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Calculation of Gas-dynamic Impact of the Active Shielding Gas on the Electrode Metal Drop in Gas Jet Shielded Welding

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Abstract. A combination of various factors and phenomena determines the quality of the welded joints. The basic role in setting the properties of the welded joints belongs to the processes taking place in the drop of the melted electrode metal. The paper considers the influence and vector components of the basic forces on the melted metal drop in gas jet shielded welding a moment before the drop transfers from the electrode to the weld pool. Methods of calculating the force exerted by a shielding gas jet on the drop of the electrode metal and subject to its dissociation are offered. The frequency and stability of drop transfer to the weld pool increase with the growth of the shielding gas impact force on the electrode metal drop in double jet gas shielding.

Introduction

Welding processes develop according to complex physical and chemical laws under high temperature. The complex of various factors and phenomena determines the quality of welded joints. This influence is particularly significant when welding of hardenable items. The structure and the phase state of a metal are developed in accordance with its chemical composition and conditions of the thermal impact, basically determined by conditions of welding [1–5]. The processes developing in the drop of the melted electrode metal and in the weld pool are of great importance for setting the properties of welded joints [1–3, 5].

The transfer of the electrode metal is governed by different factors and phenomena in the zone of welding. It is found [2, 4, 5], that in conventional single-jet gas shielded welding the electrode metal drop is effected by the following main forces: the pressure force of arc plasma jets F_p, the force of surface tension F_{st}, the reactive force of evaporating metal and gas emission F_r, the gravity force F_g, the electro-dynamic force F_{ed}. The components of these forces are subject to conditions of arc burning, i. d. to materials of the electrode, arc voltage, welding current, welding wire and drop moving velocities. These forces, in accordance with their directions, either block the transfer of the electrode metal or contribute to it.

Methodology

In certain conditions of jet gas shielded welding with consumable electrode the electrode metal drop is exposed both to the main forces and to the significant impact of the force of a shielding gas jet [2, 4–9]. The substantial impact of this force is registered in double-jet gas shielding in CO_2 [9–11]. The experimental conditions are as follows: mechanized downhand single-pass welding of plates of the steel 30HGSA with the welding wire Sv-08G2S 1.2 mm in diameter in single jet and double jet gas shielding in CO_2, the welding current I = 200 A, the electrode wire extension L = 12 mm, the shielding gas consumption Q = 20 l/min, the arc voltage U = 27 V, the welding velocity V = 25 cm/min.

Results and Discussion

We consider the influence and vector components of each force on the electrode metal drop when welding in conditions mentioned above a moment before the drop transfers from the electrode to the welding pool [2–4] (Fig. 1).

1) The pressure force of arc plasma jets $F_{p.}$.
It is caused by moving plasma jets which develop in the zone of discharged spots [2–4]:

$$F_p = M_p \cdot v_p\text{, H,} \tag{1}$$

where M_p – the mass of plasma jet, passing through the pre-set cross section in a period of time, kg/s; v_p – the velocity of plasma jet in the pre-set cross section, m/s; $v_p = 100$ m/s [3, P. 162].

This force depends on materials of the electrode and the gas medium of arc burning and is, thus, one of the main components of forces for all welding arcs.

It is known [2–4], that the plasma jets (the cathode and the anode ones) are directed anti-parallel to each other, the cathode jet envelopes the anode one. In welding in CO_2 with the wire Sv-08G2S the reversed polarity is applied, therefore, the cathode plasma jet is directed towards the electrode wire. Leaving from the anode jet the drop of the electrode metal gets to the counter jet (the cathode one) which blocks its transfer and, therefore, increases the scattering of the electrode metal. Thus wise, the reduced size of the drop or the widened anode jet further the transfer of the electrode metal. For the set experimental conditions $F_p = - 4.734*10^{-3}$ N.

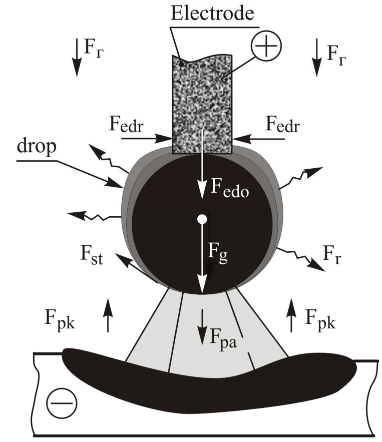


Fig. 1. Forces, effected the electrode metal drop:

F_{p_a} – the force of pressure of the anode plasma jet of the arc; $F_{p\,k}$ – the force of pressure of the cathode plasma jet of the arc; F_r – the reactive force of the evaporating metal and gas emission; F_{st} – the force of surface tension; $F_{ed\,r}$ – the radial component of the electro-dynamic force; $F_{ed\,a}$ – the axial component of the electro-dynamic force; F_g – the gravity force; F_Γ – the impact force of a shielding gas jet

2) The gravity force $F_{g.}$.

It depends on the drop mass (the volume and the density of the material) and the intensity of gravity [2]:

$$F_g = m \cdot g = \rho \cdot V \cdot g = \rho \cdot \frac{4}{3} \cdot \pi \cdot r_{\mathrm{d}}^3 \cdot g\text{, H,} \tag{2}$$

where m – the mass of the metal, kg; g – the intensity of gravity, m/s^2, g = 9.8 m/s^2; ρ – the density of the metal, kg/m^3, for the melted metal of a structural steel is 6800 kg/m^3; V – the volume of the drop, m^3; r_d – the radius of the drop, m.

The force of the gravity is associated with the intensity of gravity; its vector is down-directed. When welding in different space positions the force of gravity can either further or block the transfer of the drop from the electrode to the weld pool in accordance to the direction of the intensity vector. The drop size is determined either on the basis of high-speed shooting (Fig. 2) or on that of calculation with taking into account the velocity of wire feed and the transfer frequency. For the set experimental conditions $F_g = +0.94*10^{-3}$N.


a) b)

Fig. 2. Fragments of the high-speed shooting (the speed is 750 images/s, camera «Videosprint»): a) conventional single jet gas shielding; b) double jet gas shielding

3) The force of surface tension F_{st}.

This force is up to the material of the electrode, the composition of the gas medium in the arc gap, the coefficient of surface tension, the radius of the wilding wire, and under the short circuit – to the radius of the drop contact with the weld pool. The force of surface tension is directed according to the drop position relative to the weld pool. When arc is burning, the force of surface tension can be calculated by the following formula:

$$F_{st} = 2 \cdot \pi \cdot r \cdot \sigma \text{, H,} \tag{3}$$

where r – the radius of the electrode wire, *m*; σ – the coefficient of surface tension, the references provide various values of the coefficient of surface tension of steel σ = 1.10–2.5 N/m [2, 5], for calculations σ = 1.2 N/m is recommended [2].

This force usually blocks the transfer of drops. The coefficient of surface tension on the border of the drop and the electrode depends on the chemical composition of the alloying elements, the temperature of the drop, as well as on the surface condition of the drop, when oxidation the coefficient of surface tension decreases. For the set experimental conditions F_{st}. = - 4.522*10^{-3} N.

4) The reactive force of the evaporating metal and gas emission $F_{r.}$.

It develops when the metal starts evaporating from the discharged spots on the electrode and those on an article, from the drop surface; it is directed perpendicular from the evaporating surfaces and blocks the transfer of the drop and that of the electrode metal.

$$F_r = M\,v, \text{ H,} \tag{4}$$

where M – the mass of the metal evaporating per unit of time, kg/s, for the structural steel 7.1*10^{-5} kg/s [12, P. 78]; v – the initial velocity of the vapor jet, m/s, the velocity of vapors in the centre of the anode spot can rise up to 37 m/s [12, P. 77].

The reactive force is up to the temperature and the material of the anode and the cathode, i. d. is associated with welding current and doesn't depend upon the space position of a weld. For the set experimental conditions F_r = - 2.637*10^{-3} N.

5) The electro-dynamic force F_{ed}.

It develops when the current flows in the conductor (in the core of the welding arc, under the short-circuit – in the liquid medium). The electro-dynamic force has a significant impact on the transfer of the electrode metal, in particular, in different space positions of a weld. If the conductor has a constant cross-section, F_{ed} is directed along the radius towards the axis of the conductor and tends to press it together. The cross-section of the conductor varies in length in the zone of welding; therefore, the electro-dynamic force is composed of two components: the radial force and the axial one. The current interacts with its own magnetic field that causes the radial force to be directed along the radius towards the axis of the conductor and to tend to press it together. The axial component accelerates the plasma flow or that of the liquid metal and is directed from the tiniest cross-section to the biggest one. In general, the electro-dynamic force is expressed as follows:

$$F_{\text{ed}} = \frac{\mu \cdot \mu_0 \cdot I^2}{4 \cdot \pi} \cdot \ln \frac{R_2}{R_1} \text{ , H,} \tag{5}$$

where μ, μ_0 – the magnetic conductivity of the material, H/m; I – the current of the arc, A; R_2 – the biggest radius of the plasma flow (the radius of the arc core, the radius of the drop), m; R_1 – the smallest radius of the plasma flow (the radius of the discharged spot on the drop, the radius of the welding wire), m.

For liquid metals one can suggest that their magnetic conductivity is approximately equal to that of the vacuum $\mu_0 = 4\pi * 10^{-7}$ H/m, and the radius of the core depends upon the current and conditions of arching [12, P. 261]. The electro-dynamic force can be computed by the formula:

$$F_{\text{ed}} = 10^{-7} \cdot I^2 \cdot \ln \frac{R_2}{R_1} \text{ , H,} \tag{6}$$

The electro-dynamic force doesn't depend on the current direction. That is why, taking into account, that the radius of the drop of the electrode metal is bigger than that of the electrode wire (except welding with the jet transfer of the electrode metal), the axial component will promote the droplet detachment and the transfer of the drop to the weld pool. For the set experimental conditions $F_{ed} = +7.04 * 10^{-3}$ N.

6) The impact force of a shielding gas jet F_Γ [11].

The force is directed along the electrode to the article to be welded and promotes the positioning of the drop along the axis of the electrode (Fig. 3).

To demonstrate the impact of a shielding gas jet on the electrode metal drop it is assumed that the initial pressure of the gas on the drop is equal to the pressure of gas on the face of the welding nozzle but under the condition of gas dissociation (CO_2):

$$CO_2 \leftrightarrow CO + O \tag{7}$$

The dissociation of CO_2 develops in the high-temperature area of the zone of welding [13], i.e. when the melted electrode metal reaches the surface of the drop (3000 °C). The size of the high-temperature zone and the heat distribution in the zone of welding are subject to the welding current, the voltage, the consumption of CO_2 [5, 11, 13], the velocity and way of gas outflow from the welding nozzle [14].

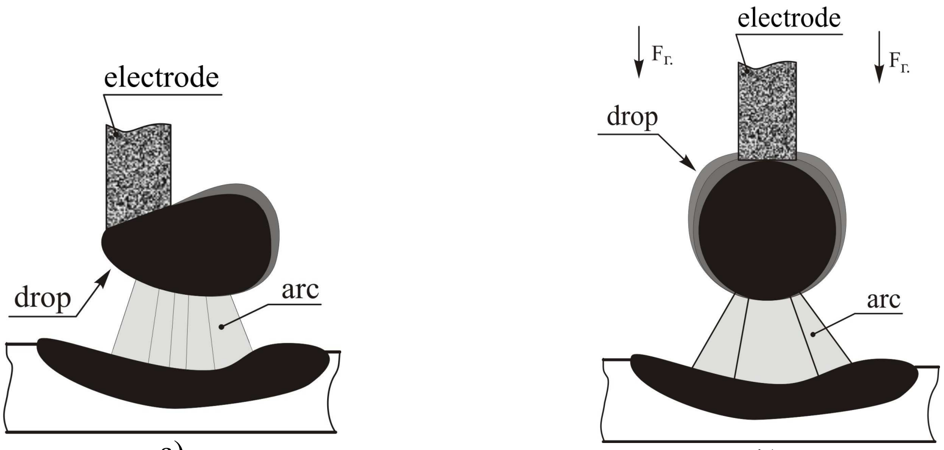
A sharp expansion of gas at the moment of dissociation can be considered as an explosion. In this case to calculate the pressure of the shielding gas subject to dissociation, a formula to compute the maximum pressure of explosion can be used [15]:

$$P = \frac{P_0 \cdot T_{\text{exp}}}{T_0} \cdot \frac{m}{n} \tag{8}$$

where P_0 – the initial pressure, Pa, calculated by the formula (9) [9]; T_0 – the initial temperature, K, $T_0 = 300$ K; T_{exp} – the temperature of explosion (dissociation), K, $T_{\text{exp}} = 3300$ K; m – the number of moles (kilo-moles) of combustion gases (dissociation) (CO + O), m =2; n – the number of moles (kilo-moles) of primary gases (CO_2), n =1.

$$P_0 = \frac{\rho V^2}{2} \tag{9}$$

where ρ – the gas density, kg/м^3; V – the velocity of flow, m/s, V=Q/S; Q – the consumption of the shielding gas, m^3/s, S – the cross-section zone of the nozzle, m^2.



a) b)

Fig. 3. The impact force of a shielding gas jet on the drop:
a) conventional single jet gas shielding; b) double jet gas shielding

The impact force of a shielding gas jet on the drop of the electrode metal is calculated by the formula (Tabl. 1):

$$F_{\Gamma} = Pc_xS_d = Pc_x 2\pi r_d\sqrt{r_d^2 - r_{\mathrm{w}}^2} \tag{10}$$

where P – the pressure of the shielding gas on the drop surface, Pa; r_{d} – the radius of the drop, m; r_{w} – the radius of the welding wire, m; c_{x} – the aerodynamic coefficient of the sphere strength, c_{x} = 0.48 [16].

Table 1. The impact force of the shielding gas (CO_2) jet on the drop of the electrode metal subject to the dissociation

Method	Cross-section zone S, mm^2	Gas density p, kg/m^3	Outflow velocity V, m/s	Gas pressure P_0, Pa	The maximum pressure of explosion (dissociation) P, Pa	The impact force of a shielding gas jet F_Γ, H*10^{-3}
Single jet	286	1.97	1.16	1.34	29.5	0.183
Double jet	82		4.07	16.3	354.7	2.205

The calculations and the results of theoretical research have shown that the methods suggested enable estimation of the impact force of a shielding gas jet on the drop of the melted electrode metal subject to dissociation. It has been determined, that for the selected (average) temperature of dissociation 3000 °C the impact force of a shielding gas jet on the drop of the electrode metal amounts to 0.183*10^{-3} H in single jet shielding and to 2.205*10^{-3} H – in double jet shielding. In this case, the impact force of a shielding gas jet on the drop of the electrode metal is 12 times higher in conditions of double jet gas shielding than in those of single jet shielding. The graph of the dependence of the impact of a shielding gas jet on the gas consumption is shown in Figure 4.

The impact force of a shielding gas jet on the electrode metal drop increases and gets comparable to the main forces with the growth of the shielding gas to be consumed in double jet gas shielding. Due to the co-axial position with the electrode and to the decrease in chaotic oscillation of the drop the frequency and stability of drop transfer to the weld pool increase with the growth of the shielding gas impact force on the drop of the electrode metal in double jet gas shielding. The analysis of fragments of high-speed shooting of the experiments (Fig. 2) [17] have demonstrated, that time of the drop existence when welding in CO_2 with the wire Sv-08G2S 1.2 mm in diameter (I = 200A, U = 27V, Q = 20 l/min, l = 12 mm) in single jet gas shielding varies in the range between 65 and $100*10^{-3}$ s, and in double jet shielding changes in the range between 35 and $60*10^{-3}$ s.

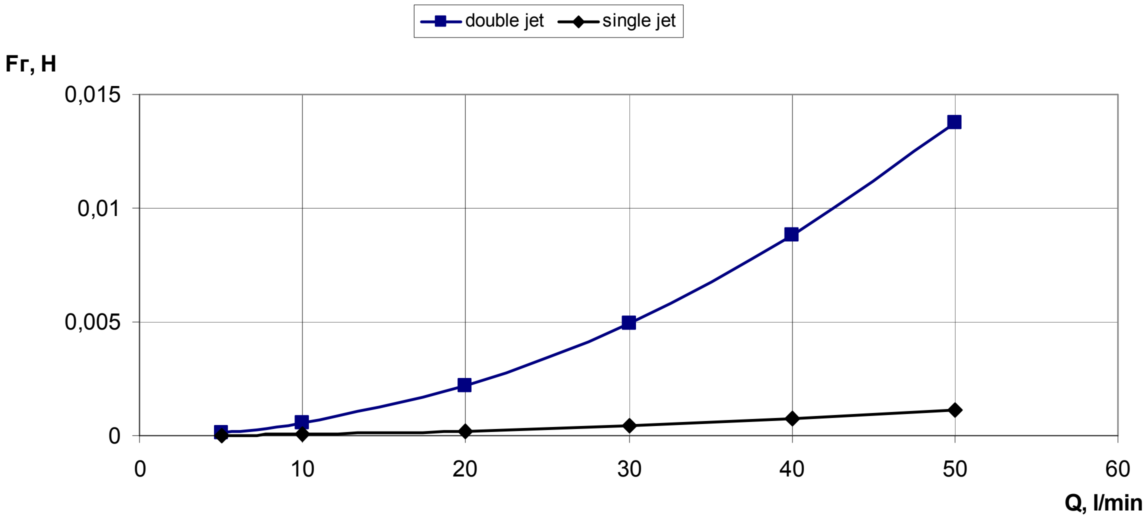


Fig. 4. The graph of the dependence of the impact force of a shielding gas jet on gas consumption

Conclusion

With the application of double jet gas shielding the impact force of a shielding gas jet on the drop of the electrode metal and on the surface of the weld pool increases. Varying the gas-dynamic impact (gas consumption), the transfer of drops of the electrode metal, the chemical composition of the weld metal, thermal and other processes of consumable electrode welding can be controlled, as well as the required properties of the welded joints can be set.

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