The impact of the shunting processes in a plasma arc on the melting performance of the filler wire

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Abstract. The methodology for experimental measurement of the shunting current has been developed in the article. Upon reaching a certain depth of immersion of the filler wire into plasma due to an increase in the potential difference between the end face of the wire and the surrounding plasma, the shunting current is significantly increasing reaching several dozen amperes. By changing the immersion depth of the wire by changing the value of the shunting current, it is possible to control the heat input into the base and filler metal, as well as to manage the transfer of the filler metal.

Investigations of shunting processes in a plasma arc were carried out using CO2 as a plasma-forming gas. In this case, the arc has a high potential gradient in the column, and therefore, the relationship between the depth of the axial immersion of the filler wire into the plasma and the shunting current magnitude is more evident.

When using CO2, the permissible axial depth of the filler wire in the plasma is significantly limited in comparison with the plasma arc in argon.

Reducing the depth of the axial immersion of the wire into the plasma under other constant conditions leads to a significant increase in the distance between the end face of the filler wire and the product Lпр and intensive burnout of alloying elements in the filler wire.

Based on the above, the welding method must simultaneously meet two conditions:

\[
\frac{U_k + U_a}{E} > \frac{U_k}{E} \quad (1)
\]

\[
L_{\text{пр.н}} = \text{min} \quad (2)
\]

where \(L_{\text{пр}}\) is the distance between the end face of the wire and the product.

However, the minimum distance between the wire and the product (and, consequently, the length of the plasma arc) is, as a rule, a technological parameter and does not depend on the type of plasma-forming gas and cannot be substantially changed. Therefore, it is not possible to use a plasma welding method with an axial feed of filler wire when using plasma gases as plasma-forming media in which the plasma has a large potential gradient and high enthalpy.

To study the simulation processes, the scheme shown in figure 1 [1] was proposed.
According to this scheme, two filler wires 4 and 5 were fed into the arc through guide tips 3 and 6 perpendicular to the axis of the column with a speed of $V_{n1} < V_{n2}$ so that the distance between the wire feed vectors was equal to a certain value of $L_{np}$. The filler wire feed speeds were selected depending on the plasma current so that both ends were on the axis of the arc column. To protect against interference, the measuring circuits were made of shielded twisted pairs. Thus, two filler wires electrically connected through a shunt simulated the case of filler wire supply during welding, when the plasma potential at the point of entry of the wire into the plasma and in the region of its end face has a certain difference, i.e. when the filler wire is immersed in the axial column of the plasma arc.

Figure 2 shows the dependence of the shunting current on the potential difference between the filler wires. The potential difference between the wires was measured with an open shunting circuit. For measurement, a C8-11 electronic storage oscilloscope was used. The data obtained confirm that with a small distance between the wires, when $\Delta U_{\text{э-э}} < U_{k}$, the value of the shunting current is insignificant and does not exceed 4 ... 6 A. In this case, when $\Delta U_{\text{э-э}}$ reaches $U_{k}$, a cathode spot is formed at the end face of the lower filler wires, and the shunt current is increased stepwise (figure 2).

With a further increase in the distance between the wires, when $\Delta U_{\text{э-э}} > U_{k}$, the shunting current rises sharply, reaching several dozens of amperes. Plasma arc shunting with filler wire leads to the fact that, the electrodynamic force in addition to the velocity pressure of the plasma flow also begins to influence the transfer of filler metal.

Figure 3 shows the dependence of the critical current of the plasma arc, at which the transition to droplet transfer occurs, on the depth of the axial immersion of the filler wire into the plasma.
Figure 3. The dependence of the critical current of the plasma arc on the depth of the axial immersion of the filler wire into the plasma: \( d_c = 10 \text{ mm} \); \( g_{pl.g} = 0.66 \text{ g/s} \); \( L_{c-h} = 30 \text{ mm} \) straight polarity, \( d_p = 1.6 \text{ mm} \) (Sv00G2S), the position of the melting point of the wire: vertically - 15 mm from the nozzle exit, horizontally - 5 mm from the axis nozzle.

The obtained dependence shows that when a certain depth of immersion of the filler wire into the plasma is reached, the critical current of the plasma arc is significantly decreasing. The direction and feed rate of the filler wire were chosen so that in all experiments the melting of the filler metal occurred at the same point relative to the plasmatron nozzle.

The results obtained made it possible to develop a plasma welding method [2], which uses the shunting effect for technological purposes (figure 4).

Figure 4. Schemes of the plasma welding process in CO\(_2\) during melting of the filler wire in the arc column (a) and at the exit from the column (b): 1 - electrode; 2 - forming nozzle; 3 - a protective nozzle; 4 - plasma forming and protective gases; 5 - filler wire; 6 - arc; 7 - product; 8 - seam.

The developed method simultaneously meets two conditions: 1 and 3. This goal is achieved by the fact that in the plasma welding method, in which the filler material is fed into the plasma arc of direct action and direct polarity between the forming nozzle and the product at an angle to the longitudinal axis of the arc column, and the angle between the longitudinal axis of the plasma arc column and the direction of the filler material is set in the range:
that when used as plasma-forming media-gases in which the plasma has a large potential gradient and high enthalpy, it provides the formation of a cathodic voltage drop region on the filler wire, allowing to achieve high melting performance, and also allows to maintain a minimum distance between the end face of the wire and the product.
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