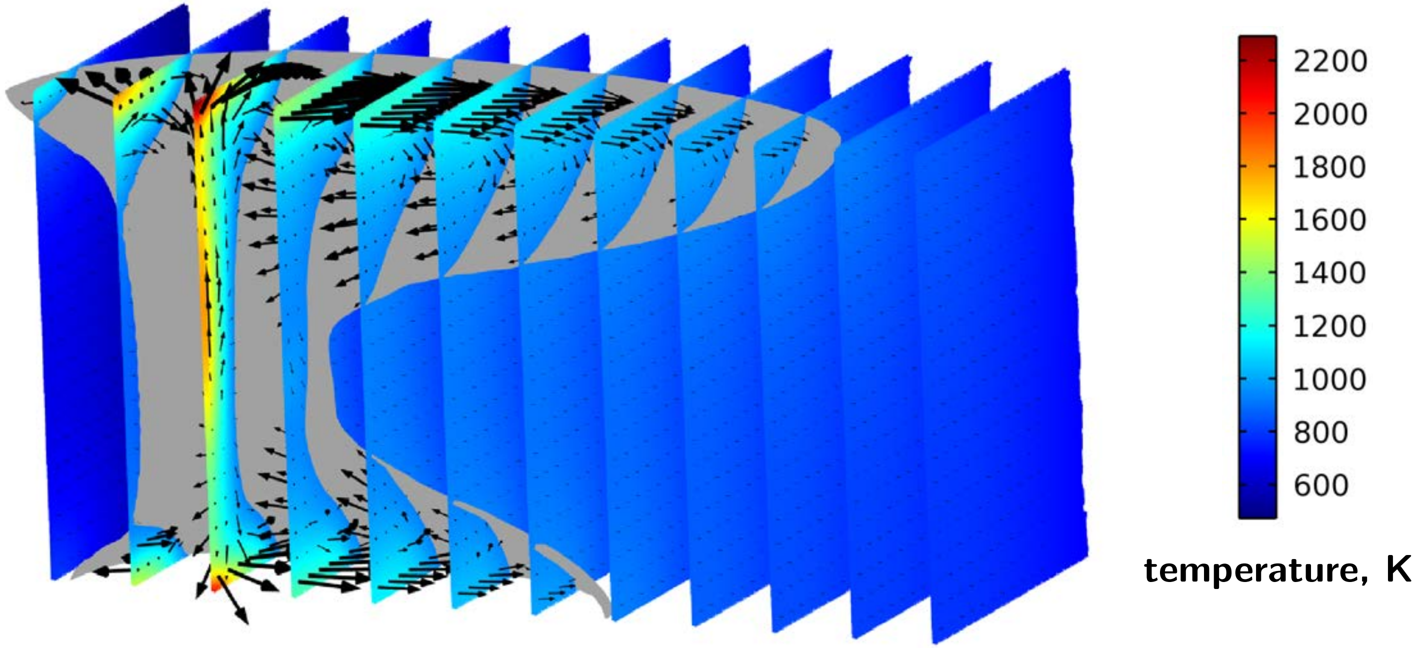


Navier Stokes equations volume source term

$$\mathbf{F} = -\rho \mathbf{g} - c_1 \frac{(1-f_L)^2}{f_L^3+\epsilon} (\mathbf{u} - \mathbf{u}_{weld}) + \langle \mathbf{j} \times \mathbf{B} \rangle$$

Buoyancy Solidification modeling Lorentz force

Results Magnet Inactive

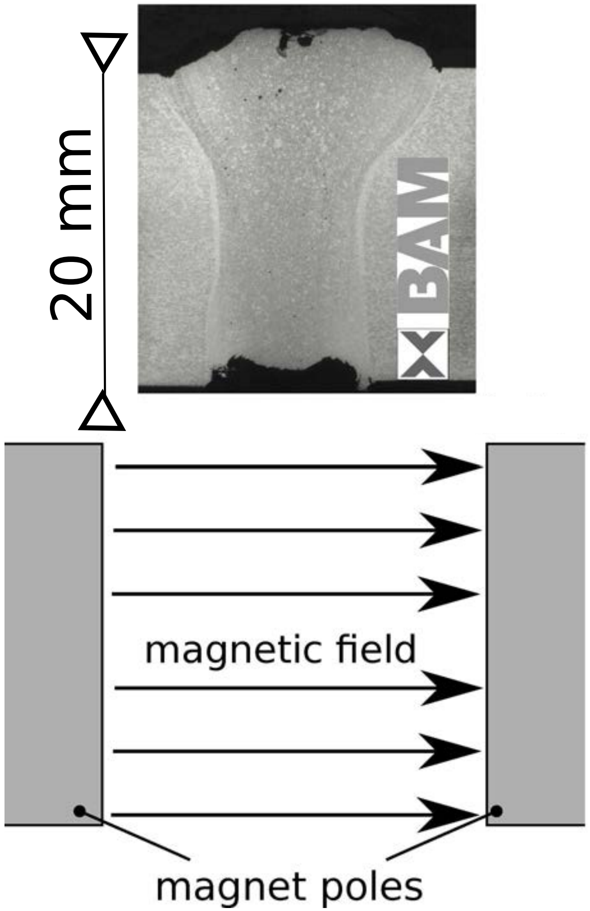


colors: temperature, arrows: velocity, contour: weld pool boundary

- Welding speed 0.5 m/min
- Natural convection
- Marangoni convection at the surfaces
- Gravity drop-out

Results Magnet Active

- 20 mm aluminum alloy 5754
- Welding speed 0.5 m/min
- Laser power 15 kW



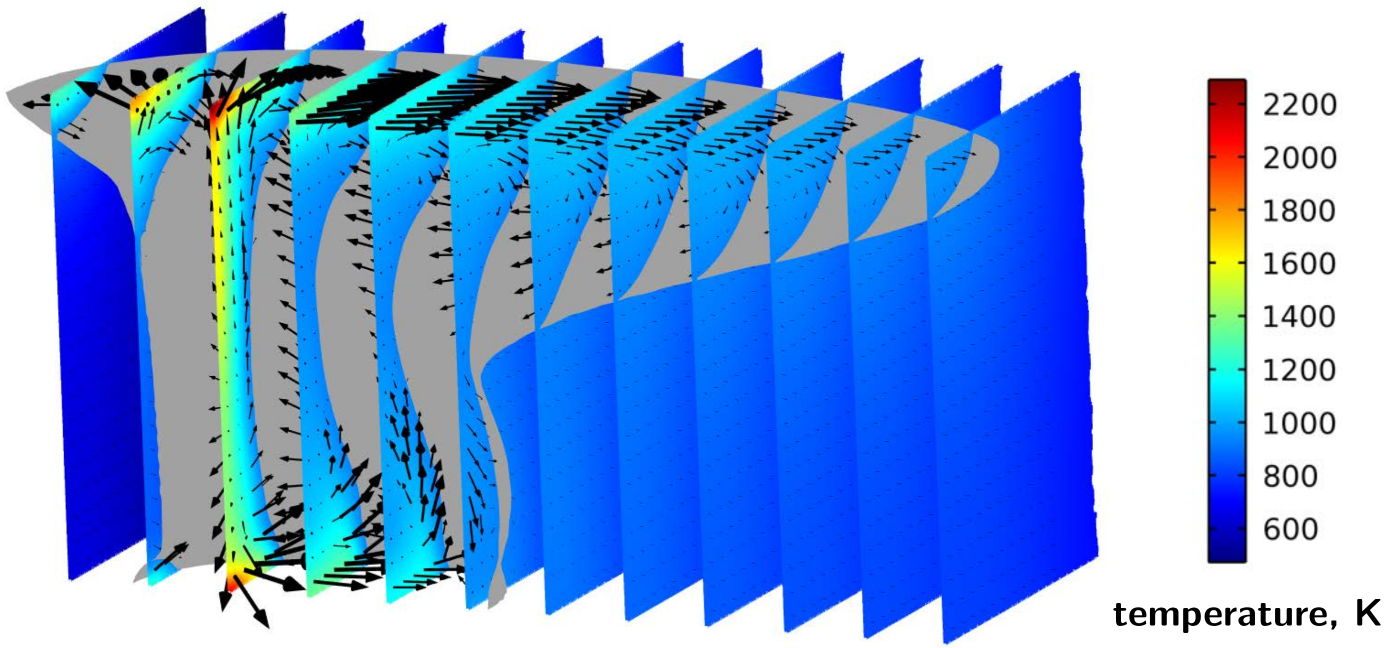
- AC frequency: 459 Hz
- Magnetic field rms value: 77 mT
- Magnet poles distance: 25 mm
- Magnet pole cross section 25 mm × 25 mm
- Distance magnet – plate 2 mm

- **Pressure compensation**
- **Y-shape of the weld bead**

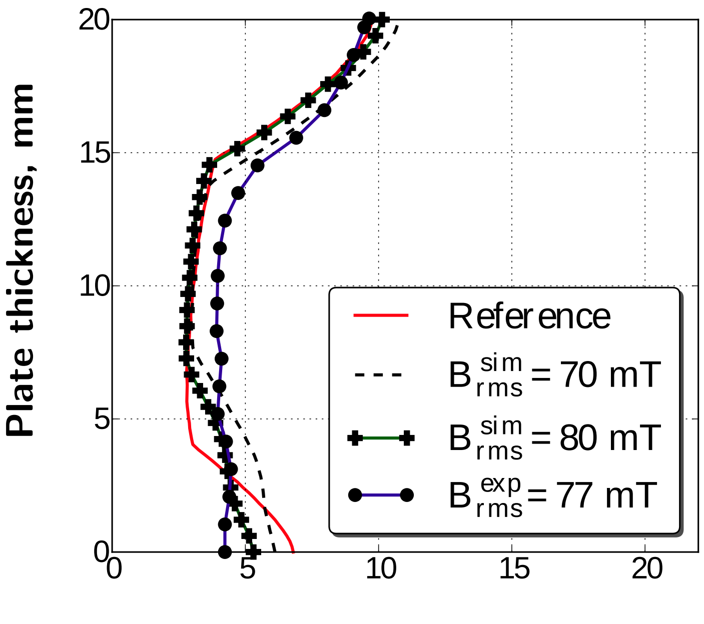
Results Magnet Active

- 20 mm pure aluminum
- Welding speed 0.5 m/min

- AC frequency: 450 Hz
- Magnetic field rms value: 70 mT
- Magnet poles distance: 25 mm
- Magnet pole cross section 25 mm × 25 mm
- Distance magnet – plate 2 mm



colors: temperature, arrows: velocity, contour: weld pool boundary



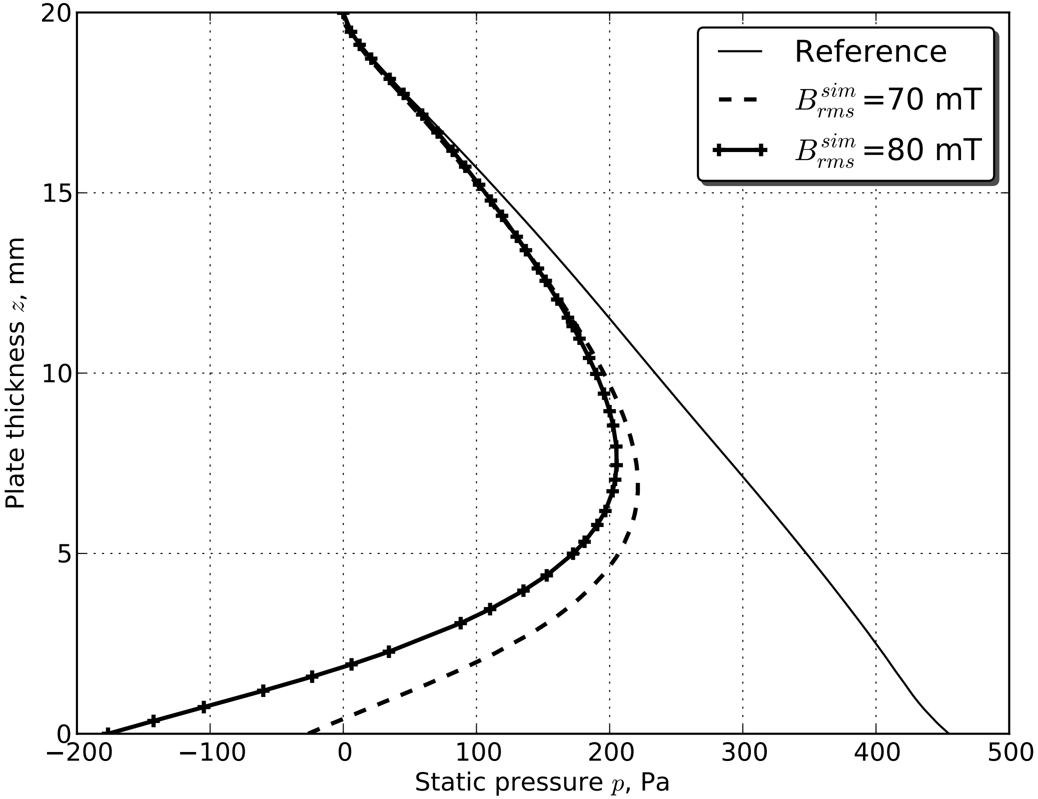
weld cross section half width, mm

Comparison

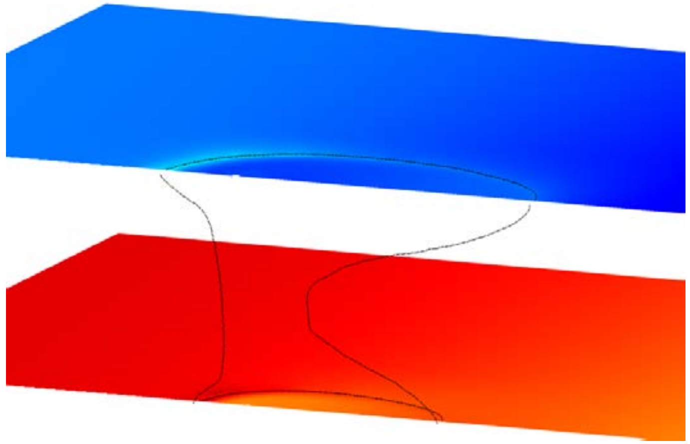
Averaged pressure difference between surfaces

Magnet inactive $B_{rms} = 0$	Optimal control $B_{rms} = 70$ **mT**	Overcompensation $B_{rms} = 80$ **mT**
+460 Pa	**+12 Pa**	**-130 Pa**

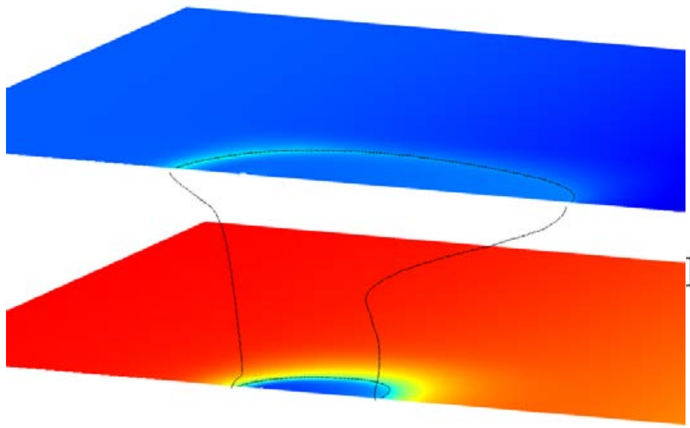
Pressure distribution 3 mm behind the keyhole

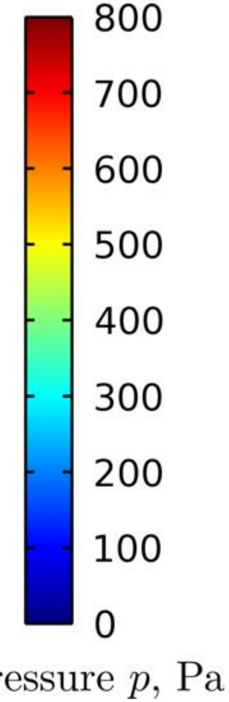


Magnet inactive



Magnet active

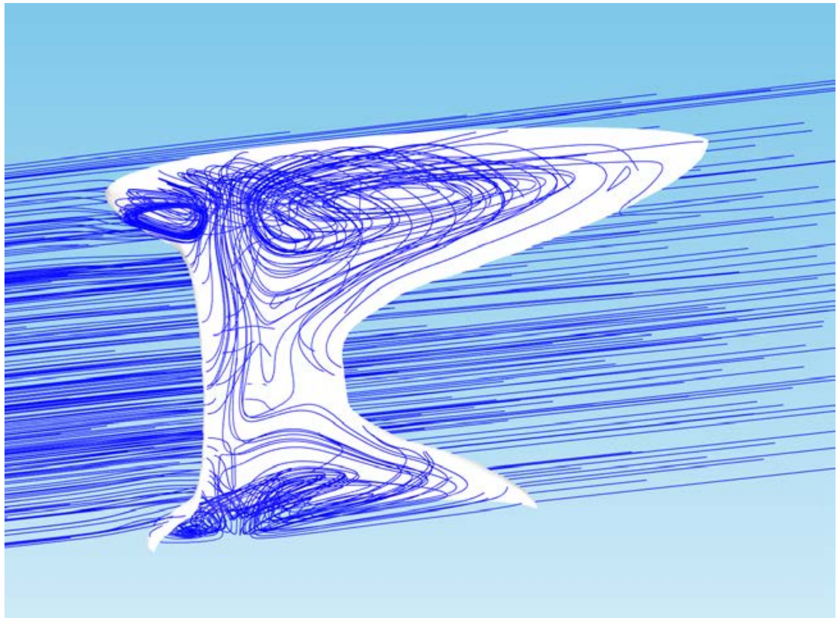




surface pressure

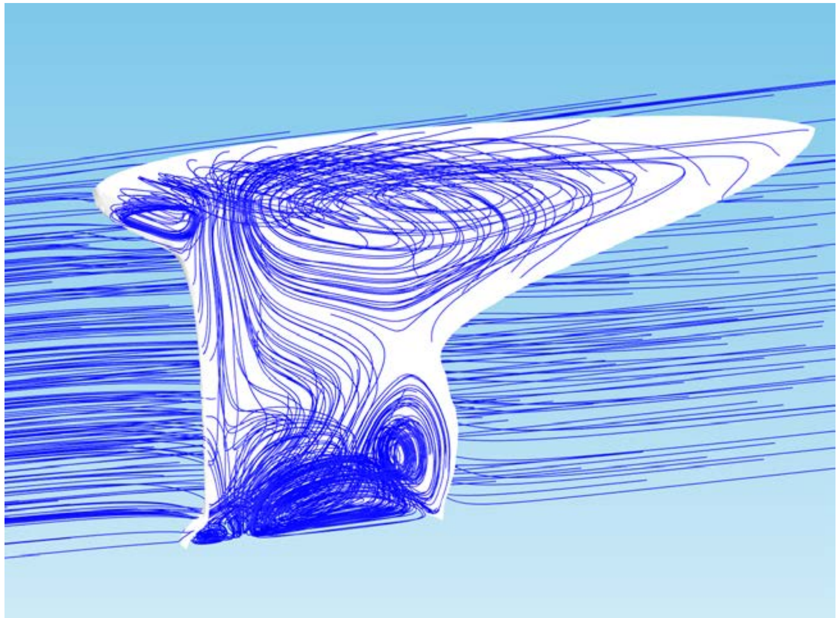
Comparison

Magnet inactive



velocity streamlines

Magnet active



- Marangoni convection
- Asymmetry (natural convection)
- Weld bead dimensions (length -35%)
- Vortex structure

Summary & Outlook

Goals:
- Stationary simulation of laser beam welding
- Establish weld pool support system

Tool:
- Contactless AC electromagnetic weld pool support system
- Simulation package COMSOL Multiphysics

Approach:
- Coupled fluid dynamic, heat transfer and electrodynamic simulation

Summary & Outlook

Results:

- Applicability of the technology is shown numerically
- Compensation of the hydrostatic pressure by potential character of Lorentz forces
- Weld pool shape changes due to combined effect of Hartmann deceleration and potential part of Lorentz forces

Conclusion:

- Simulation as effective means of investigation tool
- Oscillating magnetic fields well-suited for welding applications
- Technology allows for welding of plates of higher thicknesses

Outlook:

- Free surface simulation
- Expand to magnetic materials

Thank you for your attention.

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