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Theoretic Considerations on the Influence of Electrode Wire Additional Preheating upon MIG – MAG Welding

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The paper theoretically analyses the influence on the MIG-MAG welding process of additional preheating at the free end of the electrode wire by one or several heat sources, produced by independent current sources, and the modifications required by the welding equipment, consisting in the use of a system of electrode wire feed with the electrode wire advance speed depending on the arc voltage (SVD).

Keywords: *influence, preheating, free end, wire, MIG-MAG.*

1. Paper content

MIG-MAG welding is characterised by the existence of the free or open end of the electrode wire, at the exit from the welding gun, heated by the Joule-Lenz effect during welding.

The influence of additional preheating at the free end of the electrode wire by one or several heat sources produced by independent current sources on the welding process is highlighted by the analysis of melting process stability at the wire free end.

Figure 1 presents the diagram of the welding zone in the variant of heating the wire free end by two independent thermal sources produced by the additional current sources SC2 and SC3.

The condition of a stable melting is that the feed speed of the electrode wire (v_{ae}) be equal to the melting speed of its free end (V_t).

The momentary heat quantity developed in the melting process, also called useful or output power, expressed according to the electric parameters of the process, is [1]:

$$Q = R \cdot I_{top}^2 \tag{1}$$

where:

R – effective resistance of the molten metal;

I_{top} = I_s – intensity of the welding current [3].

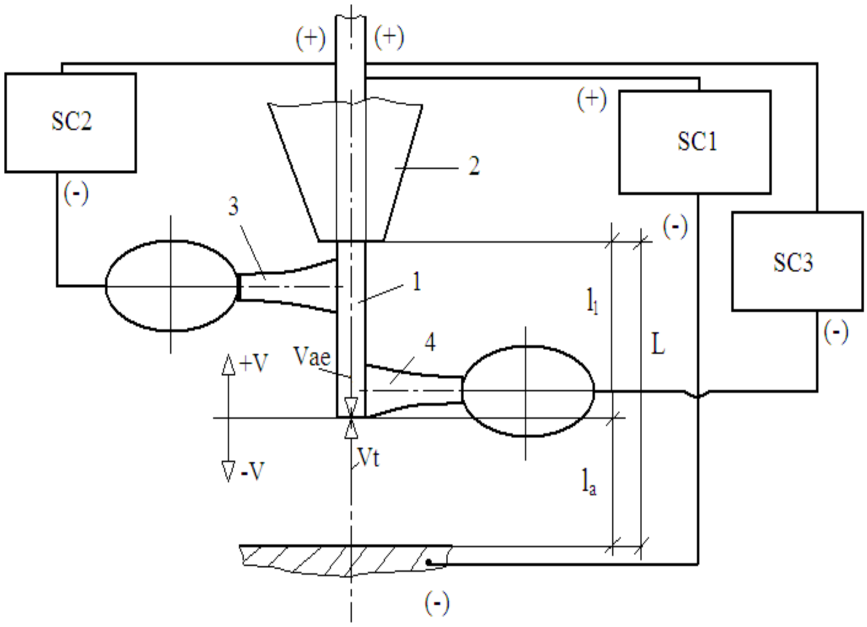

Figure 1. Diagram of the MIG-MAG welding zone in the case of using two pre-heating additional thermal sources at the electrode wire free end: 1 – electrode wire; 2 – welding gun head; 3 – additional thermal source 1; 4 – additional thermal source 2; l_l – length of the electrode wire free end; l_a – length of the MIG-MAG welding arc; v_t – melting speed of the electrode wire free end; v_{ae} – electrode wire feed speed; L – distance between gun head – part subjected to welding; SC1- MIG-MAG current source; SC2, SC3 – additional current sources.

This heat quantity is made of the heat necessary to melt the metal (Q_1) and the heat necessary for the heating of components (Q_2), which may be calculated also depending on the heat parameters of the melting process with the relation [1]:

$$Q = Q_1 + Q_2 = v_t \cdot \gamma \cdot A \cdot [c \cdot (T - T_1) + C] + 2 \cdot \lambda \cdot A \cdot dT/dx \qquad (2)$$

where:

γ - density of the electrode wire material;
A – area of the electrode wire cross section;
c – specific heat of the electrode wire material;
C – latent melting heat of the electrode wire material;
λ – diffusivity of the electrode wire material;
T – melting temperature of the electrode wire material;

T_1 – temperature of the free electrode wire (pre-heating temperature);
dT/dx – temperature gradient on the anode and cathode side of the arc.
By equaling the two relations, the melting speed results [1]:

$$v_t \approx \frac{R \cdot I^2 - 2 \cdot a_1 \cdot A \cdot \frac{dT}{dx}}{\gamma \cdot A \cdot [c \cdot (T - T_1) + C]} \qquad (3)$$

From relation 3 we remark that the melting speed increases along with the increase of temperature T_1, when the useful / output power grows and the temperature gradient drops.

The condition for the process stability is that the electrode wire feed speed be equal to the melting speed:

$$v_{ae} = v_t \qquad (4)$$

The melting of the electrode wire free end in the welding arc zone is possible only if the power of the welding machine is sufficient.

The quantity of heat necessary for melting a metal volume is given by the relation [1]:

$$Q = m \cdot (c \cdot \Delta T + C) \quad [J] \qquad (5)$$

where:
m – mass of the metal volume V ($m = \gamma \cdot V$);
γ – density of the components' material [kg/dm^3].
But:

$$V = A \cdot v_{ae} \cdot t \qquad (6)$$

where:
A – area of the electrode wire cross section [cm^2];
v_{ae} – electrode wire advance speed [cm/s];
t – melting time [s].
It results:

$$m = 10^{-3} \cdot \gamma \cdot A \cdot v_{ae} \cdot t \quad [kg] \qquad (7)$$

c – specific heat of the electrode wire metal [J/kg×grd];
C – latent melting heat of the electrode wire metal [J/kg].
Consequently:

$$Q = 10^{-3} \cdot \gamma \cdot A \cdot v_{ae} \cdot t \cdot (c \cdot \Delta T + C) \quad [J] \qquad (8)$$

The energetic equivalent of the heat necessary for melting is:

$$E = \frac{Q}{\eta} = \frac{\gamma \cdot A \cdot v_{ae} \cdot t \cdot \left[c \cdot (T_{top} - T_0) + C \right]}{3600 \cdot 10^6 \cdot \eta} \quad [KWh] \qquad (9)$$

The power necessary for melting during time t is:

$$P \geq \frac{E}{t} = \frac{\gamma \cdot A \cdot v_{ae} \cdot \left[c \cdot \left(T_{top} - T_0 \right) + C \right]}{10^6 \cdot \eta} \quad [KW] \tag{10}$$

But C may be ignored in relation with the term c·ΔT, and the dimensions γ , c and η are constant.

It follows:

$$P \geq K \cdot A \cdot v_{ae} \cdot \left(T_{top} - T_0 \right) \tag{11}$$

where:

$$K = \frac{\gamma \cdot c}{10^6 \cdot \eta} = \text{cst.} \tag{12}$$

Furthermore, power depends also on the electromotor voltage through the relation:

$$P = \frac{U_e^2}{R} \geq K \cdot A \cdot v_{ae} \cdot \left(T_{top} - T_0 \right) \tag{13}$$

But temperature T_0 of the free end of the steel electrode wire, in the case of the classic welding variant, does not exceed 100°C, whereas in the case of preheating welding it may reach even 1000°C, requiring a much lower melting temperature, and thus a much lower intensity of the welding current, and a much smaller penetration welding, making it possible to weld, without problems, the root layer with the MIG-MAG variant.

Moreover, for welding the ulterior layers, the welding current intensity may be increased within wide ranges (depending on the basic metal welded), growing the productiveness of the welding procedure (by increasing the rate of addition metal depositing).

The welding arc will be much more stable than in the classic case of MIG-MAG welding grace to the much smaller difference $T_{top} - T_0$.

However, maintaining the stability of the melting process makes it necessary to endow the welding equipment with a system of electrode wire feed with the advance sped of wire depending on the arc voltage (SVD), whose principle diagram is presented in figure 2 [2].

The electric arc 1, situated in the protecting gas atmosphere, supplied from source 3, burns between the part subjected to welding and the tip of electrode wire 4, contained in coiled wire 5.

The advance speed v_e of the electrode wire is obtained with the help of the roller mechanism 6, rotated at the speed n from the direct current motor 7, with the separate excitation 10 (stabilised at the voltage variations of the supply network), through the power amplifier 13.

The arc voltage u_a is compared in the regulator amplifier 12 to the reference voltage u_b, equal to the intended value for the welding voltage.

The output voltage u_e commands the power amplifier 13, supplied with the stabilised voltage u_B, obtained from the supply block 10.

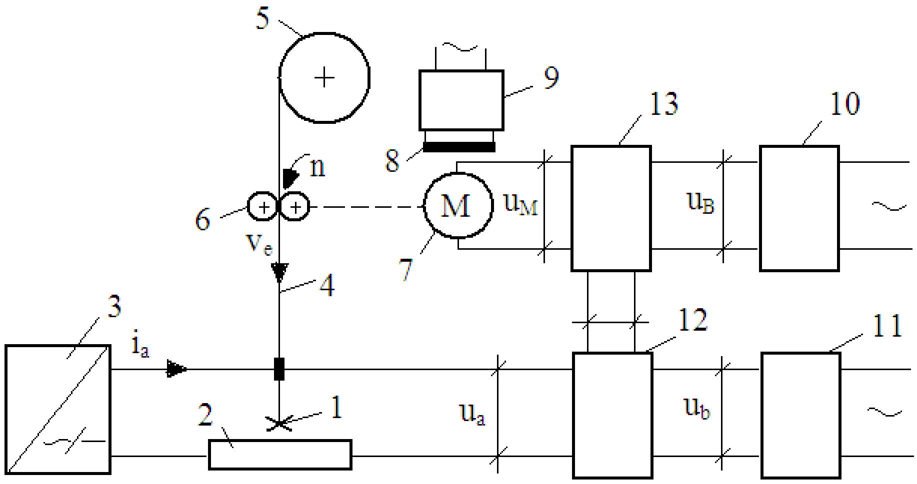

Figure 2. Diagram of the system of electrode wire feed with the wire advance speed depending on the arc voltage (SVD): 1 –electric arc; 2 – part subjected to welding; 3 – current source for welding; 4 – electrode wire; 5 – electrode coiled wire; 6 – roller mechanism; 7 – direct current motor with separate excitation; 8 – motor excitation; 9 – stabilised redresser; 10 – stabilised supply block; 11 – stabilised supply block; 12 – voltage regulator amplifier; 13 – power amplifier; i_a – arc current; u_a – arc voltage; v_e – electrode wire advance speed; n – number of revolutions of the advance system motor roller; u_e – output voltage from the regulator amplifier 12; u_b – reference voltage obtained from the supply block 11; u_B – stabilised voltage obtained from the supply block 10; u_M – motor supply voltage.

At the accidental increase - or due to preheating - of the arc voltage u_a above the imposed value u_b, the amplifier 13 increases the supply voltage of motor 7, so that the increase of its rotating speed triggers an increase of the advance speed of the electrode wire, and thus a decrease of the arc length and of its voltage, down to the reaching of a value close to the imposed dimension u_b, the error depending on the characteristics of the adjustment system.

2. Conclusions

The use of preheating for the electrode wire free end, during the MIG-MAG welding with additional thermal sources, produced by independent current sources, aims at improving, from the energetic point of view, the welding process with the MIG-MAG procedure, allowing the obtaining of the following advantages:

- problem-free welding of the root layer through the variant MIG-MAG, due to the much smaller necessary welding current compared to the classic variant of MIG-MAG welding, and thus a much smaller welding penetration;

- minimum thermal affectation of the basic metal (beneficial in the case of welding weakly alloyed and alloyed steels);

- increase of welding procedure productiveness in the case of welding non-alloyed steels, by the growth of the addition metal depositing rate (due to the possibility to increase the welding current within wide ranges).

In order to preserve the stability of the melting process one needs to endow the welding equipment with an electrode wire feed system with the advance speed of the wire depending on the arc voltage (SVD).

References

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