Multiphysics Process Simulation of the Electromagnetic-Supported High Power Laser Beam Welding of Austenitic Stainless Steel

Marcel Bachmann*, Vjaceslav Avilov, Andrey Gumenyuk, Michael Rethmeier
BAM Federal Institute for Materials Research and Testing, Unter den Eichen 87, 12205 Berlin, Germany
*Corresponding author: Marcel.Bachmann@BAM.de

BAM Federal Institute for Materials Research and Testing

Introduction & Motivation

- High power laser beam welding is a time and cost efficient joining technology. Advantages compared to conventional arc welding methods are the narrow welds with small heat affected zones and low distortions, high process velocities, small amounts of filler metal and the high flexibility and reproducability.
- In full-penetration laser beam welding, liquid metal tends to sagging or drop-out when the thickness of the material exceeds a threshold depending on surface tension forces at the root side
- An electromagnetic weld pool support system was applied to prevent the liquid metal from drop-out

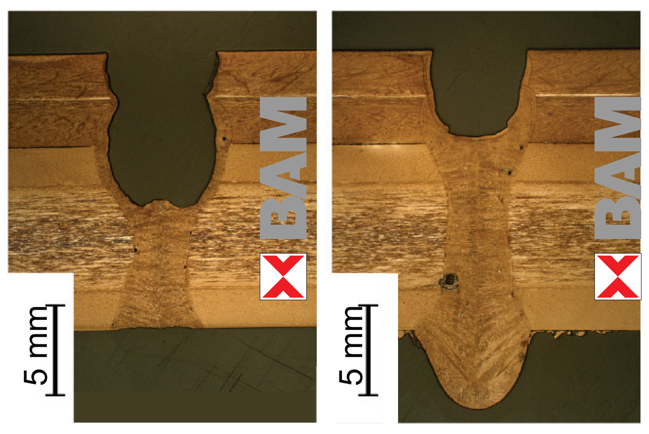


Figure 1: Macro sections of test welds without magnetic weld pool support for 15 mm AISI 304 stainless steel with 12 kW laser power, -4 mm focus depth and a welding speed of 0.4 m/min.

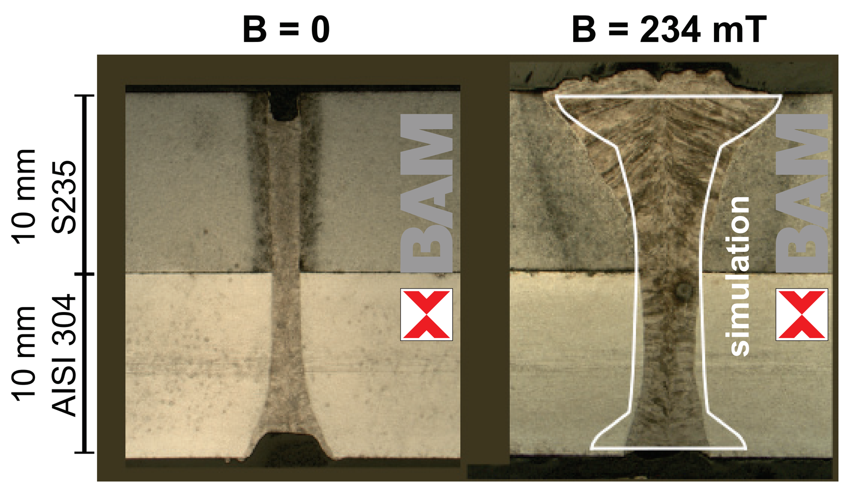
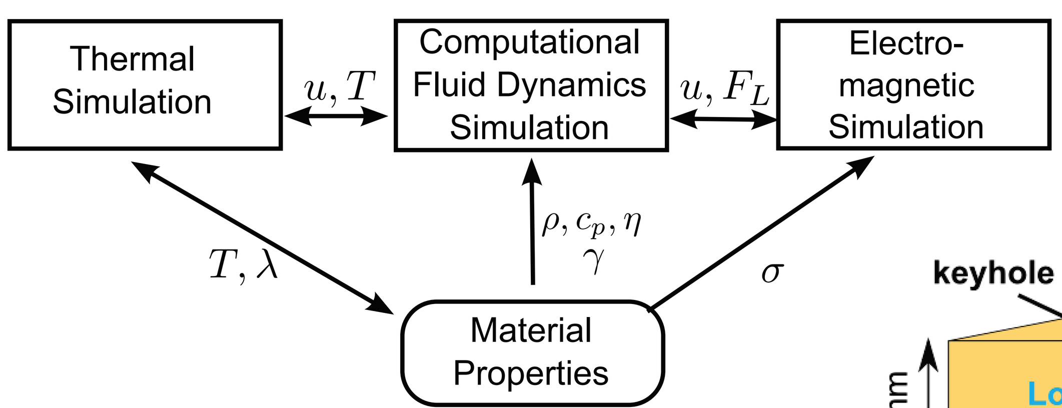


Figure 2: Macro sections of 20 mm welds consisting of 10 mm stainless steel AISI 304 and 10 mm ferritic steel S235, which is outside the penetration depth of the magnetic field. The laser beam power is 18 kW, the focus depth is 6 mm inside the material, the welding velocity is 0.4 m/min.

Weld Pool Support

- An oscillating magnetic field below the welding zone induces eddy currents
- The interaction of magnetic field and electric currents produces Lorentz forces that are directed against gravity
- Use of COMSOL Multiphysics 4.2 *Non-Isothermal Flow* and *Magnetic and Electric Fields* Interface



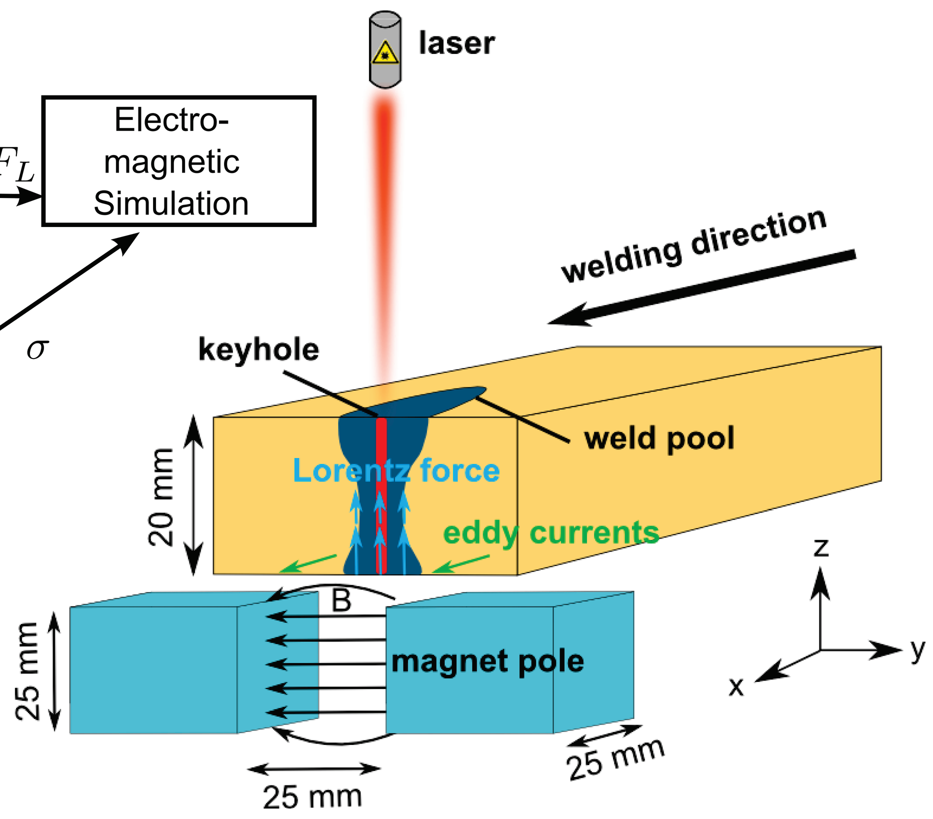


Figure 3:

Left: coupling between fluid dynamics, heat transport and electromagnetic quantities

Right: schematic electromagnetic weld pool support system.

Numerical Model

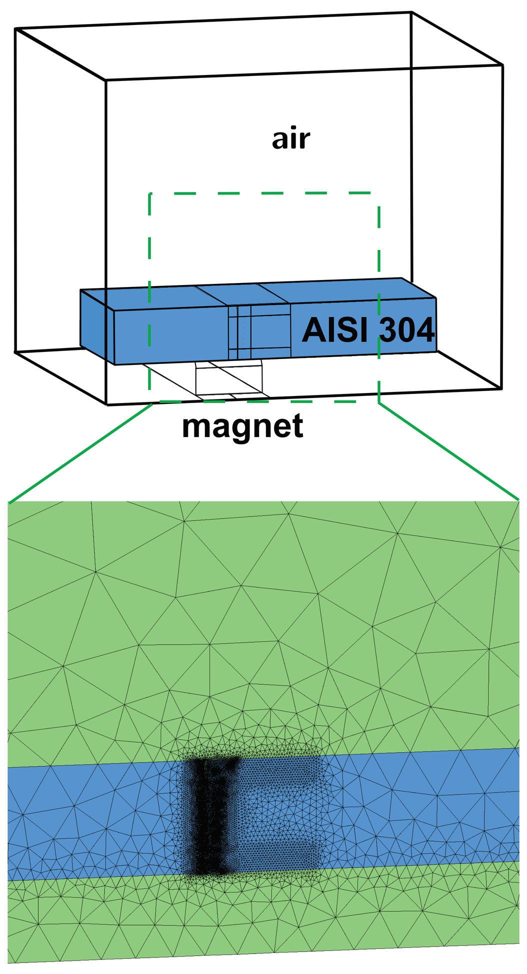
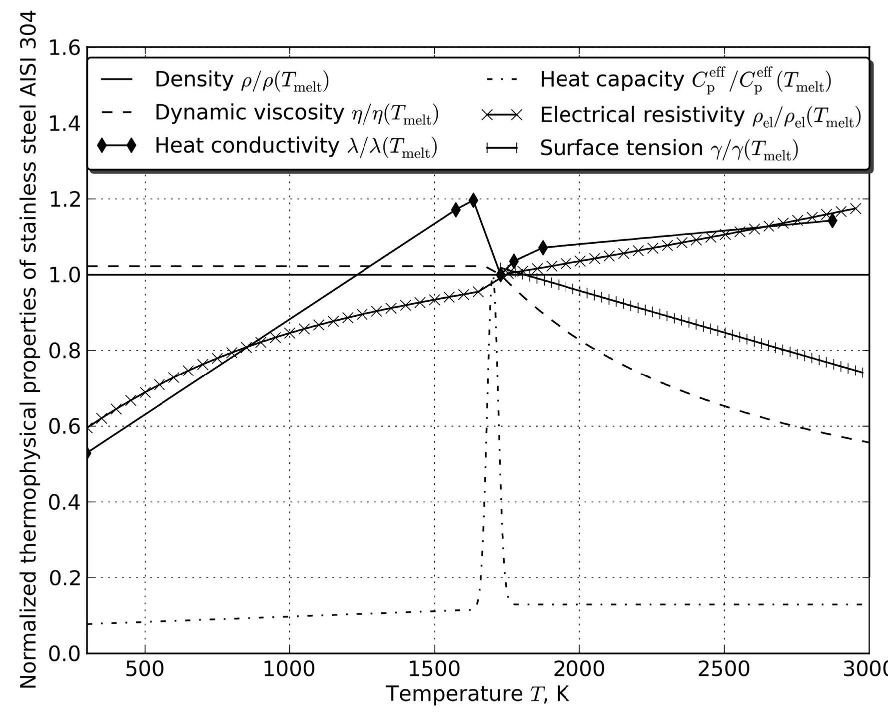


Figure 4: COMSOL model and meshing.

- P. Sahoo *et al.*, *Metall. Mater. Trans. B* **19B** 483-491 (1988)
- K. C. Mills *Recommended Values of Thermophysical Properties for Selected Commercial Alloys* Woodhead Publishing Ltd (2002)
- B. Wilthan *et al.*, *Int. J. Thermophys.* **29** 434-444 (2008)



melt. temperature T_{melt}	1700 K	evap. temperature T_{evap}	3000 K
density ρ	6900 kg/m^3	heat capacity C_p	800 J/kgK
latent heat of fusion H_{f}	$2.61 \cdot 10^5$ J/kg	heat conductivity λ	28 W/mK
dynamic viscosity η	$6.4 \cdot 10^{-3}$ Pa s	elec. resistivity $\rho_{el} = \sigma^{-1}$	$1.33 \cdot 10^{-6}$ Ω m
Marangoni coefficient γ'	$-4.3 \cdot 10^{-4}$ N/m K	surface tension γ	1.943 N/m

Figure 5: Material model for stainless steel AISI 304.

Numerical Results

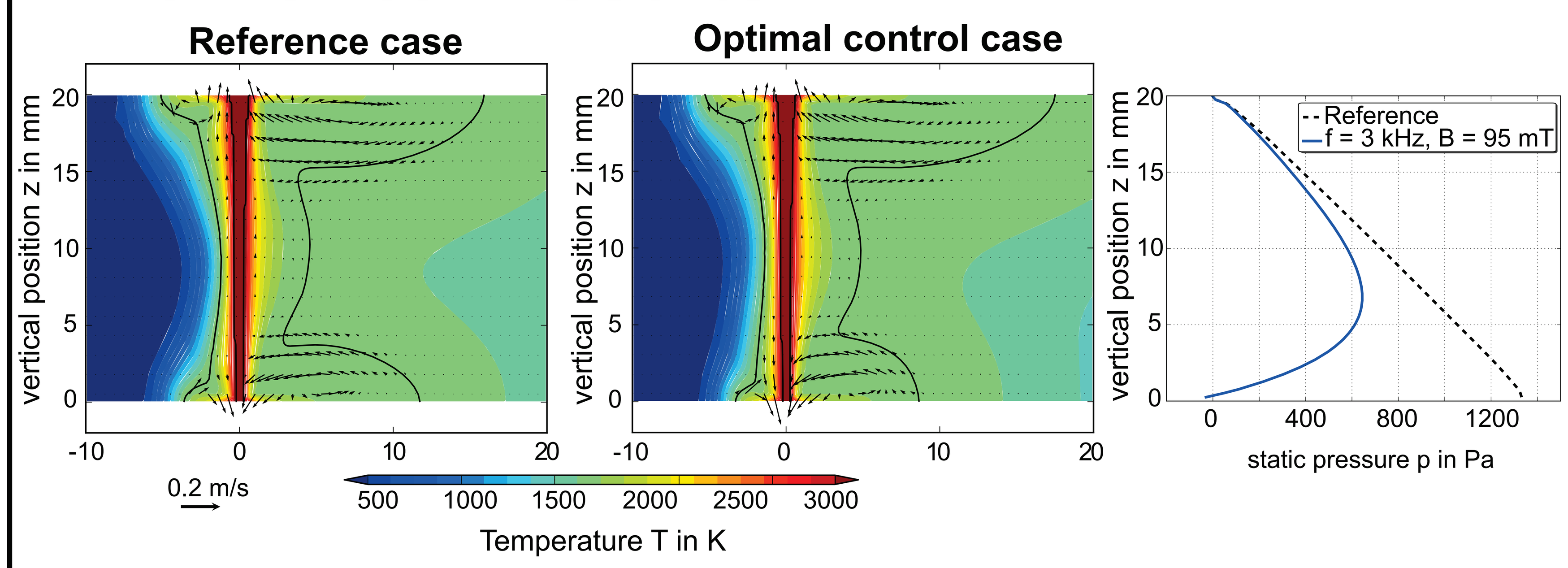


Figure 6: Temperature and velocity distributions in the symmetry plane of the weld for the case without electromagnetic support and applied electromagnetic forces as well as corresponding pressure distributions for a welding velocity of 0.4 m/min.

- Only minor changes in the temperature and flow field
- Essential differences in the pressure distribution along the vertical directon
- Results point to successful weld pool support for a magnetic flux density of 95 mT at an oscillation frequency of 3 kHz
- Drop-out of weld metal as well as undercuts and sagging of the weld could be avoided experimentally by the applied electromagnetic forces for a magnetic flux density of 234 mT at an oscillation frequency of around 2.6 kHz (Figure 2)

Conclusions

- Magnetic flux density for optimal compensation was higher than predicted by COMSOL
- Possible influence of weakly ferromagnetic properties of stainless steel AISI 304 in combination with the excess of the Curie temperature around
- Influence of dynamics in the weld pool associated to evaporation at the keyhole wall

References & Acknowledgements

- This work is supported by the Deutsche Forschungsgemeinschaft (Bonn, Germany) under Grant No. DFG GU 1211/2-1.

- R. Moreau, *Magnetohydrodynamics*, Kluwer Academic Publishers (1990)
- V. Avilov *et al.*, *Proc. EPM 2009*, Dresden, Germany
- M. Bachmann et al., *J. Phys. D: Appl. Phys.* **45** 035201 (2012)