Chemical composition of the weld formation at high concentrated energy source welding in vacuum

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Results of numerical modeling of formation of a final chemical composition at electron beam welding with oscillations and dynamic splitting of an electronic beam on three thermal sources are presented in this article. Verification of settlement data with experimental data is carried out. For a pilot study of the chemical composition of the welded seams X-ray fluorescent analysis on the cross-sections is executed on various modes has been carried out. When processing experimental data the dependences of the concentration of the easily evaporated elements on the welding process parameters have been constructed.

Химическия състав при формиране на заваръчния шев при влияние на силно концентриран източник на енергия (Е. Саломатова, Д. Трушников, Т. Олшанская, В. Беленкий). *Тази статия представя резултатите от цифрова симулация на формирането на крайния химическия състав при електроннолъчево заваряване с колебания и динамично разделяне на електронния лъч на три топлинни източника. Направена е проверка на изчислените данни с експериментални данни. За начално изследване на химическия състав на на заваръчните шлифове е проведен рентгено-флуорисцентен анализ при различни параметри. При обработката на експерименталните данни е намерена зависимостта на концентрацията на леснолетливите елементи от параметрите концентрацията е на летливи елементи от параметрите на заваръчния процес.*

Introduction

The electron beam is almost inertia less heat source. The ability to fine-tune the power, and the focus of the beam position allows extensive use of the beam control system and programming welding modes, providing high-quality weld formation [1]. Using a beam control system can create new technological solutions, such as dynamic splitting of the electron beam, allowing the beam to act simultaneously processed in multiple zones or combining processes such as welding and heat treatment [2]. To date, we conducted a large number of works, considering the dynamic effects on the electron beam and the influence of the parameters of the effects on the weld geometry. At the same time, there are three main technological stages:

1) the oscillation of the electron beam;
2) scanning the electron beam focus;
3) splitting the electron beam.

The vibrational motion of the beam provide additional opportunity to influence the welding process, and hence to the formation of the weld. In this case an electron beam, having a constant power density, successively acts on a series of points in the immediate vicinity of the welding site [1]. Electron-beam bonding plays a special role among welding methods due to its high power concentration in electron welding beam and because of its capability to penetrate deep in the metal. These characteristics cause wide application of electron-beam welding in the production of critical parts from different alloys.

At electron-beam welding vapour and gas channel is formed, where an intensive evaporation of the material occurs. This may lead to the depletion with some elements in the melt metal comparing with the base metal. One can observe such process for metal alloys containing low-melting impurities. In turn, the pressure of the vapour leaving the melting zone at evaporation deflects the surface of a molten pool and the deep and narrow penetration channel is formed, which liquid walls are hold by vapour pressure [1 - 3]. Therefore evaporation processes in electron-beam welding are interesting for the development of theoretical models of a weld joint formation process [4 - 5].

Evaporation processes are considered in the works

[6], but the diffusion of impurities in the melt bulk is the base limiting process for the determination of the alloying components loss at electron-beam welding. The diffusion processes will occur in a thin layer near the penetration channel. The problem becomes nonlinear in the case of the strong (exponential) correlation between the diffusion coefficient and the temperature of the melt.

The purpose of the work is the construction of a theoretical model describing the chemical composition of a weld joint being in a liquid state at electron-beam welding. Such processes like the evaporation of the chemical elements from penetration channel walls, condensation of elements of the alloy on the penetration channel walls and the diffusion of the elements in the melt will have a great influence on the chemical composition of a weld joint

Formulation of the problems

A number of simplifications are introduced to construct the model.

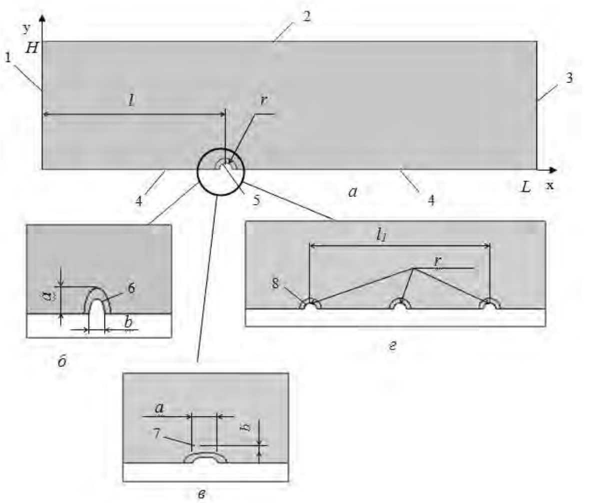


Fig.1. Calculated geometry of the problem: a - static beam; б, в - longitudinal and transverse oscillation of the electron beam; г - a dynamic splitting of the electron beam on the three thermal power.

1. The shape of a penetration channel is approximated to a cylinder and ellipse. The surface of the keyhole is considered to be isothermic at a given temperature being equal the temperature of the environment.
2. Heat and mass transfer along the penetration channel axis are neglected. Thus the problem comes to tow-dimensional formulation.
3. The diffusion coefficient is used in the dependence of the melt temperature.
4. Whole medium is considered to be liquid because the depletion with alloying elements in the melt occurs in a thin layer near the penetration channel surface.
5. The pressure in the penetration channel is different from the pressure under the penetration channel by several orders of magnitude, and metal vapour reaches sonic speed c in the outlet of the channel.

Calculated geometry of the problem is represented in the Figure 1.

Simulation evaporation processes in electron beam welding

I. Diffusion heat and mass transfer elements in the melt:

$$(1)\quad \vec{U}\cdot\nabla C_i = D_i\cdot\nabla^2 C,\quad \nabla^2 = \frac{\partial^2}{\partial x^2}+\frac{\partial^2}{\partial y^2}$$

where $\bar{U}$ is a liquid velocity vector in the point (x, y); C_i is the concentration of an *i*-component in the alloy; D_i is the diffusion coefficient of an *i*-element of the alloy, being determined in terms of the equation $D_i=D_{0i}\cdot exp(Q_i/(8.13\cdot T))$ where D_{0i} is the diffusion factor of an *i*-element of the alloy; Q_i is the activation energy of an *i*-component in the alloy.

$$(2)\qquad D(T)=\begin{cases}1 & T>T_L\\ \frac{T-T_S}{T_L-T_S} & T_S\le T\ge T_L\\ 0 & T<T_S\end{cases}$$

II. Hydrodynamic movement of a melt is described by Navier-Stokes equation:

$$(3)\qquad \left(\vec{U}\cdot\nabla\right)\vec{U} = -\frac{\nabla P}{\rho}+\nu\Delta\vec{U}$$

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;

III. The solution of the problem of element condensation is carried out with the use of flow density of the alloying elements on the penetration channel wall, which is determined by sum of flow densities caused by evaporation (Jev_i) and condensation (Jc_i):

$$(4)\qquad J_i = Jev_i+Jc_i$$

Flow density of condensation Jev_i is directly proportional to impurity concentration and flow density of evaporation under an i-element $J0_i$:

$$(5)\qquad Jev_i=J_{0i}\cdot C_i/C_{oi}$$

where J_{0i} is the diffusion flow density of an i-element evaporation; C_{0i}, C_i is the initial and current concentrations of an i-element in the alloy, respectively.

$$(6) \qquad J_i = \frac{dm}{dt} = \sqrt{\gamma P_0 \rho_0} \left(\frac{2}{\gamma + 1} \right)^{\frac{1+\gamma}{2(\gamma-1)}} \cdot S_{\min}$$

γ is the adiabatic index; S_{min} is the minimum area a keyhole.

IV. The solution of a heat problem comes to nonstationary energy transfer equation:

$$(7) \qquad \rho C_p \vec{U} \cdot \nabla T = \nabla \cdot \lambda \nabla^2 C_i$$

where ρ is a melt density; $\bar{U}$ is a liquid velocity; C_p is a heat capacity at constant pressure; λ is heat conduction coefficient; C_i is the concentration of an *i*-component in the alloy.

Specify the following boundary conditions:

1. On the boundaries 1 and 3 (Fig. 1) the boundary conditions of the first type are $C_i = C_{0i}$ and $T = T_0$, where T_0 is the temperature of medium. q=const – $\lambda dT/dn = q$; $dq/dn = 0$. Also the condition of continuability (q = const) is kept on these boundaries: $d^2T/dn^2 = 0.2$. The boundary 2 is adiabatic: $dT/dn = 0$. 3. The solutions being symmetric on x-axis, mass and heat energy flows on the boundary 4 are defined like zero: $dT/dn = 0$ и dC_i/dn. 4. Constant temperature is defined on the penetration channel surface which corresponds with the boundary 5: $T = T_0$ where T_0 is the temperature on the penetration channel surface. And the constant mass flow density is expressed: $D_i dC_i/dn = J_i$.

Results simulation evaporation processes in welding

Thus, the observed deviation of the Mg concentration of the chemical composition of the base metal, which is about 4 - 7% with the oscillations of the electron beam. This depletion of Mg calculated for welded joints made with the longitudinal oscillations of the electron beam is less than 3.5% than the calculated depletion of Mg - for transversal oscillations. Mg content is calculated by using a static beam confirms that the electron-beam welding with the static beam evaporation of volatile components does not exceed 5%, in this case, depletion calculations for Mg was 3%.

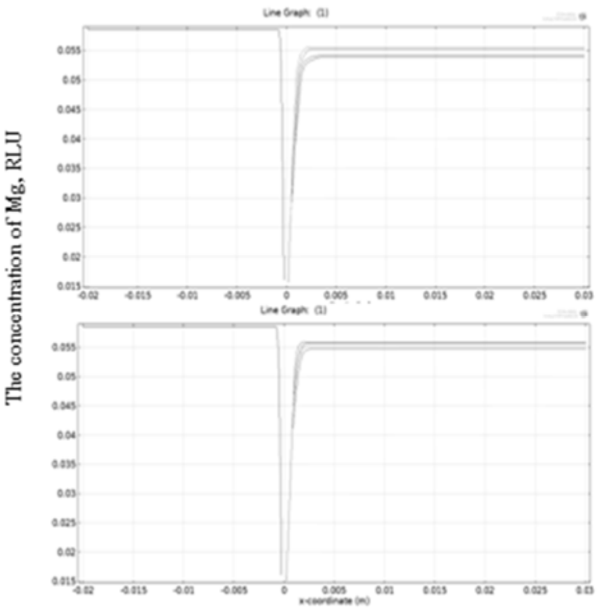


Fig.2. The results of numerical modeling of the magnesium content in the seam when oscillations of the electron beam

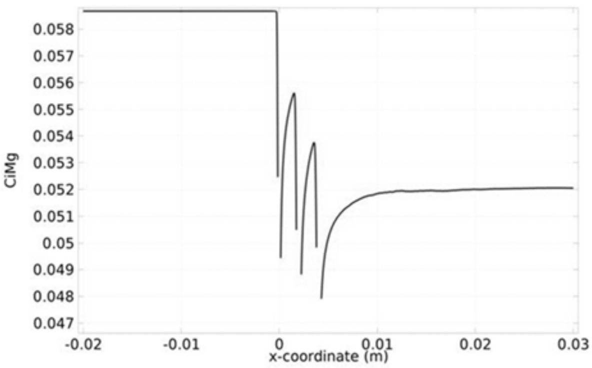
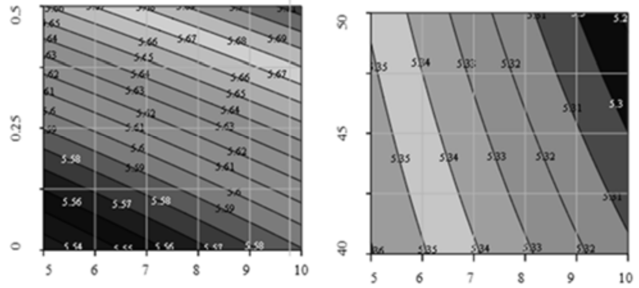


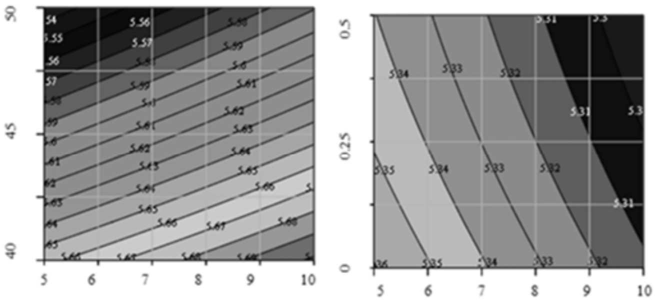
Fig.3. The results of numerical modeling of the magnesium content in the seam at splitting of the electron beam

The graph in Fig. 3 can be divided into four regions along the axis X. The first area of 0.02 m to 0 m - is the primary metal. The second region from 0 to 0.004 m, is responsible for the processes of vaporization. In a third region of 0.004 to 0.01 m, there is a liquid welding bath and the fourth area - crystallized weld. In the second area, where there are steam-gas channels, Mg concentration falls from 0.058 to 0.048 rel. u, which is associated with the intensive process of evaporation. Further, the liquid weld puddle Mg concentration increases due to the diffusion processes in the liquid and solid phase concentration of Mg equalized and become constant equal to 0.052 rel. u.



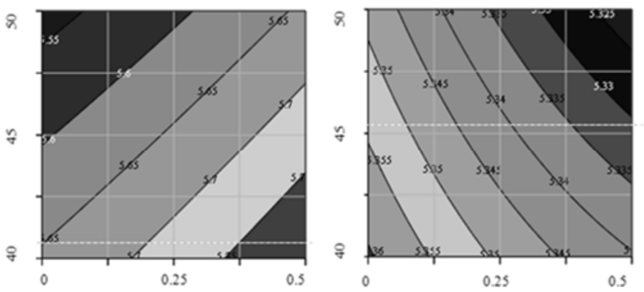
a *b*

Fig.4. Influence of parameters of welding conditions to change the concentration of magnesium in the joint: a - Y-axis - the amplitude of the oscillations along the X axis - welding speed; b - along Y axis - the beam current, on the x axis - the welding speed



a *b*

Fig.5. Influence of parameters of welding conditions to change the concentration of magnesium in the joint: a - the X axis welding speeed Y-axis - the amplitude of the oscillations along; b - Y-axis - the amplitude of the oscillations along the x axis - welding speed



a *b*

Fig.6. Influence of parameters of welding conditions to change the concentration of magnesium in the joint: a) Y axis – beam current, x axis – amplitude of beam oscillations b) X axis welding speed; Y-axis - the amplitude of the oscillations along

Just from the resulting calculations can be concluded about the influence of welding speed on the intensity of evaporation and the chemical composition of the welds. Welding speed has little effect on the final chemical composition of the weld seams (4%).

Experimental Result

It was built a matrix of planning and weld passes are made on different modes.

After statistical processing of the data, the dependencies, presented in figs. 4-6, are obtained.

Conclusions

1. A numerical model that accurately determines the high concentration of easily evaporated alloy components in the weld in electron beam welding.
2. Verification of the numerical model, the error calculation does not exceed 7% compared with the experimental data.
3. In the treatment of experimental data determined the effect of welding parameters mode to change the concentration of magnesium in the weld.

Acknowledgements

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