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MODELLING OF FUSION ZONE FORMATION IN SHIELDED METAL ARC WELDING

MODELIRANJE OBLIKA FUZIONIH ZONA KOD E-POSTUPKA ZAVARIVANJA OBLOŽENOM ELEKTRODOM

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Keywords
- shielded metal arc welding (SMAW)
- melting front
- fusion zone evolution
- mathematical model
- weld formation control

Ključne reči
- E postupak zavarivanja obloženom elektrodom
- zona stapanja
- evolucija fuzione zone
- matematički model
- kontrola formiranja zavara

Abstract

The reported paper explores the formation of a fusion zone in shielded metal arc welding with coated electrodes (SMAW). The study investigates the importance of an electrode grade, a power supply source type, and welding parameters for the fusion zone formation. The key parameters essential for the geometry control of a fusion zone, i.e. its depth and width are identified. A computational model for the fusion zone formation in SMAW is developed to trace the evolution of a fusion zone vs. time. The estimated data are verified by the experimental results.

Izvod

U radu se istražuje formiranje fuzione zone kod E postupka zavarivanja, obloženom elektrodom (SMAW). U istraživanju se daje značaj tipu elektrode, vrsti izvora struje, kao i parametrima zavarivanja, koji utiču na formiranje fuzione zone. Identifikovani su ključni parametri, koji su značajni u kontrolisanju geometrije fuzione zone, na primer, dubina i širina ove zone. Razvijen je računarski model formiranja fuzione zone kod E postupka zavarivanja obloženom elektrodom, kojim se prati razvoj fuzione zone u vremenu. Dobijeni podaci su verifikovani eksperimentalnim rezultatima.

INTRODUCTION

To date, the control of the electrode metal transfer in SMAW remains a not formalized problem for a majority of random factors and uncontrolled variables when forming a weld pool.

Several studies have been focused on the electrode metal transfer in mechanized welding and cladding with wire, /1-3/, and strip electrodes, /4, 5/, including control actions, /6-8/. Researchers /9-13/ have considered the methods to estimate dimensions and mass of electrode metal drops vs. dynamic characteristics of a power supply source, /9/, protective coatings on a surface to be welded /10/, and components of SMAW electrode coatings, /11-13/.

Nevertheless, there is little published data on the effect of these parameters on a fusion zone size, its growth and development, which play an important role for the strength of a welded joint, /14, 15/.

GOVERNING EQUATIONS

Statistically processed experimental data on the fusion zone size in submerged arc cladding /16/ and welding in shielding gases /17/ have laid the foundation for models of the fusion zone evolution till its crystallization in a form of a generalized nonlinear function:

$$\bar{V}_i(\bar{x}) = \left[\varepsilon_1 \bar{x}^2 + \varepsilon_2 \exp(\bar{x}) + \frac{\varepsilon_3}{\exp(\bar{x})} + \varepsilon_4 \bar{x} + \varepsilon_5 \right]^{-1}, \quad (1)$$

where: $\bar{V}_i(\bar{x})$ is relative velocity of an i interval; $\bar{x}$ is the relative coordinate of a melting point; ε_i are coefficients - functional connections with manufacturing parameters, where an electrode feed rate and its diameter represent principal independent variables.

In SMAW it is impossible to use the feed/melting rate of a rod as an input variable in the model, therefore, electric current I_w = 90-120 A; voltage U_w = *const* are accepted in calculation methods. In this case, coefficients in Eq.(1) are to be corrected if an electrode diameter and grade, a power supply source type, etc. are changed.

The time evolution of the melting front varies dramatically for the specific nature of a fusion zone to form in SMAW, hence, an additional study has explored the role of processing parameters, electrode metal transfer, and a power supply source for the fusion zone development in SMAW.

To assess whether and how dynamical characteristics of power supply sources affect the phenomenon of interest, an inverter-type converter ARC-250 for the high-frequency energy conversion and a VD-306E-type diode rectifier based on the traditional energy conversion were used. For the purpose of research, we selected MP-4 and UONII-13/45 electrodes 3 mm in diameter for an electric current value varying in a range 80-120 A. Samples of a base material were fabricated as low-carbon steel 12 mm thick plates (200×300 mm).

On completion of testing, a depth and a width of the fusion zone were recorded for different arc time values. Figure 1 represents a correlation between the fusion zone behaviour and an arc time.

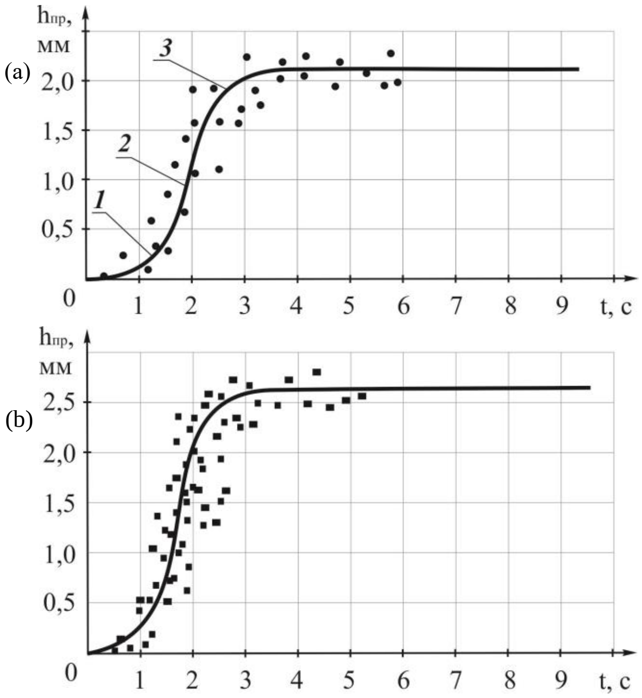

Figure 1. Fusion zone expansion for different electric current value: a) 90 ± 8 A, VD-306E; b) 120 ± 3 A, ARC-250.

It is apparent from the data (Fig. 1a) that a growth curve of the penetration depth is divided into three characteristic zones: the growth starts gradually (zone 1), for the base metal is heated and begins melting, the fusion zone expands proportionally (zone 2), and the growth becomes moderate and stops (zone 3).

Welding parameters make no difference for the curve behaviour, keeping constant the sequence of characteristic zones 1-3 (Fig. 1b). Furthermore, the study has revealed that an electrode grade has no significant effect on fusion zone parameters in the range of the considered given electrodes, while electrodes of the same diameter are used.

As seen (Fig. 1), the penetration depth for an inverter-type source covers a narrower range compared to a standard diode rectifier. Researchers /9/ have suggested the reason for this pattern: the electrode metal is transferred in smaller drops and by lower peak values of short-cut current, as a consequence, natural disturbances in a form of arc gap short-cuts are turned faster by the inverter, making, thereby, the welding process more stable.

ANALYTICAL SOLUTION

Macro-sections of welded metal are measured, and the data is processed mathematically with the help of a designed computational model for the fusion zone development (see Fig. 2).

In the computational model (Fig. 2), the melting front at the beginning represents a semi-circle with a radius, which is accepted similar to an electrode radius. The semi-circle is made by a number of points M_i (x_i, y_i) arranged at an interval $\Delta l \to 0$ on a circle. The time that the melting front moves is divided into N equal intervals t_k^{1-N}, where each M_i obtains increments dx_i and dy_i, calculated as $d\chi_i = v_\chi^i t_k^{1-N}$, where v_χ^i is the velocity of M_i in a time interval k for each coordinate.

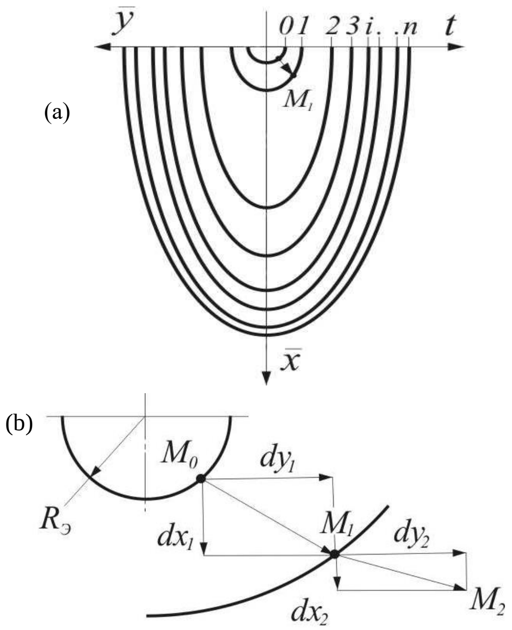

Figure 2. The computational model a); and the procedure b) to determine melting front coordinates.

An increase in the melting front velocity and its reduction to zero as the crystallization of a fusion zone starts are not simultaneous for points located at various intervals from the weld axis, hence, a melting line is not uniform. Since the formula, Eq.(1), connects an instant velocity increment with a relative coordinate, the summing up of increments $\bar{V}_i(\bar{x})$ for a time interval t' results in a depth of this point on the melting line. A corresponding time interval t' is found in a correlation between a time that a fixed source is active in a certain point, and its movement velocity for a quasi-stationary case, /18/.

A time increment t', immediately prior to the crystallization starting in a line point under consideration, represents a function of a welding velocity and other technological parameters, so the only option to find it is empirical. However, this function is general for broadly ranging input data, so coefficients of the equation are to be corrected for different data, /1/.

An interval for the fusion zone formation is divided into 10 sections. Within each section, all points of the melting front are accepted to move at a constant velocity. The results of calculations, as well as the contrasting experimental data are presented in Fig. 3.

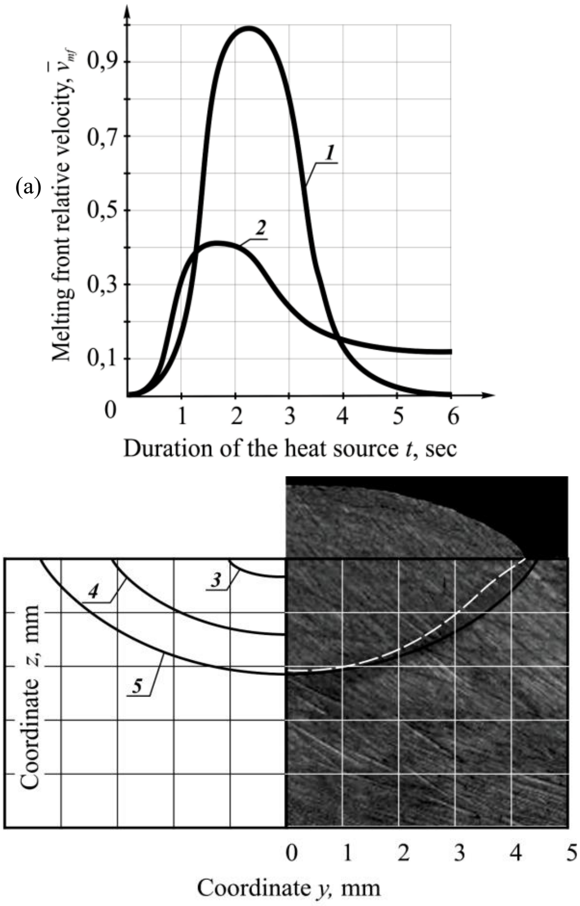

Figure 3. Behaviour of estimated values for the melting front growth a); and compared estimated and experimental melting isotherms b): 1, 2 - axial and radial curves of the relative growth velocity, in respect; 3, 4, 5 - melting isotherms of a base metal for time points 1 s, 2 s, and 5 s (MP-4; ∅ 3 mm; 120 ± 8 A; VD-306E).

From the data in Fig. 3, it is apparent a fusion zone develops to a depth within seconds after the arc starts burning. Furthermore, once the surface of the base metal is slightly heated and a melting front moves slowly, a fusion zone expands considerably in axial and radial direction. Then, an axial component of the velocity decreases intensively, and the radial one gets stabilized, ranging 20-30 % of its maximal value. The research has revealed a sufficient correlation between estimated and experimental data on the fusion zone in the range 5-10 % (Fig. 3b).

CONCLUSIONS

- The experiments have pointed out in SMAW an inverter-type power supply source provides a narrower range of penetration depth, if compared with a diode rectifier.
- The evolution of a penetration depth in SMAW is determined with the help of mathematical modelling, based on a developed computational model.
- Comparing the results of modelling and experimental data, the validity of the developed model for fusion zone formation and a possibility of its practical application are confirmed.

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