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

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Abstract

Introduction:
Laser beam welding with laser intensities above a critical limit enforces the so-called keyhole mode welding, where a small amount of metal vaporizes. This builds a cavity in the weld pool that must be flown around by the surrounding melt which is additionally accelerated by Marangoni stresses at the weld surfaces due to temperature-dependent surface tension. Welding thick plates in full-penetration mode promotes the occurrence of melt sagging and drop-outs, when the surface tension of the melt cannot balance the hydrostatic pressure of the melt column at the lower weld bead surface.

In this investigation, an oscillating magnetic field B is applied below the weld specimen being aligned perpendicular to the welding direction below the specimen inducing eddy currents j being aligned parallel to the welding line and forming upwards directed Lorentz forces in the melt that counteract the gravitational forces, see Figure 1.

Use of COMSOL Multiphysics®:
A three-dimensional turbulent steady state numerical model was used to investigate the influence of an alternating current (AC) magnetic field during high power laser beam keyhole welding of 20 mm thick stainless steel AISI 304 being modeled as an ideal non-ferromagnetic material. Three-dimensional heat transfer and fluid dynamics as well as electromagnetic field equations were solved taking into account the most important physical effects of the process, namely the thermo-capillary (Marangoni) convection at the weld pool boundaries, natural convection due to gravity in the melt volume and latent heat of the solid-liquid phase transition at the phase boundaries. The COMSOL Multiphysics® package's Non-Isothermal Flow Interface (NITF) as well as the Magnetic and Electric Fields Interface (MEF) were used.

Results:
It is numerically shown that the gravity drop-out associated with welding of thick plates due to the hydrostatic pressure can be prevented by the application of an AC magnetic field of 95 mT at an oscillation frequency of 3 kHz. The flow characteristics in the melt pool are not significantly influenced by the induced Lorentz forces. Moreover, an electromagnetic damping of the dynamics in the melt was not observed, see Figure 2.

Experimentally, a value of around 230 mT was found to be necessary to allow for single-pass laser beam welding without sagging or drop-out of melt.

Conclusion:
The application of an oscillating magnetic field on the high-power full-penetration laser beam welding process of a 20 mm thick stainless steel plate was numerically and experimentally investigated. It was shown, that the application of an oscillating magnetic field that induces eddy currents in the melt results in a Lorentz force that is capable of compensating for the hydrostatic pressure due to gravity. The needed magnetic flux density for an optimal compensation was higher than predicted by COMSOL Multiphysics®. A possible reason for that are the weakly magnetic properties of the austenitic steel AISI 304, that were not accounted for in the model.

Figures used in the abstract

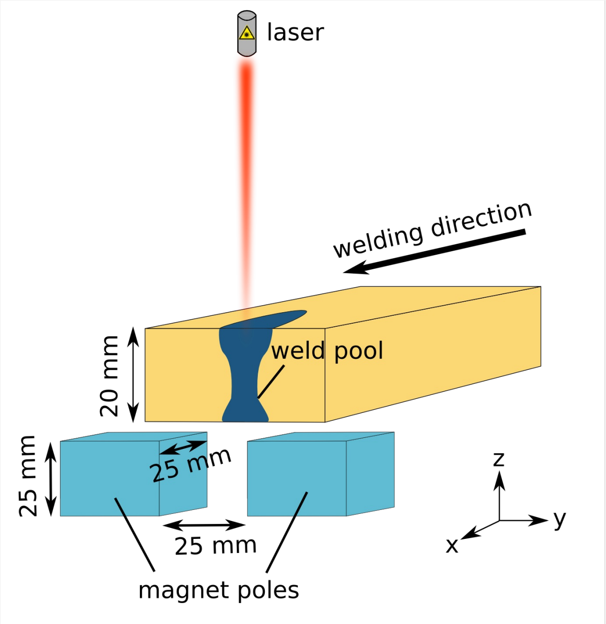

Figure 1: Sketch of the electromagnetic weld pool support.

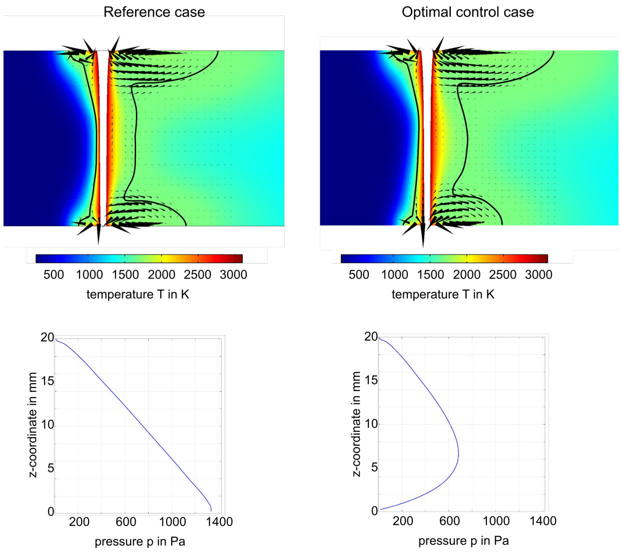

Figure 2: top: Temperature and velocity distributions in the symmetry plane of the weld pool for the reference case without magnetic fields applied and the case of optimal control for a magnetic flux density of 95 mT and a frequency of 3 kHz. bottom: Corresponding pressure distributions in the weld pool for both cases. The pressure distribution for the optimal control case shows the compensation of the hydrostatic pressure.