A numerical model for the simulation of shallow laser surface melting

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ABSTRACT

We present a multi-physics model for the approximation of the coupled system formed by the temperature-dependent Navier-Stokes equations with free surfaces. The main applications are the industrial processes of shallow laser surface melting (SLSM), for laser polishing of thin surfaces. Although no substrate is incorporated into the mixture, the goal of this study is to simulate the internal motion of the melting pool, and accurately model the free surfaces that arise in laser polishing processes.

More precisely, we consider incompressible flow equations with solidification, by using a classical Boussinesq approximation. We add thermal effects with an enthalpy-based convection-diffusion heat equation, and we model the laser source through physically-consistent boundary conditions. We incorporate surface tension effects through the Marangoni model to drive internal motion in the liquid metal.

The numerical method incorporates all the physical phenomena within an operator splitting strategy. In particular, diffusion processes, such as heat diffusion and the Stokes model, are decoupled from the transport phenomena. The volume-of-fluid approach is used to track the free surfaces between the (liquid or solidified) metal and the ambient air. The numerical space discretization relies on a multi-grid approach that uses an unstructured finite element mesh for the diffusion phenomena and a structured Cartesian grid for the advection phenomena. Local mesh refinement is incorporated in order to accurately track the free surfaces, as well as to provide an accurate description of the heat source represented by the laser impact.

A proof of concept of the numerical model is achieved through some numerical experiments. In particular, we show the sensitivity of the influence of Marangoni effects on the liquid metal during the re-melting process. We conclude with a simple example to show how laser polishing processes can reduce surface roughness through the redistribution of liquid material.

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