257. The research of characteristics of electric arc on weld pool formation

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Abstract. Stability and controllability of a welding arc have a large influence on both the weld quality and welding productivity in the process of welding. Metal fusing and weld forming depend on the forces affecting the arc. Welding current creates electromagnetic forces, which basically define the influence of arc forces on molten metal. While estimating the magnitude of the influence of electromagnetic forces, it is necessary to investigate the radial distribution of arc pressure on the surface of a weld pool and take into account the dependence of distribution of electromagnetic forces on the non-consumable electrode tip geometry.

Keywords: TIG, welding arc pressure, influence of electromagnetic (Lorenz) forces, liquid metal convection.

1. Introduction

One of the basic problems of perfection of performance of arc welding is the increase of speed of the mechanized welding. As it is known, more often speed of welding is limited to occurrence of the deviation of the weld geometry and welding defects. The hydrodynamic processes in welding pool influence the pool geometry and after solidification the shape of weld. The study of the hydrodynamical phenomena and ways to control the weld formation by pool control is the way to create new technological receptions and increase the rate of welding. The last studies in the field of arc welding in protective gas are directed on study of the nature, size and character of distribution of the forces acting in the arc gap. The physical processes running in a welding pool could determine a weld forming. The influencing on a welding pool will allow to improve a weld forming at high speeds of welding. The magnitude and nature of forces, which are governing liquid metal of a welding pool, is one of the basic factors in a problem of a liquid metal convection control.

During a TIG welding process it is the welding area and arc plasma that contain the information on the characteristics defining the quality of the welded joint of the running process: mode and intensity of liquid metal convection, degree of arc compression as well as forming of the weld. In case of fusion welding the arc has both the thermal and mechanical effects on the welded metal [1]. The mechanical effect of the arc asserts through the mechanical pressure of gas stream, vapours of metals and action of ionised particles directed to the surface of metal in treatment. Volumetric electromagnetic forces occur and operate both in the arc column and in the welding pool, creating a mechanical compression in arc column and causing the liquid metal convection [2-8]. Therefore, the complete effect of arc forces consists from arc gas stream pressure and action of volumetric electromagnetic forces in the welding arc and pool.

2. The technique of the research

In the research of welding arc power action the manometric way of arc pressure measuring was used. In all experiments welding was carried out by using a fixed magnitude direct current of the straight polarity: welding current I = 150 A, diameter of electrode $\phi = 5$ mm, the length of an arc column - 2.4 mm. The shape of the tungsten electrode tip: sphere, cone 30°, cone 60° and cone 90°.

Operational analysis of a metering device (analyzer of pressure) [9] displays, that manometric system of the device has a surge characteristic $h(t)$:

$$h(t) = (1 - e^{-\frac{t}{\gamma}}) \tag{1}$$

where γ - stationary value of time of the system; t - time.

At known magnitude for γ the equation (1) allows to define the most admissible velocity of the analysis, at which the contortions of manometric system are small. The folowing relation binds the velocity of the analysis with its time:

$$v_a = \frac{D}{t_a} \tag{2}$$

where v_a - velocity of analysis; D - diameter of a rotationally symmetric spot of pressure; t_a - time of the analysis.

The analysis of a pulse propagation of different duration through a system with the surge characteristic, held with the help of the Duhamel integral displays, that for achievement of small contortions of impulses the execution of requirement is necessary.

$$\chi = \frac{\gamma}{t_a} = \frac{\gamma}{d} \times V_a \le 0.01 \tag{3}$$

where χ - non dimensional velocity; t_a - time of the analysis; d - diameter of strobing holey spot; V_a - velocity of the analysis.

In this case at applying an ideal transmitter (pipe with infinitesimal cross-sectional area) the automatic metering instrument of the analyzer will play back real curve of radial allocation of a welding arc force. The intensity of the force has the dimension of pressure and is bound to it by the relation:

$$F_{\max} = P_{\max} \times S \tag{4}$$

where F_{max} - maximal force of welding arc; S - area of strobing spot; P_{max} - maximal pressure.

However to implement such a transmitter is practically impossible. The sizes of the transmitter reduce the average of force intensity, therefore the experimental distribution curve differs from the curve of real allocation:

$$P_r = P_e \times \frac{\alpha^2 r^2}{2[1 - e^{-\alpha r}(\alpha r + 1)]} \tag{5}$$

where P_r - real pressure; P_e - experimental pressure; α - parameter of law, α=(0.9-1.2)mm-1; r - radius of strobing holey spot.

For mathematical modelling of processes, which are taking place in the welding arc and the pool, the finite element method (FEM) was used. For FEM simulation 2-temperature model of a welding arc was used.

The analysis of the distribution of electrical and magnetic fields, and also of arising electromagnetic forces was made with estimation of the thermal effect of a power source on welded metal, geometrical shape of tungsten electrode tip (cylindrical, spherical and conic), arc shape (electrode not immersed, immersed electrode) and the temperature-dependent physical characteristics of the welded metal and argon plasma.

Considering static and dynamic fields and neglected currents displacement (quasi-stationary limit), the following subset of Maxwell's equations could be applied:

$$\nabla x\{H\} = \{J\} \tag{6}$$

$$\nabla x\{E\} = -\frac{\partial\{B\}}{\partial t} \tag{7}$$

$$\nabla \cdot \{B\} = 0 \tag{8}$$

where $\{H\}$ - magnetic field intensity vector;
$\{J\}$ - total current density vector;
$\{E\}$ - electric field intensity vector;
$\{B\}$ - magnetic flux density vector.

At flowing the liquid metal brake because of overcoming the hydrostatic pressure of liquid metal of tail front of a pool, and resistance forces - because of viscosity of the flow. The change of speed of liquid metal movement from a forefront of a pool towards tail depends on welding rate, form of a fusion line and direction of a current connection plug location. Magnetic forces (Lorenz forces) in current carrying conductors are numerically integrated:

$$\{F^{jb}\} = \int_{vol} \{N\}^T (\{J\} x \{B\}) d(vol) \tag{9}$$

where $\{N\}$ - vector of shape functions.

The hydraulic flow of liquid metal is modelled by model of Newtonian fluid. From the law of conservation of mass comes the continuity equation:

$$\frac{\partial \rho}{\partial t} + \frac{\partial (pV_x)}{\partial x} + \frac{\partial (pV_y)}{\partial y} + \frac{\partial (pV_z)}{\partial z} = 0 \tag{10}$$

where V_x, V_y and V_z - components of the velocity vector in the x, y and z directions, respectively;
ρ - density;
x, y, z - global Cartesian coordinates;
t – time.

3. Discussions and analysis of results

The experimental method allows to define local values of the total magnetic and brake pressures on a surface of the chilled copper anode, and also the magnitude of force of pressure by graphic integration of pressure distribution on radius. This method does not allow to determine the magnitude of electrodynamic forces acting on a welding pool. In the literature the stationary values of time of measuring systems, velocity of the analysis and diameter of the strobing canal frequently are not pointed out. Many researchers notice a strong dependence of magnitude of measured pressure from the velocity movings of the arc above strobing canal. The sizes of the channel hole of the analyzer are reduced to an average of instantaneous amplitudes of pressure of plasma stream that cause aperture contortions of distribution curve of the pressure. It does not allow to judge about actual pressure distribution on the anode plane Fig. 1.

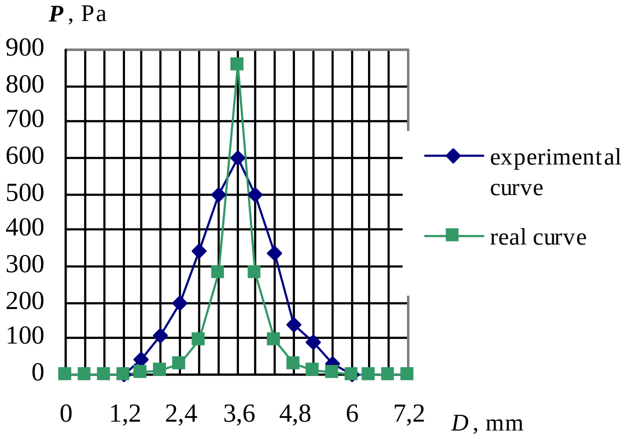

Fig. 1. Experimental and real (an experimental curve with the account of the inertia of the analyser) distribution of impact pressure of an arc on a surface of the anode: shape of the tungsten electrode tip - cone 60°, direct current, straight polarity, 2mm of arc length, 200A

The experimental curve is unbalanced frequently. This is explained that in the moment, when the arc pressure on an input of the analyzer will exceed a maximum and will begin to diminish, in the gating channel there is a counter current. It pushes the arc aside from the hole and sometimes even changes electrical condition of welding process. Therefore uprising part of the curve reflects process of change more correctly.

The maximal real pressure of an arc was established when the tip of the tungsten electrode was cone 30°, and the minimal when the tip of the tungsten electrode was cone 90°.

Using FEM the distribution of current density in the welding arc and pool was calculated depending on the shape of the tungsten electrode tip.

In case of the conic shape of the tungsten electrode tip, in the arc there will be a maximal absolute magnitude of the vector of current density, and in case of the spherical shape of the tungsten electrode tip - the maximal magnitude of only a vertical component of the current density (Fig. 3).

Even the small changes of physical and chemical state of the surface of tungsten electrode and shape of its tip determine the change of important parameters of the welding arc: the shape of the plasma column, distribution of equipotential fields of arc voltage, magnitude of current density on the surface of the welding pool. In peripheral area of the arc the distribution of current density is not completely symmetrical in relation to the axis of the arc, but near to the arc column and in the column itself it can be considered as approximately symmetric.

Comparing the experimental and calculated distribution curves of current density it was established, that in arc zone with 10000 °K temperature the curves do not coincide, though the greatest magnitude of the current density in both cases is practically identical. In the arc zone of the low temperature (5000 °K) the experimental and calculated curves coincide (Fig. 2).

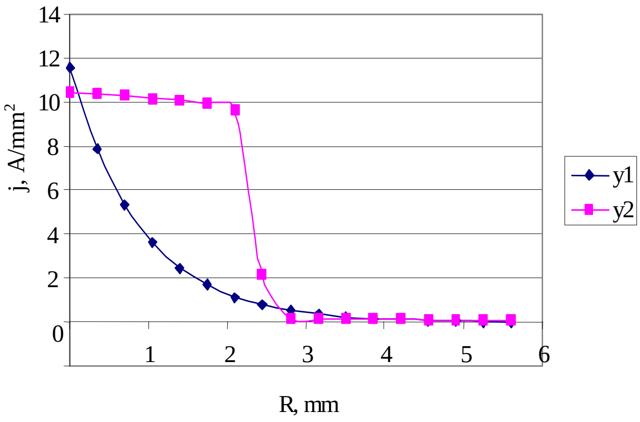

Fig. 2. Distribution of arc current density on the surface of the metal obtained by different methods (the shape of the tungsten electrode tip - cone 60°): y1 - an experimental curve; y2 - a curve obtained by FEM

The possible error of the results occurs because the two-temperature mathematical model of a welding arc of was used. In a real welding arc the wide temperature distribution takes place.

The form of distribution of current and electrodynamic forces in different sections of a pool is built according to calculations (Fig.4, Fig.5). Therefore, it is possible to define the influence of electrodynamic forces to the mechanism of mass transfer in volume of welding pool for sectional welding conditions.

At welding the majority of current flows from forefront of pool towards the current connection clamp (Fig.4). In full length of weld the effect of the magnetic field of arc current varies.

At approach of an arc to a current connecting clamp the induction sharply grows because of local increase of a current density. For maintenance of stable welding process the current connecting clamp must be moved away from weld area.

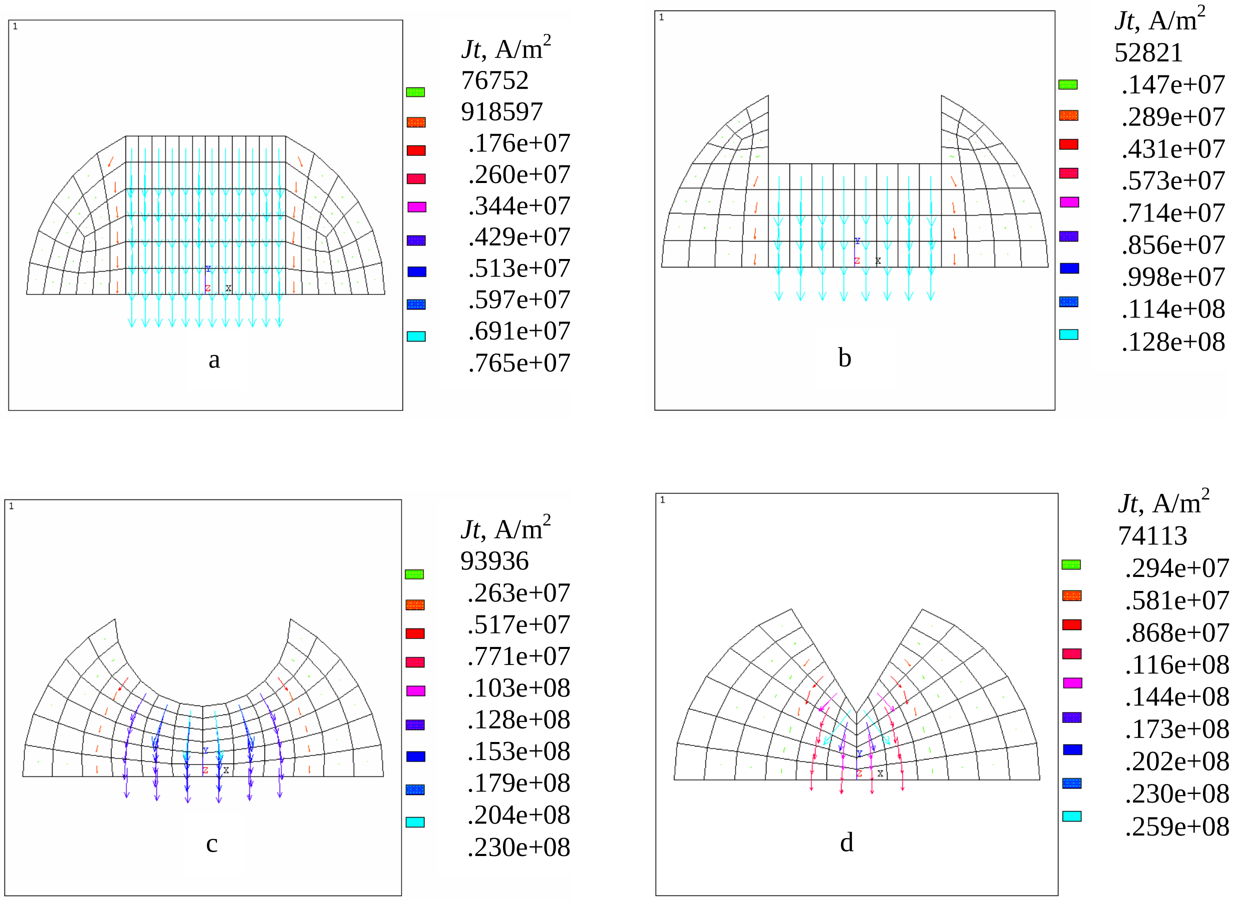

Fig. 3. Distribution of a current density in the welding arc depending on the shape of the tungsten electrode tip: a – cylindrical shape (ideal arc form); b – cylindrical shape (real arc form); c – sphere shape; d – cone shape; (I = 200 A, U = 12 V, ϕ = 5 mm, cross-sectional projection)

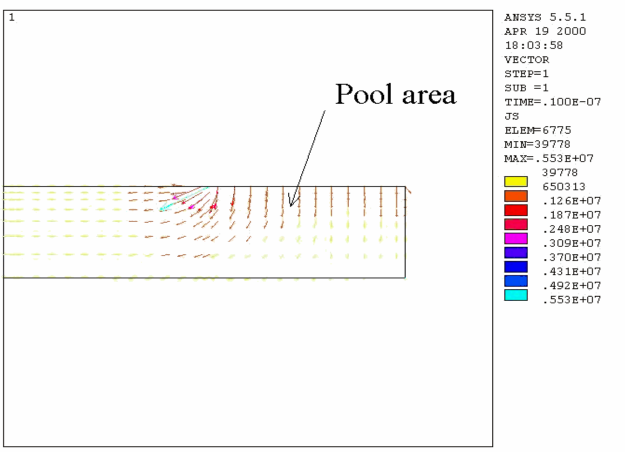

Fig. 4. Current density distribution in a welded plate (longitudinal projection)

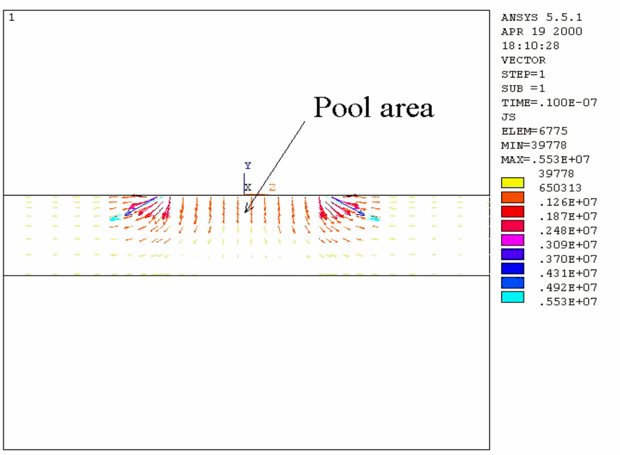

Fig. 5. Current density distribution in a welded plate (transverse section)

During electric arc welding the current of a welding circuit determines the appearance of volumetric electromagnetic forces (Fig. 6). These forces operate the movement of the welding arc and convection of liquid metal pool. The processes occurring in the welding pool and formation of weld depend on the total effect of magnetic fields and electromagnetic forces created by welding current. Under the influence of the electromagnetic force in the welding pool two circular streams of liquid metal (from the surface of the pool towards the fusion line) convection are formed (Fig. 7).

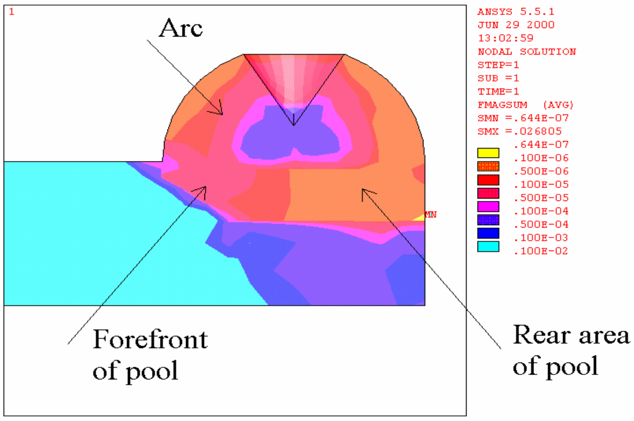

Fig. 6. Lorentz force density distribution in a welded plate (longitudinal projection, shape of the tungsten electrode tip – cone 60°)

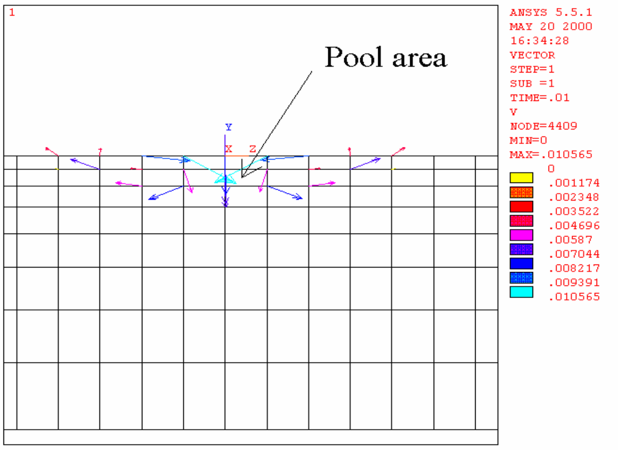

Fig. 7. Distribution of convection velocity within liquid metal under the influence of the electromagnetic force in a weld pool (the shape of the tungsten electrode tip - cone 60^0)

Conclusions

1. In case of the conic shape of the tungsten electrode tip, in the arc there will be a maximal absolute magnitude of the vector of current density, and in case of the spherical shape of the tungsten electrode tip - the maximal magnitude of only a vertical component of the current density.

2. Comparing the experimental and calculated current density distribution curves it was established, that though the greatest magnitude of the current density is practically identical, in the arc high temperature zone (10000 °K) the curves do not coincide, but in the low temperature zone (5000 °K) curves coincide very well.

3. The comparison of the experimental and calculated current density distribution shows, that two-temperature area welding arc mathematical model describes enough precisely the electromagnetic processes, which occur in the arc zone of low temperature zone (5000 °K), but in the arc high temperature zone (10000 °K) the inaccuracy of the results arises.

4. Under the influence of the electromagnetic force in the welding pool two circular streams of liquid metal (from the surface of the pool towards the fusion line) convection are formed.

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