Multi-Physics Process Simulation of Static Magnetic Fields in High Power Laser Beam Welding of Aluminum

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Overview

- Introduction
- Physical Principles
- Numerical Modeling & Results
- Experimental Observation
- Conclusions

Introduction

Applications deep-penetration laser beam welding

- Ship-building industry
- Reactor vessels & tanks
- Power plant components
- Aerospace industry

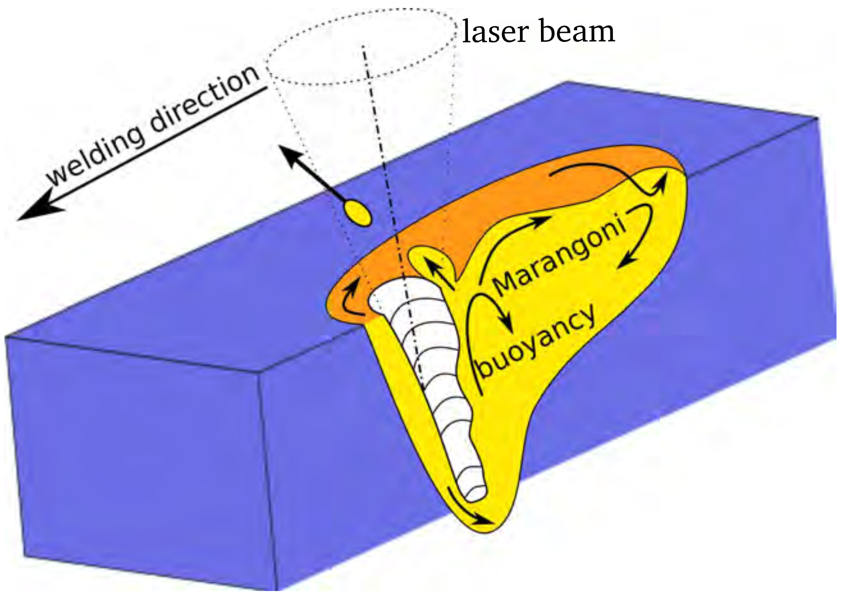
High-Speed Car Ferries
Austan Ships

Aluminum Reactor Vessels
Maulifab Engineers

NASA tank dome

Introduction

Characteristics of the laser beam welding of thick metal parts



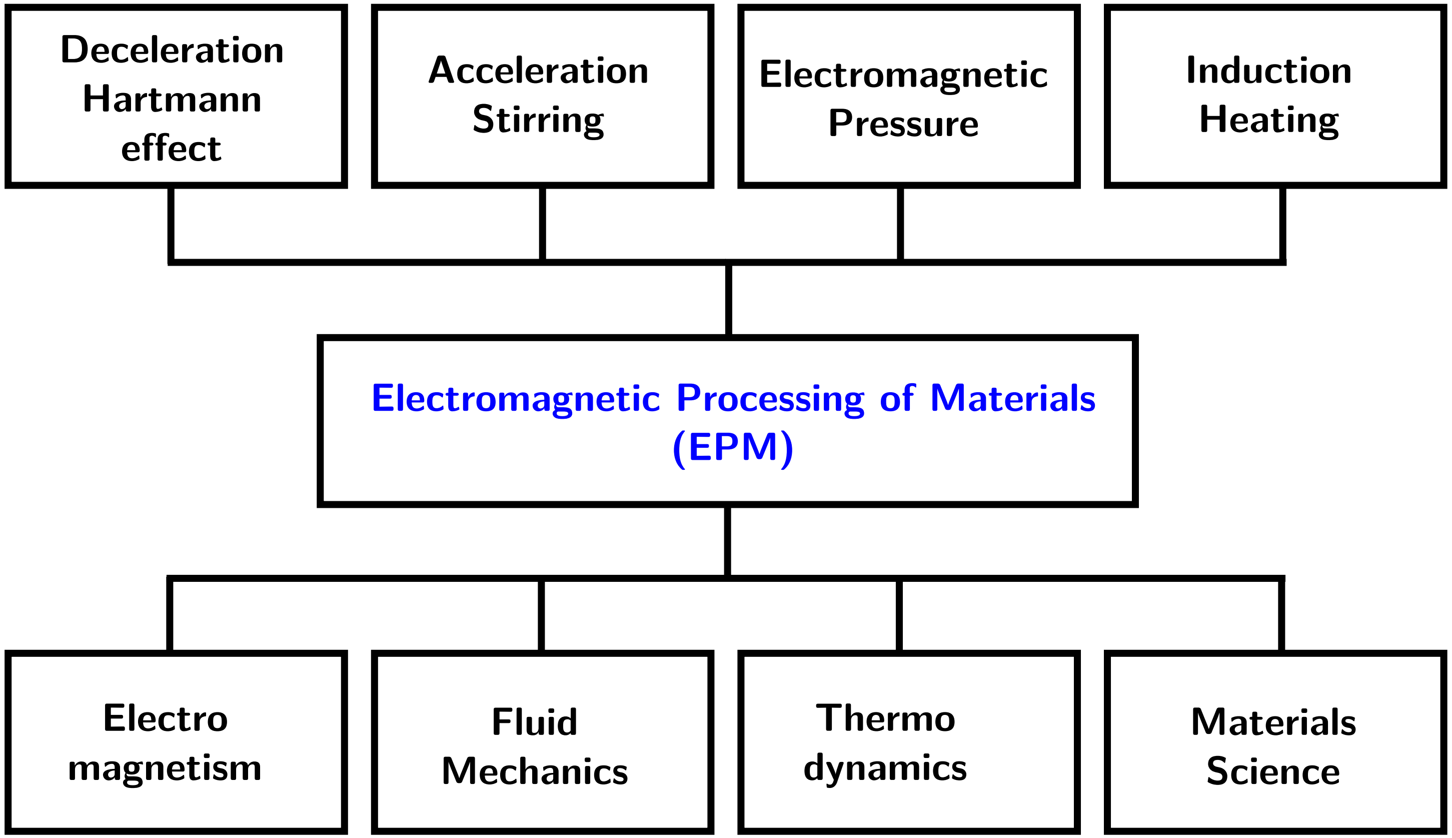
Related issues:

- Intensive Marangoni convection
- Buoyancy forces
- Recoil pressure
- Surface stability
- Melt ejections
- Non-uniform solidification

Introduction

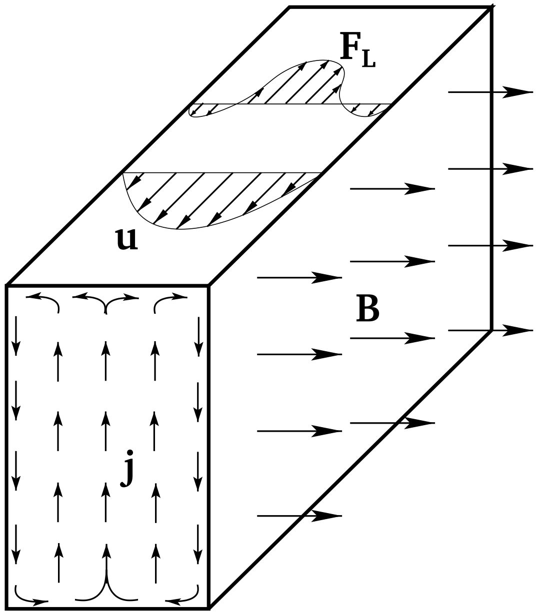
Possibility to decelerate the melt?

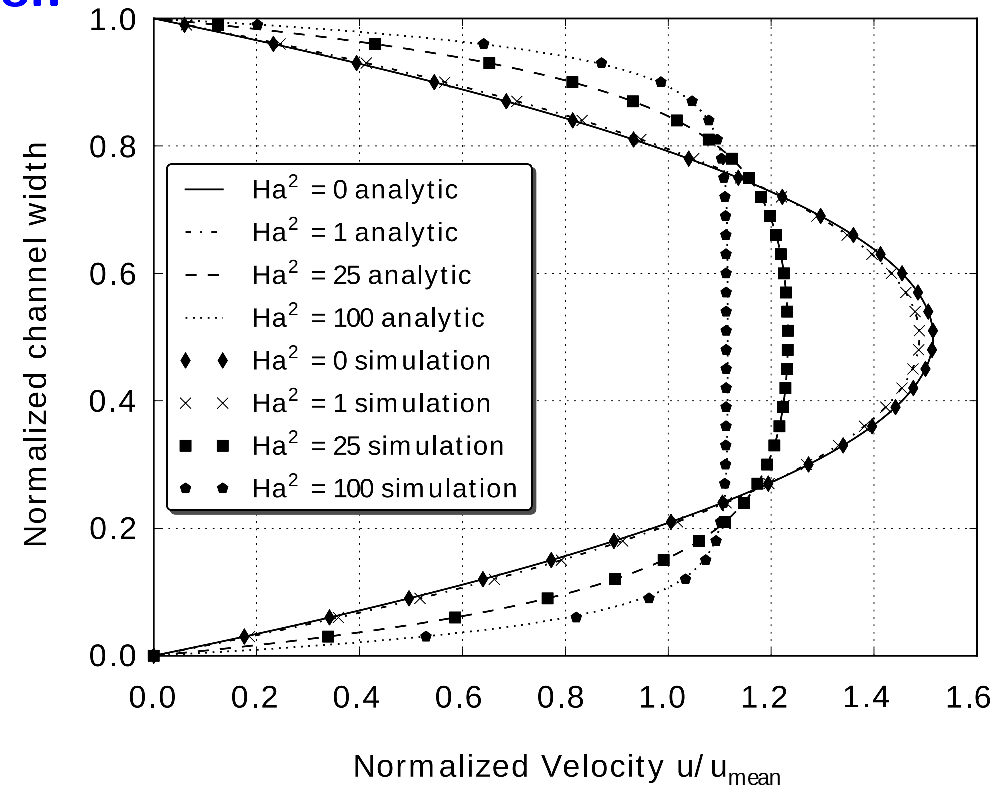
- apply volumetric forces contact-less
- all welding positions



Physical Principles

Hartmann Effect – Flow Deceleration

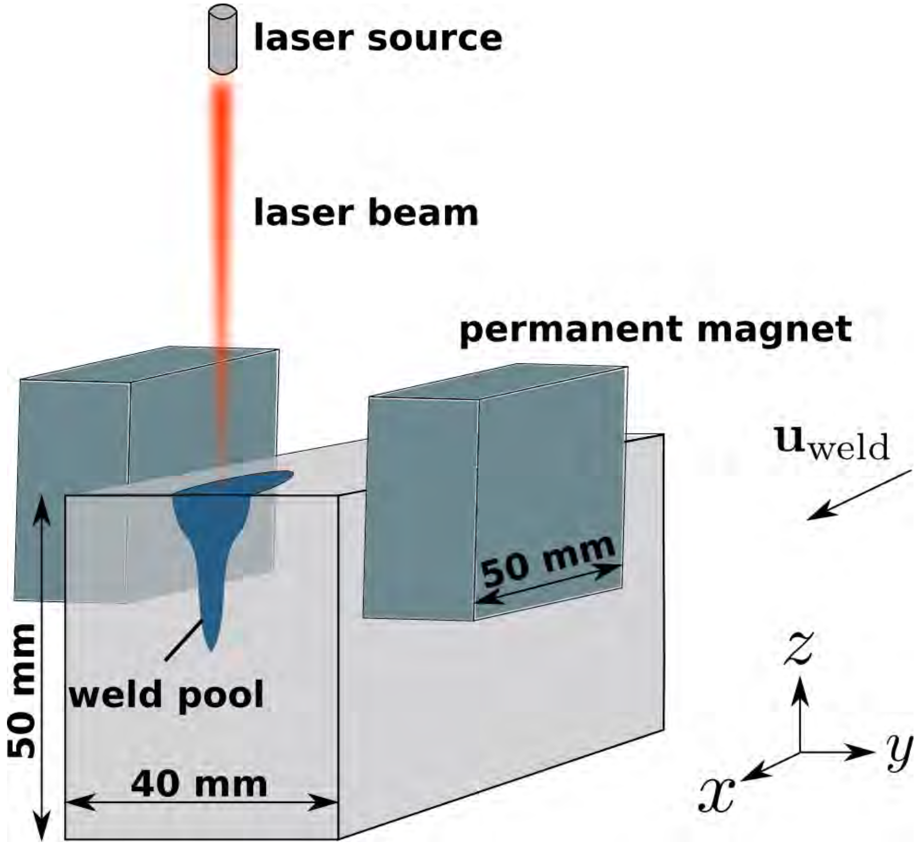




- **Liquid metal flow induces electric currents**
- **Ratio of magnetic induced to viscous drag** $\mathrm{Ha}^2 = (\mathrm{BL})^2\,\sigma/\eta$
- **Resulting Lorentz force directed against melt movement**

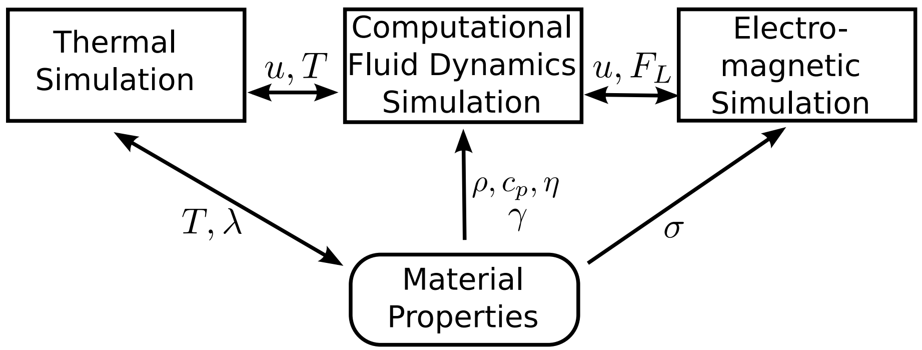
Physical Principles

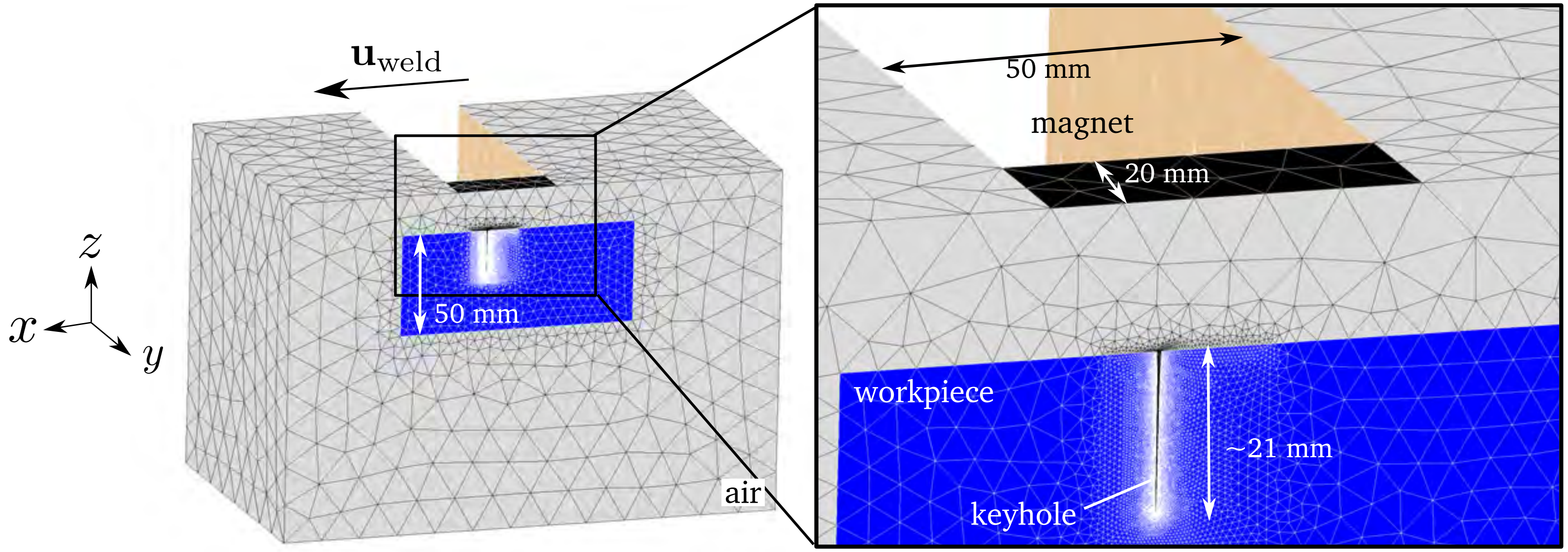
Permanent magnets applied to partial penetration welding



- Mitigation of weld pool dynamics
- Avoid turbulent flow pattern
- Achieve parallel side walls

Numerical Modelling

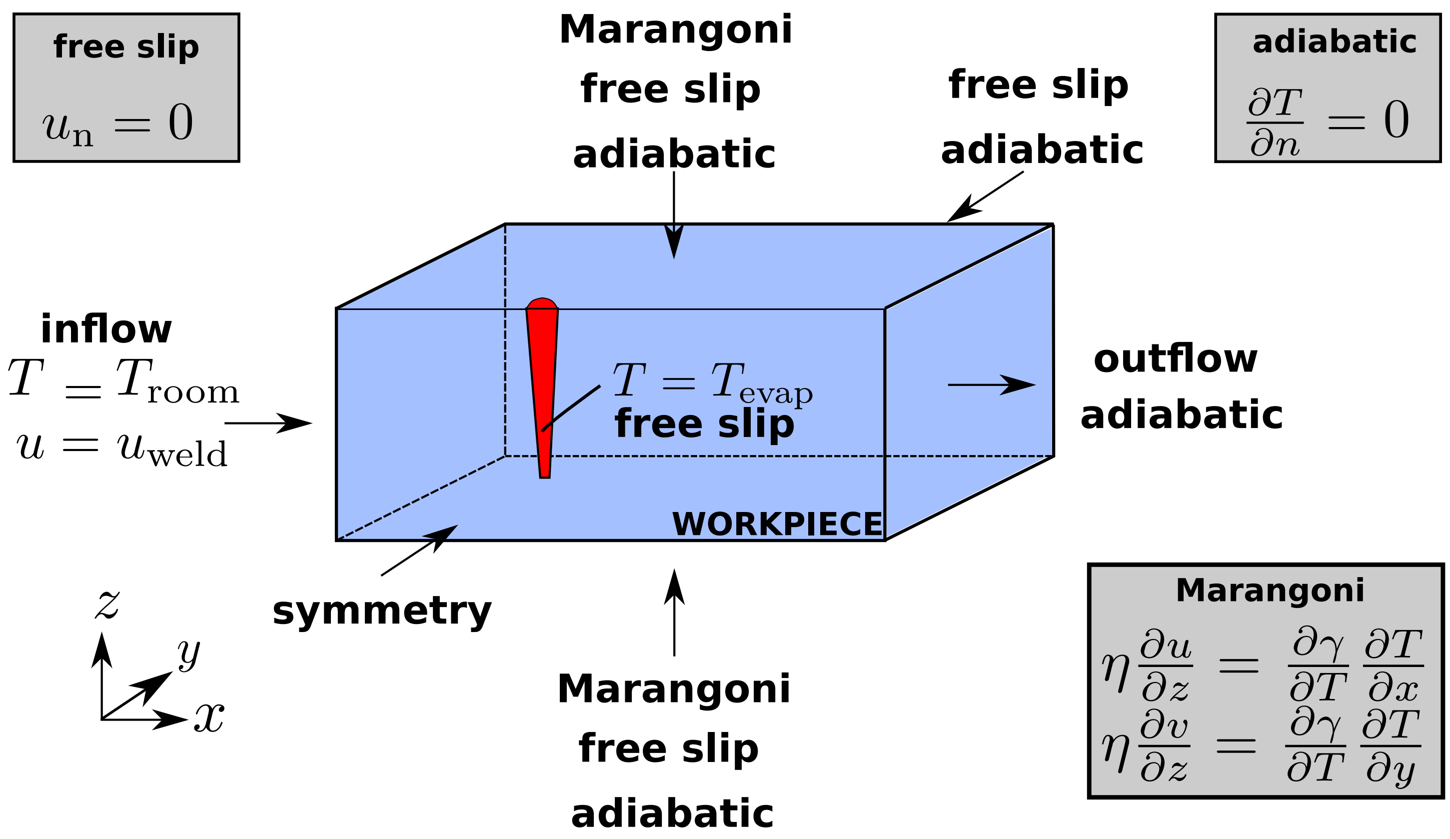




- **Workpiece width: 40 mm**
- **Magnet cross section: 50 mm $\times$ 50 mm**
- **Vertical shift of the magnet: 20 mm**

- **900,000 tetrahedral finite elements $\Rightarrow$ 8,100,000 DoF**

Numerical Modelling

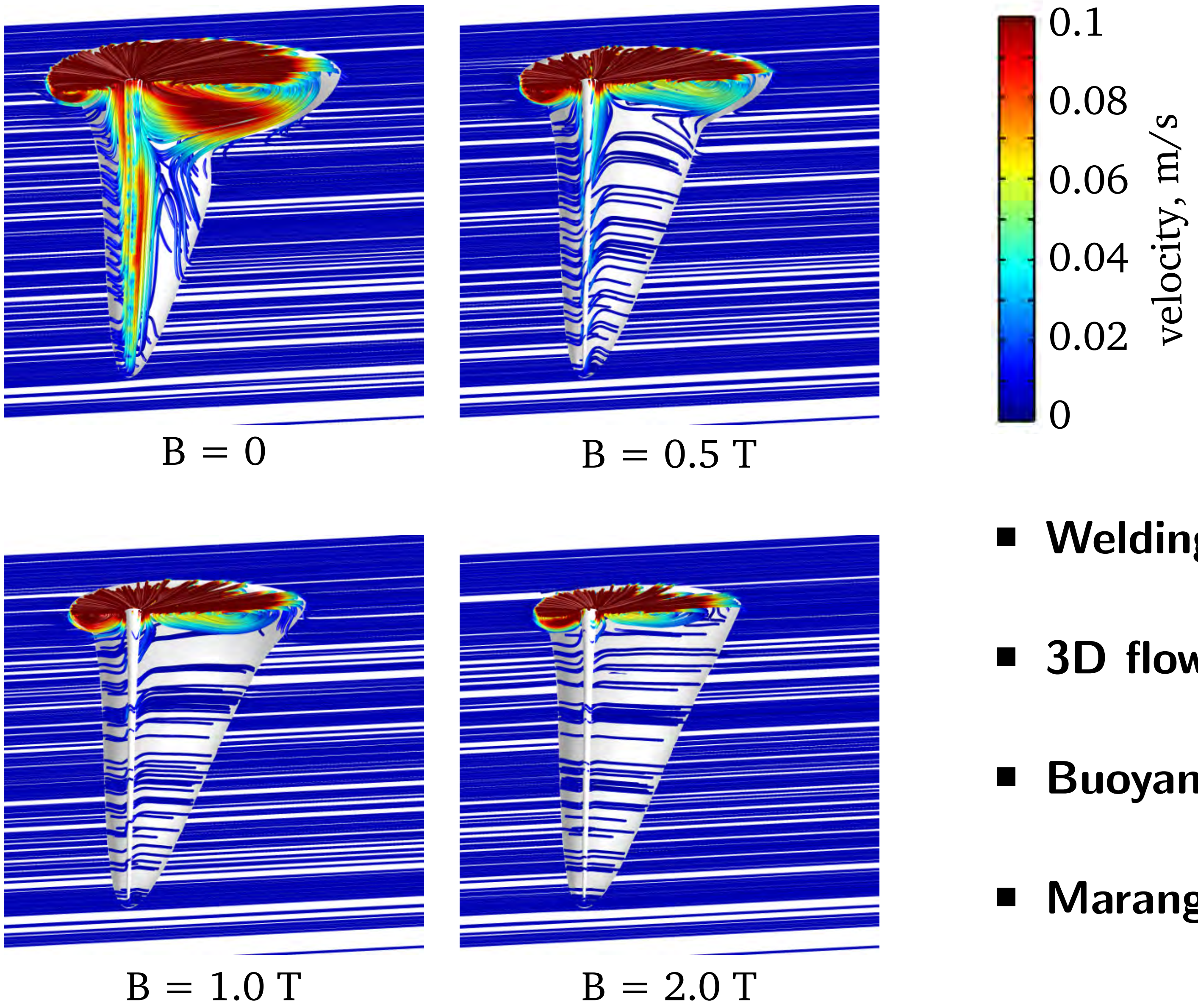


Navier Stokes equations volume source term

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

Buoyancy **Solidification modelling** **Lorentz force**

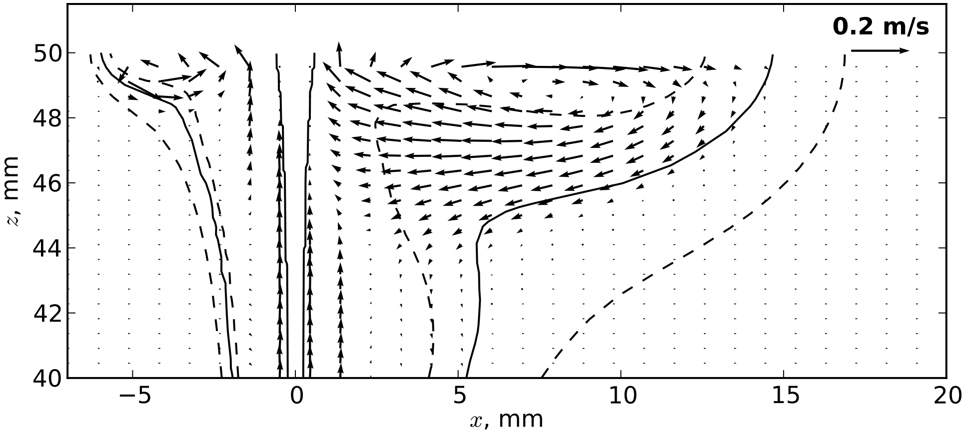
Velocity distribution



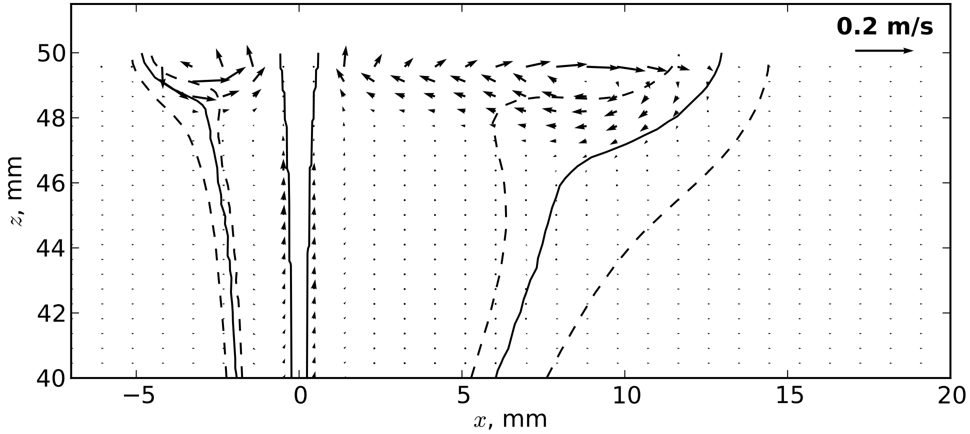
- **Welding speed 0.5 m/min**
- **3D flow ⇒ 2D flow**
- **Buoyancy suppression**
- **Marangoni flow suppression**

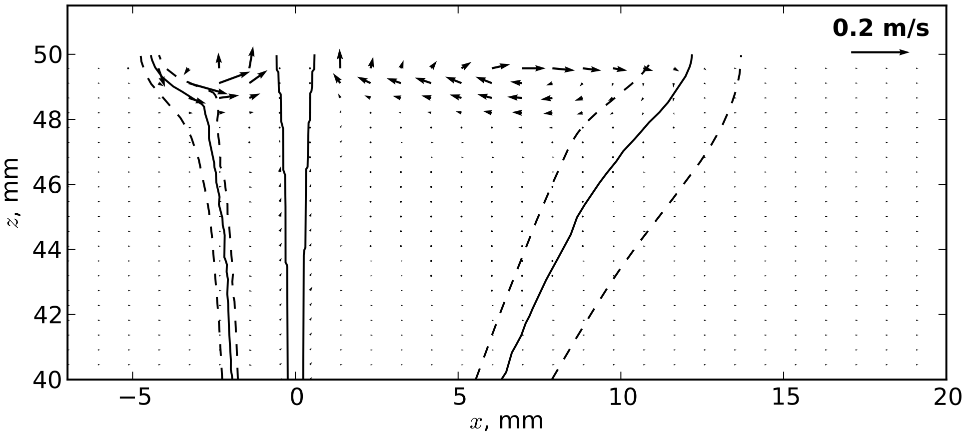
Velocity distribution

B=0

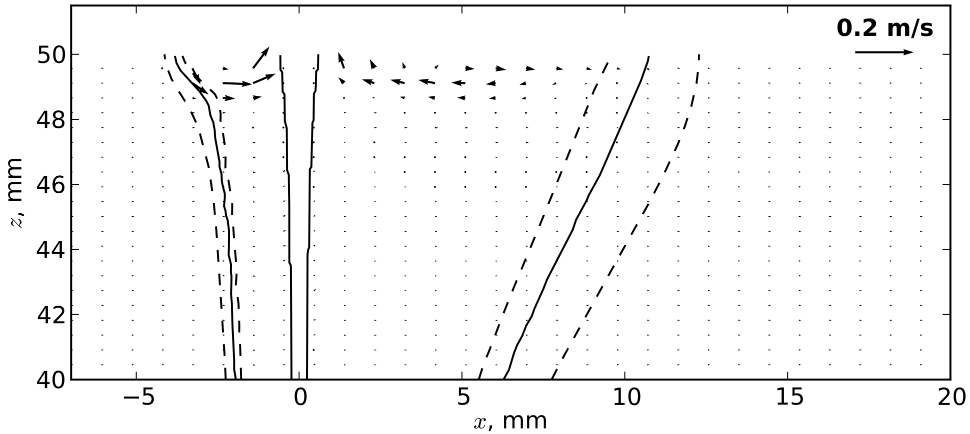


B=0.5 T



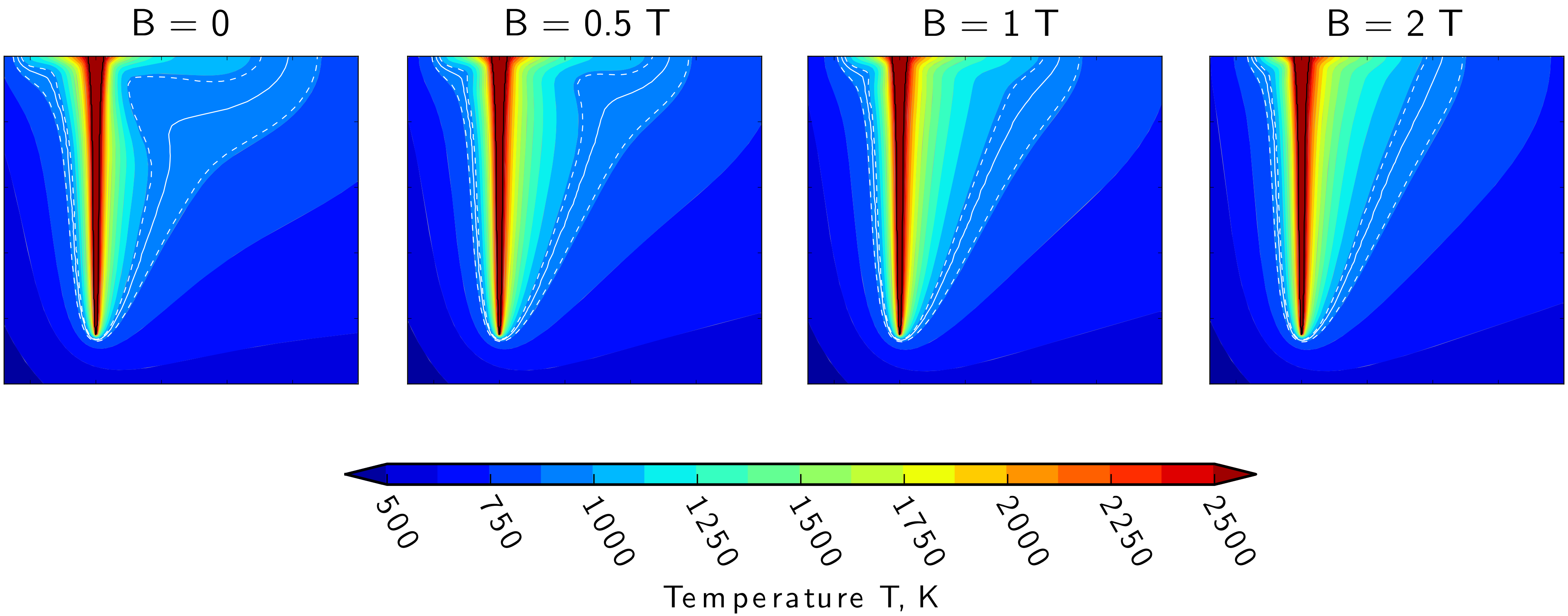


B=1 T



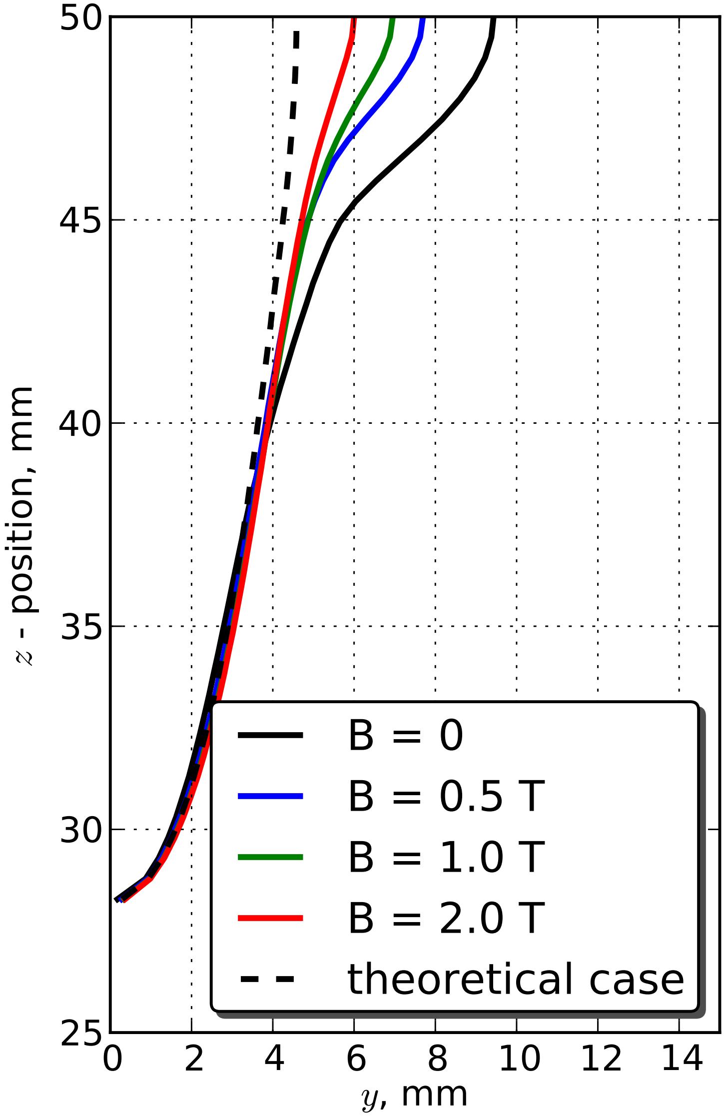
B=2 T

Temperature distribution



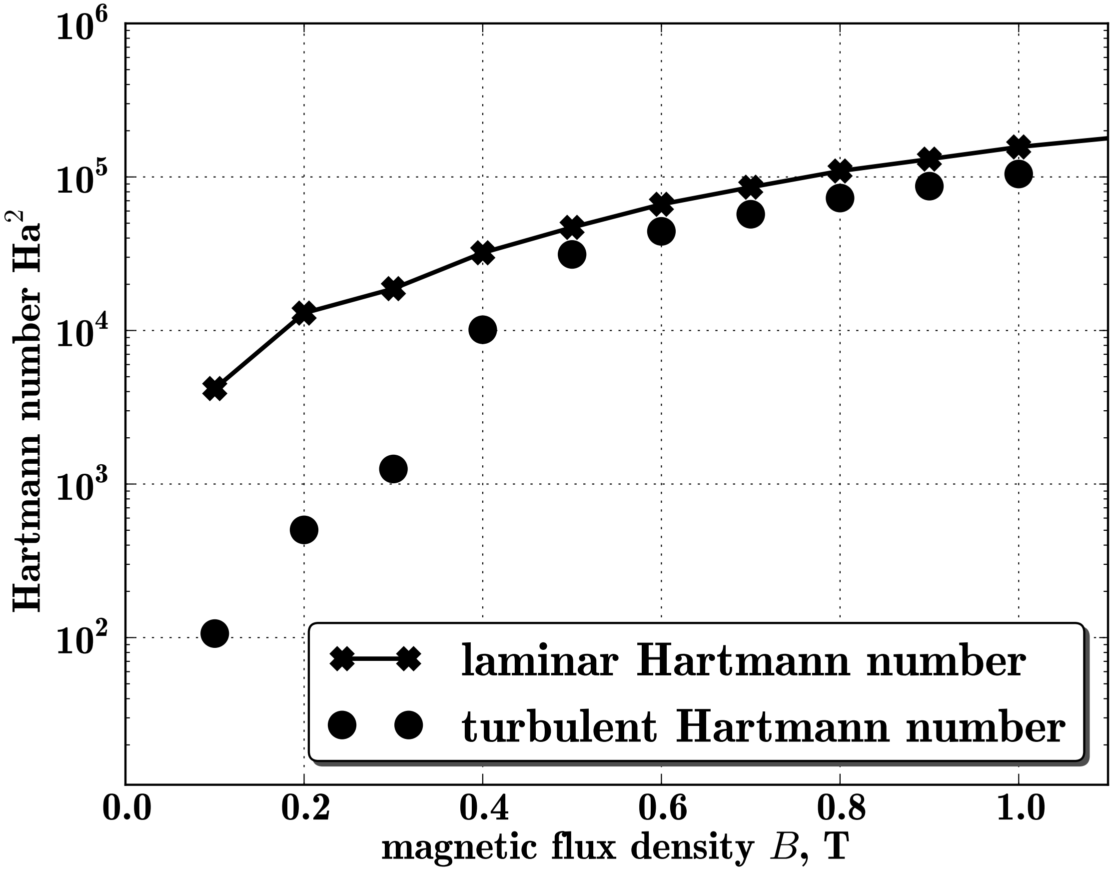
- **Marangoni convection suppressed at free surface**
- **Weld bead shortening**
- **Curvature in solidification line eliminated**

Macro Section Solidification line



- **Marangoni convection suppressed**
- **Weld bead width decrease**
- **Curvature in solidification line eliminated**

Local Hartmann Number

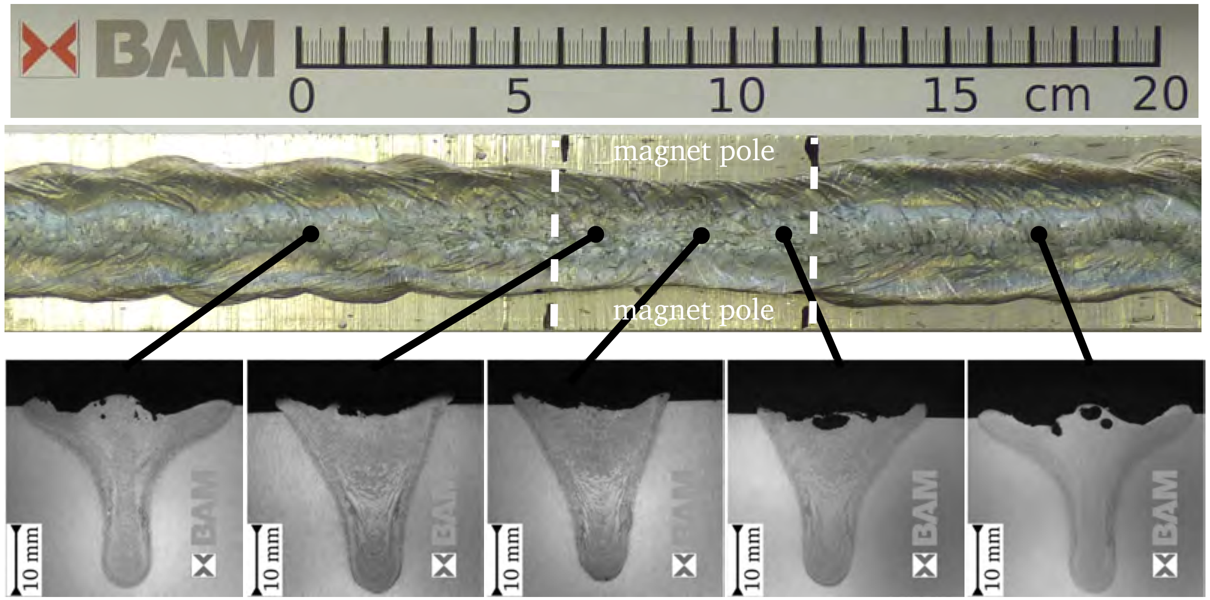


Position: 5 mm behind keyhole and 5 mm below surface

- $\eta = \eta_{lam} + \eta_{turb}$
- **Jump in $Ha^2 = (BL)^2 \sigma / \eta$**
- **Once turbulence is damped**
  $Ha^2_{lam} \approx Ha^2_{turb}$
- **Critical Ha^2 for effective flow control around B=0.4 T**

Experimental Observation

AlMg3 Welding Experiments with 16 kW disc laser system and permanent magnets

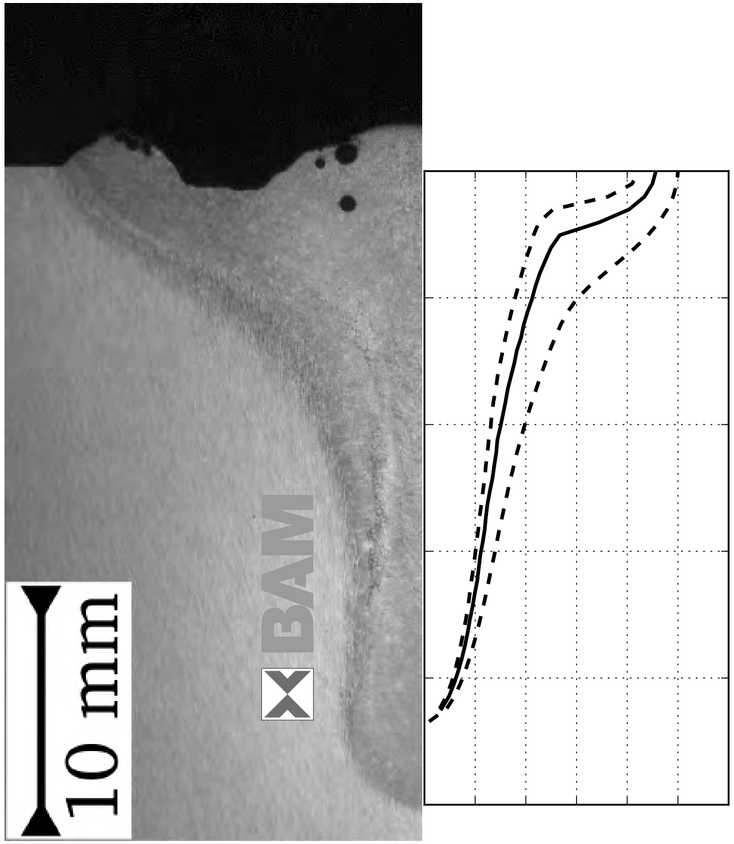


Laser power: 16 kW
Welding velocity: 0.5 m/min
Focus position: -4 mm
Shielding gas: 30 l Ar

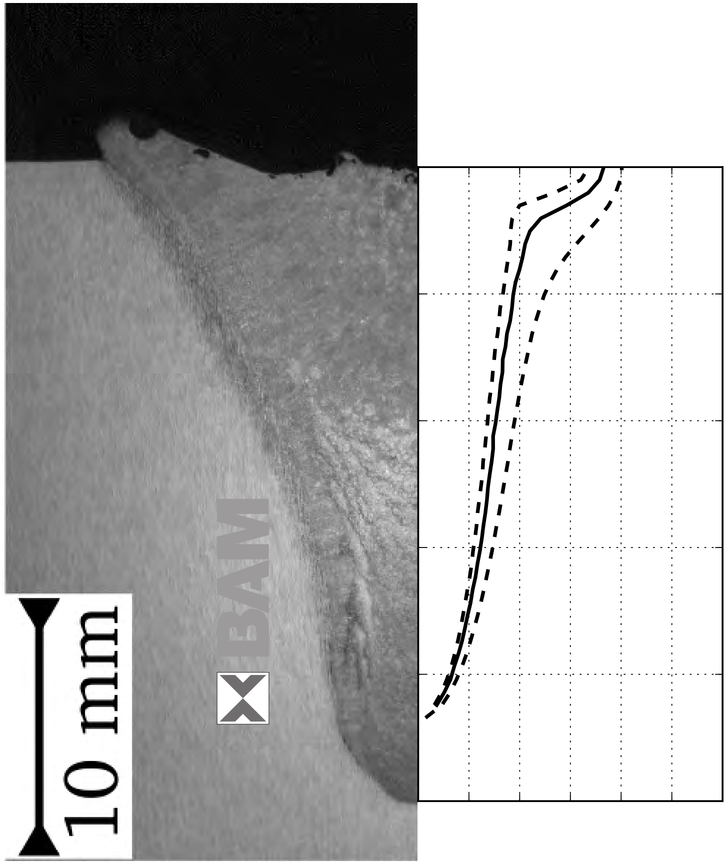
- B_{max} around 0.5 T
- Weld narrowing
- Less surface waviness
- Wine-glass shape $\Rightarrow$ V shape

Experimental Observation

Reference

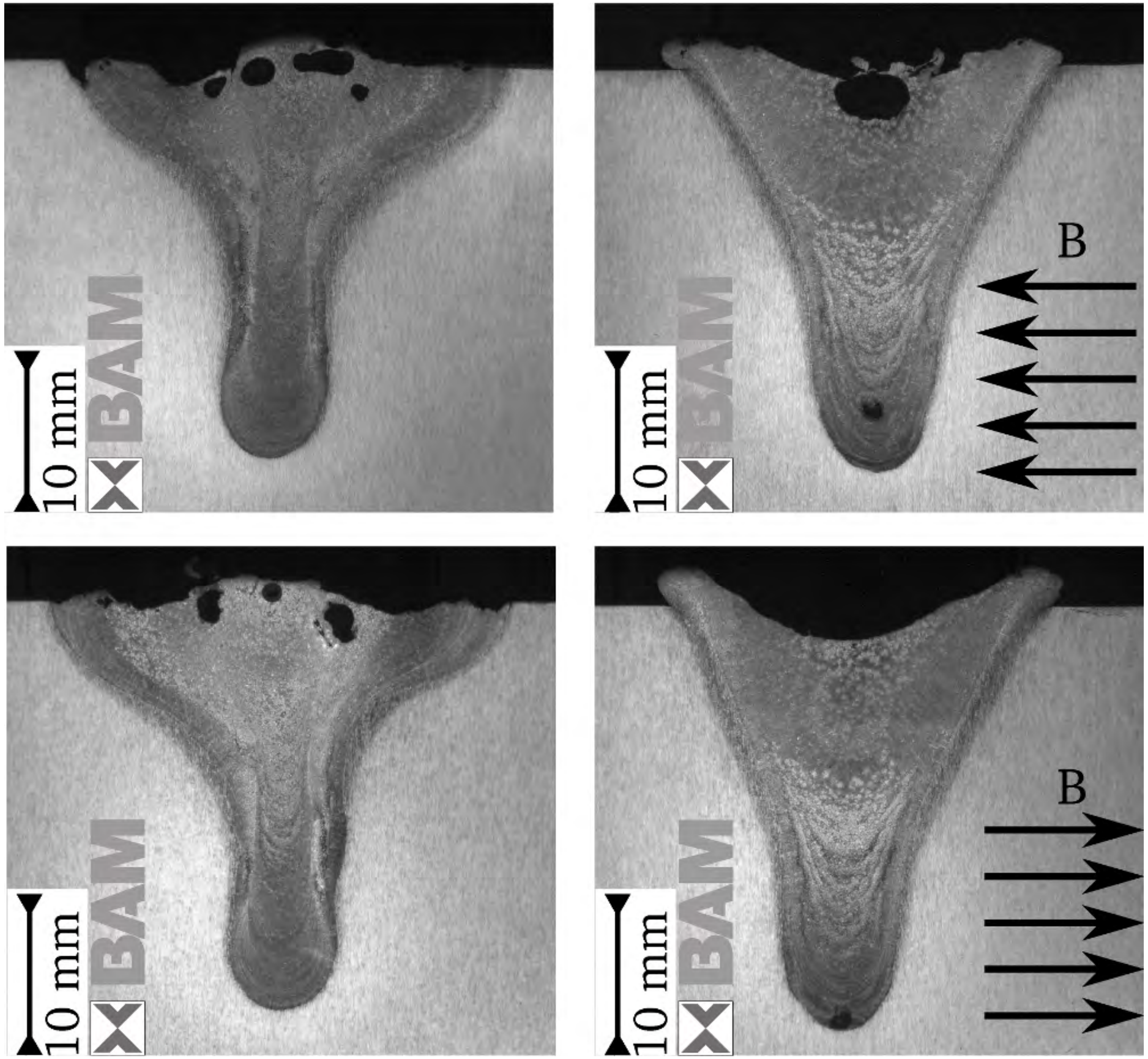


B = 500 mT



⇒ Same tendency in experiments and simulations!

Experimental Observation



- **B = 500 mT**
- **Same results with changed orientation of the magnet field**
- **Evidence for the occurance of Hartmann effect**

Laser power: 16 kW
Welding velocity: 0.5 m/min
Focus position: -4 mm
Shielding gas: 20 l Ar

Conclusions

- **Influence of steady magnetic fields in partial penetration laser beam welding of aluminium is shown**
- **Significant changes in the velocity distributions**
- **Maximal turbulence damping beginning with $\mathrm{Ha}^2 \approx 10^4$**
- **Weld pool geometry changes due to Hartmann effect with increasing magnetic field from wine-glass shape to V shape**
- **Changes in solidification line can influence mechanical and metallurgical properties**

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Thank you for your attention.

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