Multiphysics Process Simulation of Static Magnetic Fields in High Power Laser Beam Welding of Aluminum

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Abstract

Introduction: Well-known issues in high-power laser beam welding of aluminum are the highly dynamical flow behavior of the melt due to its low viscosity combined with the high heat conductivity. The weld surface becomes unstable and spattering and melt ejection occurs. The weld bead dimensions near the surfaces become very large being also supported by thermo-capillary convection caused by temperature-dependent surface tension variations. Resulting weld cross sections show a typical wineglass-shape with a strong curvature of the solidification front leading to heavy stresses in the work-piece and large distortions after cooling down. As the weld bead becomes larger with deeper penetration of the laser, that issue is of particular importance for high power deep penetration laser beam welding. The aim of this investigation is to study the influence of static magnetic fields perpendicular to the welding direction and their effect on liquid metal flows (Figure 1). The movement of liquid metal in the magnetic field causes an electric current density which builds a Lorentz force that has a component that is directed against the original flow direction (called Hartmann effect). Use of COMSOL Multiphysics: The numerical model calculates the influence of a steady magnetic field during 20 mm deep partial penetration keyhole laser beam welding of aluminum in PA position at a welding speed of 0.5 m/min. Three-dimensional heat transfer, fluid dynamics including phase transition and electromagnetic field equations were solved with COMSOL Multiphysics Non-Isothermal Flow physics interface as well as the Magnetic and Electric Fields physics interface (Figure 2). Results: The main objective of the simulations was to estimate the necessary value of the magnetic field needed to suppress convective flows in the weld pool during high power (up to 20 kW) laser beam welding of aluminum with up to 20 mm deep and 10 mm wide weld pool. The simulations show that steady magnetic fields up to 1 T can effectively lower the influence of convective motions in the weld pool. Hereby, the flow pattern changes from thermo-capillary flow induced recirculation to a flow parallel aligned to the welding direction. The flow velocity decreases significantly for increasing magnetic flux densities thus making the impact of the dynamics near the weld surface weaker (Figure 3). The turbulent viscosity has an important influence on the effectiveness of the control mechanism by lowering the level of flow control. Conclusion: The simulations show the potential of a flow deceleration by permanent magnetic fields perpendicular to the welding direction in terms of a suppression of the Marangoni flow. The induced magnetic drag component was much higher than viscous damping forces and is therefore an effective means of taking influence on the flow pattern in the weld pool. As a consequence, a narrowing of the weld cross section and a reduction of the surface roughness of the

weld are expected to be seen in welding tests.

Reference

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Figures used in the abstract

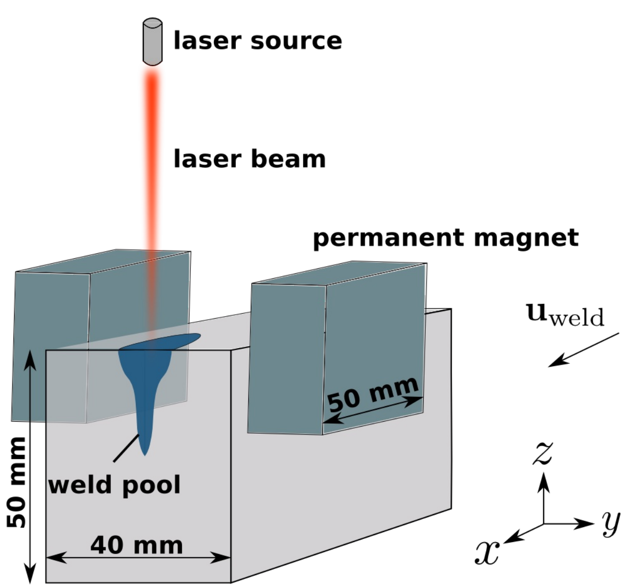

Figure 1: Flow control set-up in laser beam welding by means of static magnetic fields.

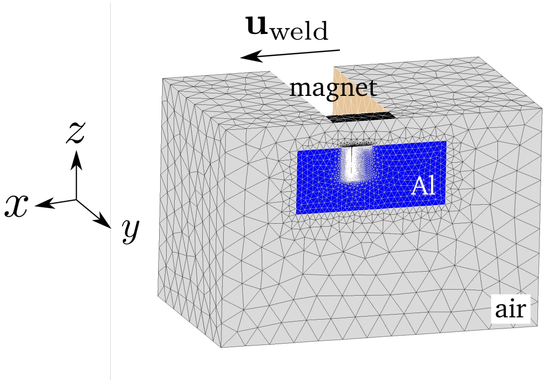

Figure 2: Simulation domains consisting of the aluminum plate (blue) and the surrounding air (grey). The magnetic field was applied by boundary conditions at the upper outer surface (black). The magnet geometry was cut off.

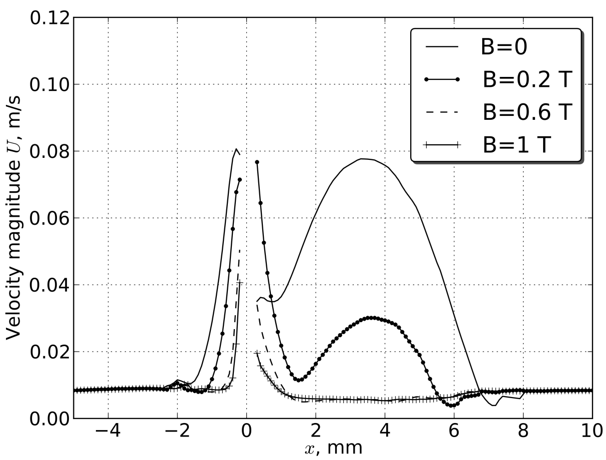

Figure 3: Magnitudes of the flow velocity 3 mm below the weld surface in the symmetry plane of the weld for different magnetic flux densities.