EVALUATION OF SHAPE AND SIZES OF WELD POOL IN SURFACING USING COMBINED STRIP ELECTRODE

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Results of the calculation evaluation of shape and sizes of weld pool in submerged arc surfacing using combined strip electrode are presented. The mathematical model was used based on solution of nonlinear differential equation of heat conductivity considering the dependence on temperature of thermophysical properties of base metal. The calculated dependencies describing the process of heat spreading in the base metal during surfacing using combined strip electrode were obtained from the conditions of additive action of three sources — one middle strip and two side strips. With increase in heat input at the edges not only shape and sizes of the pool are changed, but also the non-uniformity of penetration increases. It is shown that due to the change in rotation angle of the side strips relative to the middle strip of combined electrode it is possible to influence the shape formation of weld pool and penetration depth. Adequacy of the developed model is confirmed by a well coincidence of the calculated data with the experiment. 10 Ref., 9 Figures.

Keywords: *heat spreading, calculation of heating temperature, shape of weld pool, mathematical model, submerged arc surfacing, combined strip electrode, rotation angle of side strips, heat input at the pool edges, non-uniformity of penetration*

The process of wide-layer surfacing using strip electrode is characterized by a lower penetration of the product and decrease in the volume of participation of material of the product in the deposited layer [1]. The dispersed heat input on the melting front of the base metal [2], as well as increased heat dissipation on the edges of the weld pool, characteristic for this process, contribute to the formation of defects — lacks of penetration at the edges, undercuts, and slag inclusions (Figure 1). Their appearance is greatly influenced by an outflow of molten metal from the side borders of the weld pool with formation of axial flow directed to the tail part of the pool. This is confirmed by a large convexity of the middle part of back wall of the crater formed in surfacing using strip electrode (Figure 2).

To eliminate the edge defects it is necessary to redistribute the heat and mass transfer across the width of the pool, to change the direction of molten metal flows by improving the filling of the side areas of the pool with the molten metal. To achieve such changes the effect of magnetic field on the pool melt is used [3], as a result of which the flows are formed directed from the center to the edges of the pool and further along the edges to the tail part. At the same time, the shape of weld pool is changed, and on the back wall of the crater two convexities are formed. Similarly the shape of the pool is affected by using the strip electrode, profiled along the entire width, which allows improving the quality of bead formation, reducing the probability of edge defects arising [4]. Much wider possibilities of influencing the formation of weld pool and the conditions of wide bead formation belong to the process of surfacing using combined strip electrode, the use of which provides a strictly limited uniform penetration of the base metal and lack of defects in the fusion zone [5].

The design of combined strip electrode (Figure 3) is characterized by sizes of middle and side strips, feed speed of each strip, rotation angle α of side strips relatively to the middle one and

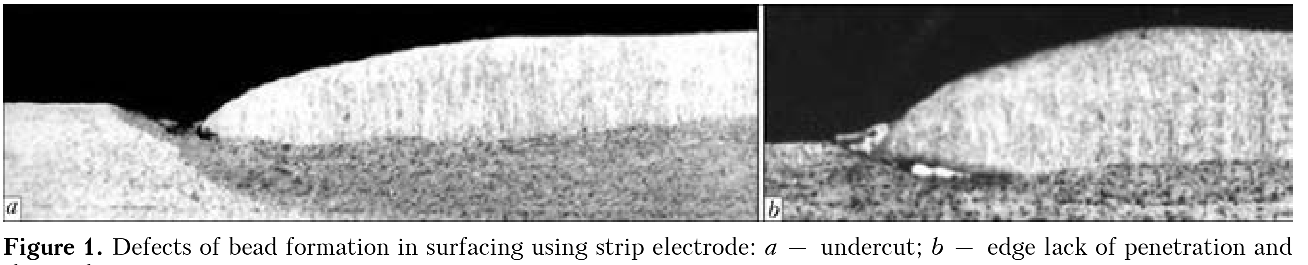

Figure 1. Defects of bead formation in surfacing using strip electrode: *a* — undercut; *b* — edge lack of penetration and slag inclusion

Figure 2. Shape of weld pool in surfacing using strip electrode of 50 × 0.5 mm

gap e between the strips. These characteristics of combined electrode affect melting conditions of the base metal, shape formation of weld pool and non-uniformity of penetration. The experimental study of these processes is quite difficult. At the same time, the numerical modeling of heat spreading process during fusion welding (surfacing) can not only reduce the labor intensity of the investigations, but also obtain new data for prediction of shape and sizes of the pool, composition, structure and properties of weld metal (deposited layer) [6, 7].

Therefore, in the present work for investigation of the shape and sizes of the weld pool in surfacing using the combined strip electrode the mathematical modeling method was applied combined with the experiments.

Mathematical modeling of heating and melting process of the base metal. Heat spreading in submerged arc surfacing using strip electrode is described by the equation of limiting condition of heating process of a semi-infinite body using the linear source of a finite width. The calculated values of sizes of penetration zone obtained during solving the linear differential equation of heat conductivity for a heat-conductive solid body with the thermophysical properties independent of temperature significantly differ from the experiment [2, 8].

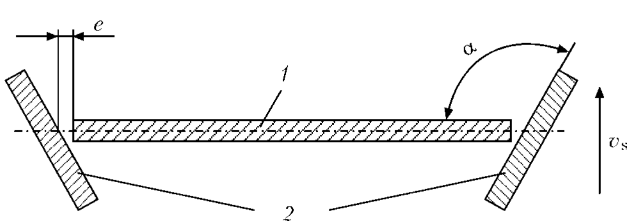

Figure 3. Design of combined strip electrode: *1* — middle strip; *2* — side strips

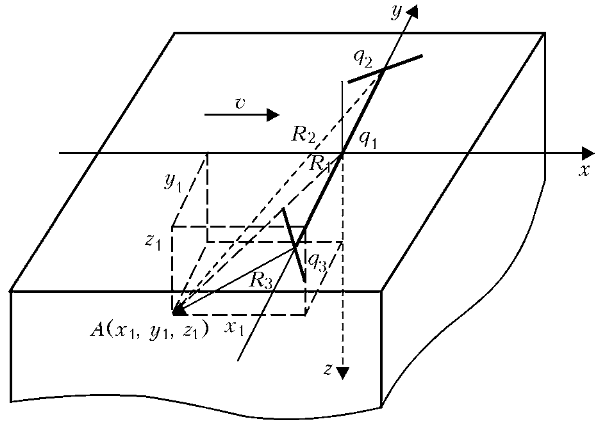

Figure 4. Calculation scheme of heating the body using three strips of combined electrode

The accuracy of calculations is significantly increased, if the thermophysical metal properties dependence on temperature is taken into account, which requires solution of nonlinear three-dimensional differential equation of heat conductivity. The numerical solution of the equation using the finite element method is used as the basis of the developed mathematical model [9]. Moreover, it was taken into account that before surfacing the temperature of all the points of the body is the same and equal to ambient temperature, during surfacing the power of heating source is completely consumed for heating the body and the heat flux at its edges is equal to zero. The use of software MSC.Patran-Nastran during modeling allowed obtaining not only the current temperature values but also the quantitative characteristics of thermal field in the area of heating and melting of the base metal.

The heating of the base metal using linear heat source [2] in the process of surfacing with combined strip electrode is determined by the combined action of three sources — middle q_1 and two side ones q_2 and q_3 (Figure 4). The heating temperature of metal from the effect of each of the strips of the combined electrode is calculated according to the dependence for the heat source of constant power moving along the surface of a semi-infinite body:

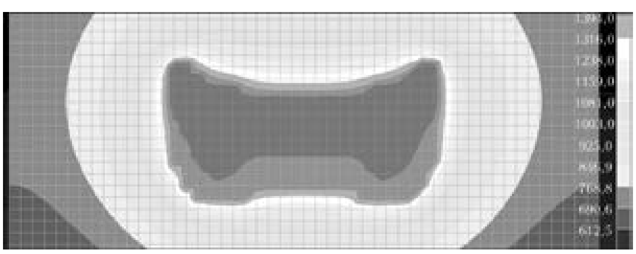

Figure 5. Model of thermal field of the body deposited surface for inclination angle of side strips α = 120°

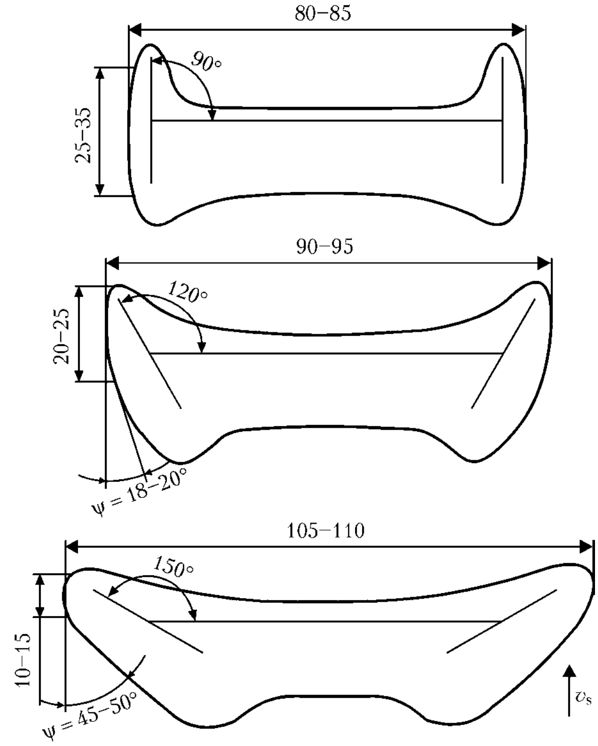

Figure 6. Modeling of shape and sizes of weld pool (boundaries of T_{melt} isotherm)

$$T_i(x, y, z) - T_0 = \frac{q}{2\pi B(b)} \int_0^{y_i} \left(\frac{1}{R_i}\right)^{\frac{v}{2a}(x_i - R_i)},$$

where $R_i = \sqrt{x_i^2 + y_i^2 + z_i^2}$.

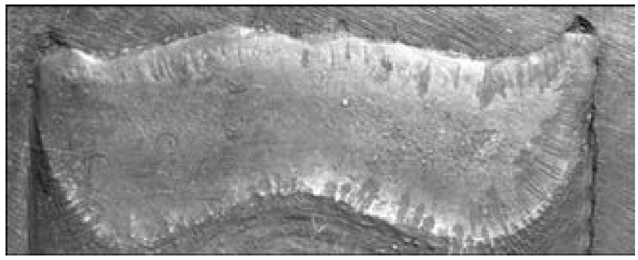

Figure 7. Shape of weld pool in surfacing using combined strip electrode at α = 120°

The calculations during modeling and experiments were carried out for the process of surfacing on the plates of steel St3 of 40 mm thickness using combined electrode of strips Sv-07Kh25N13 (middle strip was 75 × 0.5 mm, side strips were 25 × 0.7 mm), rotation angle of the side strips to the middle one α = 90–150°, gap between the strips $e = 0^{+5}$ mm. The parameters of surfacing under flux OF-10 were as follows: I_s = 1300–1350 A; U_s = 30–32 V; v_s = 14 m/h.

Modeling of thermal field of product to be deposited. To evaluate the shape and sizes of weld pool the models of thermal field and position of isotherm T_{melt} in the plane parallel to the surface being deposited were investigated (Figures 5 and 6). Moreover, it was taken into account that melting of the metal and formation of pool depends largely on rotation angle of the side strips relatively to the middle strip of the combined electrode. According to data of the preliminary experiments, the reduction in rotation

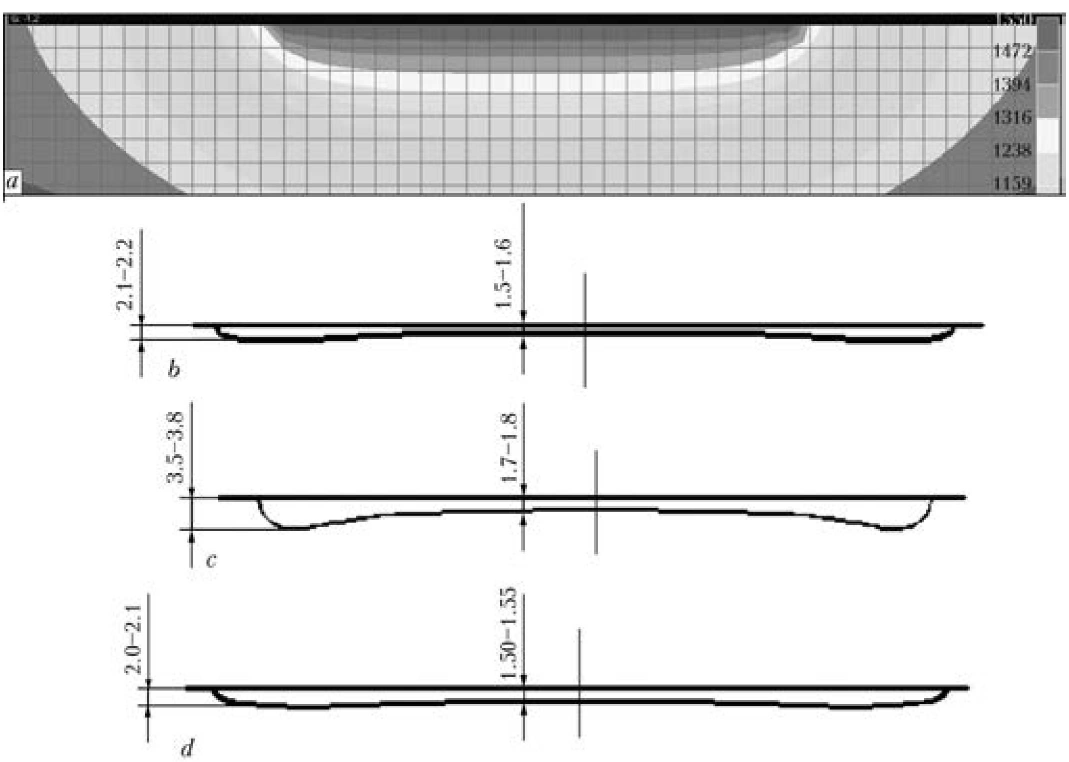

Figure 8. Model of thermal field (*a*) and boundary of isotherm T_{melt} (*b*–*d*) in the plane perpendicular to deposited surface at α = 120° (*a*, *b*), 90° (*c*) and 150° (*d*)

angle α < 90° results in deterioration of weld bead formation and increase in non-uniformity of penetration.

Therefore, in this study the results of computer modeling of thermal field for the values of rotation angle α > 90° were considered. With increase in angle α from 90 to 150° (see Figure 6) the degree of heat input dispersion and electrode metal transfer to the weld pool is changed. This influences the position of the edge of isotherm T_{melt}, obtained in modeling allowing evaluating not only the change of shape of the pool, but also the length of areas B_{melt} of melting isotherm oriented along the longitudinal axis of the pool. This influences the filling and the time of existence of the melt at the pool edge. In addition, the geometry of the combined electrode depends on angle ψ, characterizing the deviation of isotherm T_{melt} from the areas, oriented along the longitudinal axis of the pool, and determining decrease in the width of the pool tail part relatively to the width of the melting front (see Figure 6). The adequacy of the results of modeling the shape and sizes of the weld pool is confirmed by the experimental data (Figure 7).

The influence of geometry of the combined strip electrode on the shape and sizes of the weld pool considered on the model, providing improvement of bead formation, was combined with the need in providing reliable uniform penetration of the base metal. Basing on this, the choice in modeling the optimal values of the rotation angle of the side strips of combined electrode was performed considering the restrictions of penetration depth at the edges. The concentration maximum of heat and mass transfer at the edges of the pool occurs when rotation angle of the side strips is α = 90°, which is accompanied by increase in penetration depth in these zones (Figure 8, *c*).

As is seen from the edge position of isotherm T_{melt}, the main part of the penetration area comprises the areas, removed from the center of the pool. With increase in angle α up to 150° the heat flow dispersion results in significant increase in the width of the pool and the non-uniformity of penetration decreases (Figure 9, *d*). The optimum high quality combination of bead formation and uniformity of penetration are achieved when α = 120°, which is revealed in modeling of the thermal field and the edge of isotherm T_{melt}

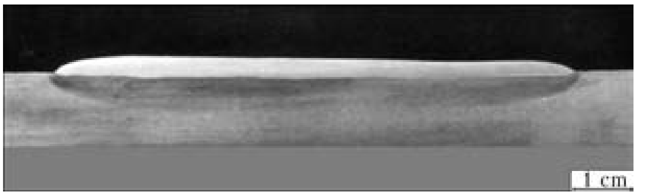

Figure 9. Macrosection of deposited bead cross-section at α = 120°

(Figure 8, *a*, *b*), and is also confirmed by macrostructure of the cross section of the weld bead (Figure 9).

In conclusion it can be noted that the accuracy of the calculated values of the temperature of heating the base metal and the position of boundary of the melting isotherm determining shape and sizes of weld pool in surfacing using combined strip electrode [10] is significantly increased in case of using thermophysical characteristics of metal, dependent on temperature, in calculations. This is confirmed by relevance of data, obtained during mathematical modeling, and the results of experiment.

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