Numerical Simulation of Evaporation Processes in Electron Beam Welding

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Introduction: The purpose of this work is to construct a nonlinear theoretical model that describes non-equilibrium processes in the liquid phase of the weld, which takes into account evaporation of chemical elements from keyhole walls, condensation of alloying elements on keyhole walls and diffusion of elements in the melt.

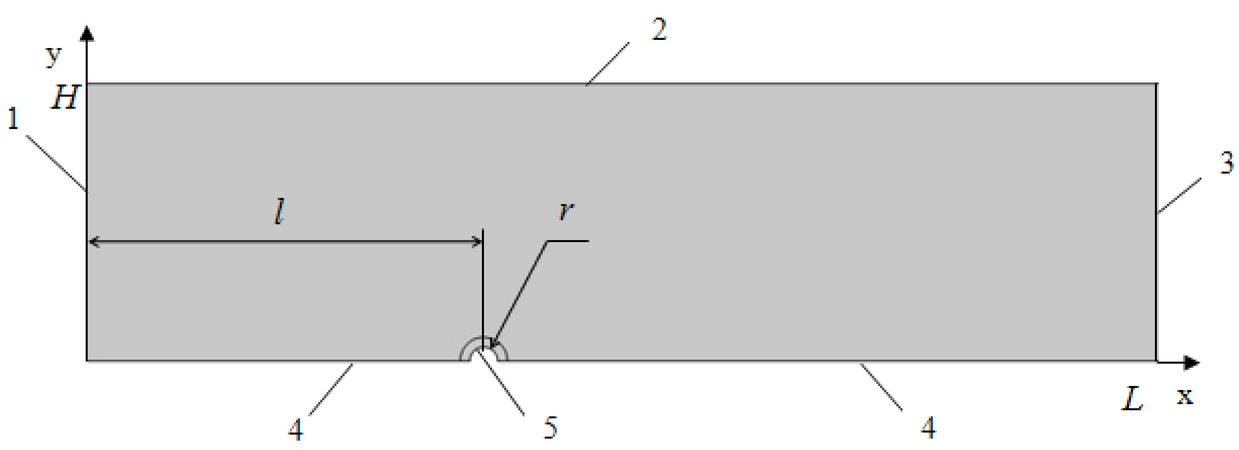

Figure 1. Calculation scheme. 1 - front boundary; 2 - lateral boundary; 3 - output boundary; 4 - axis of symmetry; 5 - keyhole.

Computational Methods: System of equations describing the processes of evaporation in EBW includes the momentum transport equation (Navier – Stokes)

$$(\vec{U}\cdot\nabla)\vec{U} = -\frac{\nabla P}{\rho} + \nu\Delta\vec{U},$$

the energy transport equation

$$\rho c_p \vec{U}\cdot\nabla T = \nabla\cdot\lambda\nabla^2 S_i,$$

the impurity transport equation

$$\vec{U}\cdot\nabla S_i = D_i\cdot\nabla^2 S,$$

Diffusion processes are described using the following equation:

$$D_i = D0_i \cdot exp(Q_i/(8.13\cdot T))$$

where $\bar{U}$ is a velocity field of the melt; P is a pressure in the melt; ρ is a melt density; ν is kinematic viscosity coefficient; c_p is a heat capacity at constant pressure; λ is heat conduction coefficient; S_i is the concentration of an i-component in the alloy.

Results: The temperature values of the vapor phase in the channel are defined by the intersection of the calculated and experimental concentration curves of the elements and are as follows: 2320 K (for Fe), 2340 K (for Cr) and 2410 K (for Mn). Thus, the average keyhole temperature for these elements is 2360 K. The arithmetic mean temperature of the keyhole for these elements is 2360 K. The vapor pressure in the keyhole at this temperature is about 2 kPa.

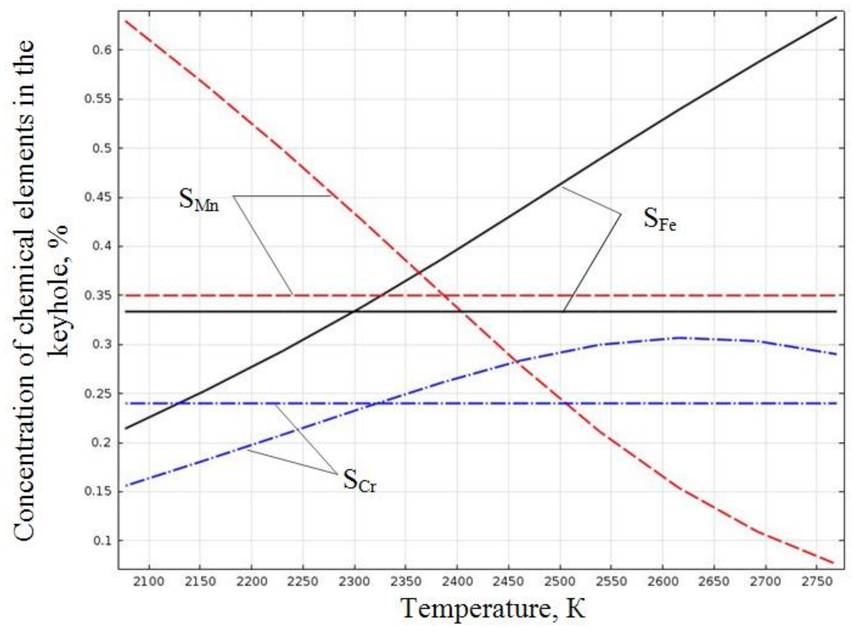

Figure 2. Dependence of concentrations of iron, manganese and chromium on the temperature of the keyhole surface for steel X12CrNiTi 18-10. Horizontal lines represent the experimental values of concentration; curves – calculated values.

Conclusions: Diffusion processes in welded material is largely influenced by the concentration of elements in the surface layer of the keyhole and, as a consequence, in the vapor above the welding zone. Results of numerical simulations of nonequilibrium processes show that the obtained temperatures are smaller (~ 2360 K) as compared to the temperatures used in the simulation of equilibrium processes (~ 2650 K). This difference in temperatures causes a significant difference in vapor pressure values in the keyhole: 2 kPa, taking into account diffusion processes (~ 2360 K), compared to 11 kPa without diffusion (~ 2650 K).

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