Numerical Analysis of the Effect of Surface Active Elements on Marangoni Flow in a Melt Pool

A. Mishra[1], K. Yadav[1]

[1]IIT Kanpur, Kanpur, Uttar Pradesh, India

Abstract

Introduction: Marangoni flow affects the heat and mass transfer occurring in the molten metal regions in welding and additive manufacturing processes. It originates from the surface tension gradient (∂γ/∂T) induced at the melt pool surface due to the temperature difference. The flow pattern within melt pool affects the segregation and melt-pool shape and size. The flow pattern and therefore the melt pool shape vary with the ∂γ/∂T, which is dependent on temperature and surface active elements concentration in the molten metal. Elements of the oxygen family, (O, S, Se and Te) are found to be strongly surface active. In the present study, numerical modeling and simulation is used to show the dependence of flow field and resulting melt pool shape on the surface active elements. Stainless steel alloy has been used as base for the modeling and sulfur is studied as the surface active element.
Use of COMSOL Multiphysics® software: Numerical modeling of marangoni convection within the melt pool has been done using COMSOL Multiphysics®. Both 2D and 3D models of laser beam induced spot melting are built. SS 316 alloy has been chosen as the domain material. For the modeling, heat transfer and fluid flow modules are used. The effect of temperature and surface active element (sulfur) concentration on ∂γ/∂T has been incorporated within the model using analytical functions.
Result: Simulations results show the effect of surface active element concentration on the melt pool dynamics and dimensions. The plot between ∂γ/∂T and temperature (T) shows the variation in ∂γ/∂T with T for varying concentrations of sulfur. The wide and shallow melt pool corresponding to negative ∂γ/∂T changed to narrow and deep as the ∂γ/∂T became positive.
Conclusion: The simulation results show that sulfur, as a surfactant, alters the flow fields in melt pool. Complete flow reversal is seen as the sulfur concentration increase. This is attributed to the sign change of ∂γ/∂T from negative to positive because of the presence of sulfur. However, with increasing temperature, the ∂γ/∂T again becomes negative at locations where temperature is greater than a critical temperature. This results in establishment of two opposing flow fields within the melt pool, which further changes the melt pool shape and affects the heat and mass transfer in the melt pool.

Reference

(1) C.X. Zhao et al.,"The effect of oxygen on transitional Marangoni flow in laser spot welding" Acta Materialia, 58 (2010), pp. 6345-6357
(2) Y. Zhao et al., "Effects of surface active sulfur on flow patterns of welding pool, Journal of material science and technology" vol. 21, no. 3,2004.