Simulation of heat transfer and metal flow in wire-based electron beam additive manufacturing

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ABSTRACT

Wire-based electron-beam additive manufacturing (also known as electron beam freeform fabrication, EBF^3 [1]) meets the requirements for structure and quality of formed metal layer, since the whole process is realized in vacuum ($10^{-1}...10^{-5}$ Pa), and size and shape of heat source can be varied by the use of magnetic deflection coils. At the same time, it is too early to talk about the wide industrial use of this technology. At present, control of metal transfer mode, which is influenced by many factors, remains a practically unsolved problem, and is primarily associated with inconstancy of heat transfer conditions in "heat source – underlayer" system. To obtain information about speed distribution and pressure, as well as temperature distribution over the depth of weld pool, it is necessary to use methods of mathematical modelling.

Heat and mass transfer in the system "electron beam –wire – deposited layer" should be described in formulation that takes into account the flow of metal under the action of pressure field, gravity, and forces due to viscosity and surface tension. The procedure for solving heat equation for metal in the solid phase and the Navier-Stokes equations in the liquid phase, based on the use of the finite-difference method and the predictor-corrector procedure [2] is described. An algorithm for numerical approximation of free melt surface motion, using the concept of the volume of fluid (VOF [3,4]), is described as well. A numerical algorithm is proposed for calculating surface tension force. It is based on the selection of a spherical region with a centre at a point lying on the surface of the melt, which allows to take into account the curvature of the surface and minimize the width of liquid – vacuum border. The model described above was realized as a program in the Microsoft Visual Studio environment. As the first computational experiment, the problem of simulating the melting of a fixedly set wire under electron beam heating was chosen. After that, electron beam was set to move along a ring trajectory and wire was set to move continuously.

Series of computational experiments were carried out to calculate metal flow during deposition with the use of 316L steel wire (diameter of 1.2 mm). Experiments showed that in the beam power range 1-3 kW, metal's flow has a laminar structure. The results of experiments are compared with experimental data achieved in MPEI on upgraded electron beam welding machine. It shows that the simulation results can be used in the future to create a rapid "digital twin" model for wire-based additive processes forecasting.

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