Laser-Driven Convection in Molten Metal: Numerical Experiment

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The processes of melting and subsequent solidification of material are an integral part of laser technology. These technologies include welding, surface engineering, sintering of powder materials, making holes, processing and cutting metal materials. The interaction of a laser with a material can be used to impart new properties to it, to structure material surface as well by formation of so-called laser-induced periodic surface structures (LIPSS) [1].

In this work, we made the first steps to construct a hydrodynamic-like mathematical model of LIPSS formation based on a numerical solution of the two-dimensional problem of thermal convection and melting with a heat source in the form of CW laser radiation and microsecond laser pulse incident on the sample surface. The motion of the melt is described by the Navier–Stokes equations in the Boussinesq approximation

$$\nabla \cdot \mathbf{u} = 0,$$

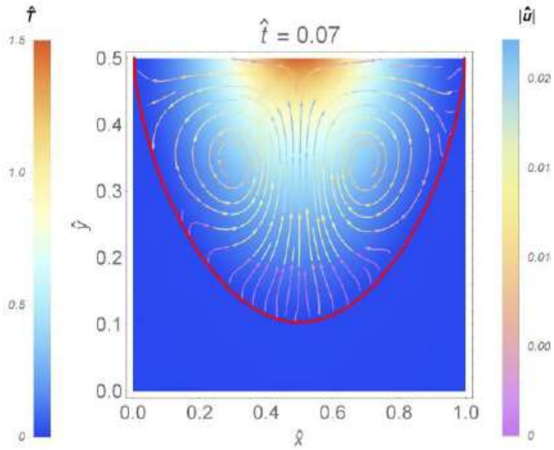
$$\rho \frac{\partial \mathbf{u}}{\partial t} + \rho(\mathbf{u}\cdot\nabla)\mathbf{u} = -\nabla p + \mu\,\Delta \mathbf{u} - \beta \mathbf{g}(T - T^*),$$

and the Stefan problem is formulated in a generalized form for the melting/crystallization processes [2]

$$\left(\rho c + L\delta(T - T^*)\right)\frac{\partial T}{\partial t} = \nabla\cdot(k\nabla T) + S(x, y, t)$$

Here $\mathbf{u}$, p, μ, β are melt velocity, pressure, viscosity, and expansion coefficient respectively, S is a heat source term, L is the enthalpy of phase transition, T^* is a melting temperature. Heat capacity c, density ρ, and heat conductivity k are considered as piecewise functions of temperature

$$c, \rho, k = \begin{cases} c_l, \rho_l, k_l, & T(x, y) > T^*; \\ c_s, \rho_s, k_s, & T(x, y) < T^*. \end{cases}$$



Motion of iron melt and temperature distribution under gaussian beam irradiation in dimensionless variables. Red line depicts the melting front.

The numerical method is based on locally one-dimensional schemes for velocity, pressure, and temperature. Equations are reduced to difference analogs by the finite volume method on staggered grids [3].

Calculations of the motion of the melt under irradiation of the iron surface with Gaussian laser pulses were performed (see figure). The influence of laser beam parameters on melting front propagation is studied.

Acknowlengement

Part of this work was performed in the frame of the ATLANTIC project. The project has received funding from the European Union's Horizon 2020 research and innovation programm under the Marie Skłodowska-Curie grant agreement No 823897.

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