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CALCULATION OF CHARACTERISTICS OF ALTERNATING TRANSVERSE MAGNETIC FIELD, HAVING EFFECT ON DROP TRANSFER IN ARC WELDING AND SURFACING

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It is shown that in submerged-arc surfacing with the effect of constant transverse magnetic field the coefficient of melting of electrode wires of 3–5 mm diameter is increased by 25–30 %. It is experimentally found that at the effect of an alternating field at unchanged level of a transverse component of induction, the effect of increase in the coefficient of melting depends on frequency of this field. With increase of the field frequency up to 10–20 Hz, the increment of the coefficient of melting decreases to zero values. A procedure was developed for determination of the minimum level of transverse component of field induction in the electrode drop zone, at which the drop is detached from a melting electrode end. It is shown that the effect of decreasing the coefficient of melting at increase in the field frequency is predetermined by the reduction in duration of pulses. The paper gives the calculated data, allowing determination of optimum values of induction and frequency of the alternating field, at which the coefficient of wire melting at submerged-arc surfacing (welding) is increased. 8 Ref., 4 Figures.

Keywords: *arc surfacing (welding), transverse magnetic field, induction, electrode melting coefficient, frequency, calculation procedure*

The use of transverse magnetic field (TMF) in arc surfacing and welding allows controlling the geometry of beads and welds [1], refining the structure of weld metal (bead) [2–4] and increasing the strength of welded joints [5].

An important problem is increasing the efficiency of the electrode wire melting process during submerged arc welding and surfacing. Currently, the main attention of researchers is devoted to the development of TMF input devices (ID). However, there are no investigations devoted to clarifying the causes for increase in the melting coefficient of electrode wires during arc surfacing and welding under the TMF effect.

In the works [5, 6], the values of coefficient of the electrode wire melting α_m during submerged-arc surfacing with the effect of the controlling TMF were experimentally determined. It is shown that its use allows increasing the coefficient of wires melting. The maximum increase in the coefficient α_m (up to 30 %) is observed at the use of constant TMF, with the growth in frequency of this field, the effect of increase in α_m decreases to zero values at frequency of 20–50 Hz. In these works, a calculation procedure is presented, which makes it possible to explain the physical principle (causes) of increase in the coefficient α_m from the effect of constant TMF during arc surfacing. However, the calculation procedure given in the works [5, 6] can be used only in the case when a constant TMF is applied during surfacing, when at the electrode end a bevel is formed. It is impossible to apply this procedure to the alternating TMF, which hinders their rational use in arc surfacing and welding.

The aim of the work is to develop a calculation procedure that allows determining the minimum level of a transverse component of induction of TMF of different frequencies, which removes a drop from the electrode wire end and, due to that, increasing the coefficient of melting the electrode wires during submerged arc surfacing and welding.

As in the works [5, 6], in the present investigation the coefficient α_m of melting electrode wires Sv-08A of the diameters of 3–5 mm in arc surfacing under the flux AN-348 at a direct current of reverse polarity was experimentally determined.

The values of α_m of wires were determined by the well-known procedure (weighing method). In this case, surfacing was performed with the effect of both constant and alternating TMF at the frequency of 2; 5; 12; 24; 33 and 50 Hz. The same TMF ID, as in the works [5, 6], as well as the device supplying the coils of TMF ID, were used. The deposits were produced also without TMF effect. In order that a workpiece (plates being deposited) did not distort the structure of the magnetic field in the zone of an electrode drop

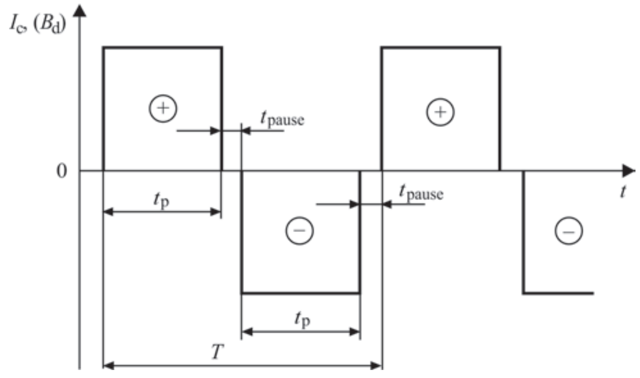

Figure 1. Diagram of current pulses I_c, supplying the coils of TMF ID

and weld pool, the plates of steel 12Kh18N10T (nonmagnetic) of 12–20 mm thickness were used. A diagram of rectangular pulses (current I_c in the coils of TMF ID and induction B_d) is shown in Figure 1. Here, the induction B_d was measured using a universal teslameter of 43205 type with Hall sensor, which had a measuring base of 0.9×0.9 mm near the base metal surface (in the future weld pool zone) under the electrode wire at a distance from its end to the plate $\Delta =$ = 5 mm. The induction B_d was measured during direct current passing in the coils of TMF ID; therefore, the maximum values of B_d in pulses, shown in Figure 1, correspond to the values which were during passing of direct current in the coils.

In all the experiments, the same values of induction $B_d = 30$ mT were maintained. There was a possibility of changing the duration of pulses (I_c, B_d) – t_p, and the pause t_{pause}. The duration of pauses $t = 0.01$ s was set (Figure 1). The duration of the period was $T =$ $= 2\ (t_p + t_{pause})$; frequency $f = 1/T$.

It was experimentally found that under the effect of constant TMF and induction $B_d = 30$ mT, the maximum increment in the coefficient α_m (Figure 2) is observed, which corresponds to the data established in the works [5, 6]. The values of α_m of wires during surfacing without TMF effect were also determined. The data showed (not given here) that the values of α_m of wires with the diameter of 3–5 mm in surfacing at $I_s = 300–500$ A are in the range of 12.5–14.5 g/(A·h), which corresponds to the well-known regularities[8].

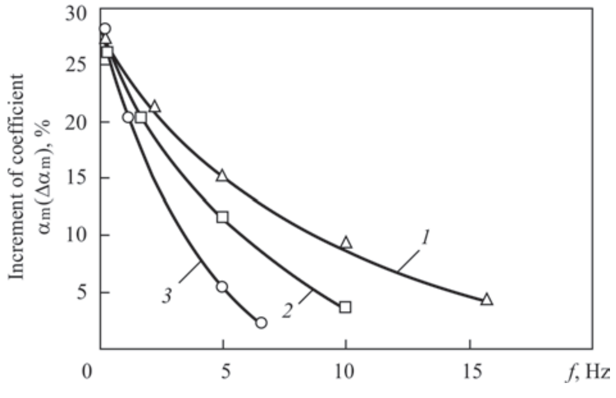

Figure 2. Effect of frequency f of TMF on increment of the coefficient α_m ($\Delta\alpha_m$) ($I_s = 480–520$ A; $U_a = 30–32$ V, $B_d = 30$ mT): *1, 2, 3* — diameters of electrodes, respectively, 3, 4, 5 mm

With increase in frequency of TMF, the effect of increasing α_m of the electrode wires decreases, but its decrease is more sharp than it was previously established in the works [5, 6] (Figure 2). The decrease in the effect of increasing α_m of wires is associated with features of a forced removal of drop from the melting end at the effect of different frequency of TMF.

Below a calculated procedure is presented, that allows explaining the effects of TMF on the coefficient α_m of melting the electrode wires in arc surfacing (welding).

In the present investigation, as was noted, the values of pauses duration $t_{pause} = 0.01$ s was used. This is connected with the fact that during the pause of the effect of TMF (short pause, $t_{pause} = 0.01$ s) a significant layer of liquid metal was not accumulated at the end of the electrode. The analysis shows that in surfacing (welding) using the wires of the diameters of 3; 4 and 5 mm and at the current $I_s = 500$ A; the speed of electrodes feeding is approximately $v_{e.f} = 2\cdot10^{-2}$ m/s (2 cm/s). Then, if $t_{pause} = 0.01$ s, then at the end of the electrode, a layer of liquid metal with a thickness of $h = v_{e.f}t_{pause} = 2\cdot10^{-2}\cdot10^{-2} = 2\cdot10^{-4} = 0.2$ mm is formed, which can be neglected.

Then, simply, it can be accepted that $t_{pause} = 0$ and the frequency of TMF

$$f = \frac{1}{T} = \frac{1}{2\left(t_p + t_{pause}\right)}, \qquad (1)$$

$$f = \frac{1}{2t_p}, \qquad (2)$$

and the pulse duration

$$t_p = \frac{1}{2f}, \qquad (3)$$

where f is the frequency of TMF, Hz.

In the works [5, 6], it was found that the bevel of the electrode end in arc melting of wire is not formed if the frequency of TMF is higher than 1–2 Hz. This regularity is taken in the present investigation.

Let us assume that at the end of a melting electrode before the effect of TMF pulses (B_d), a drop in the form of hemisphere was present with a sphere radius $r = d/2$ (d is the diameter of the electrode wire, m).

In this case, the drop volume

$$V_{drop} = \frac{1}{2}\frac{4}{3}\pi r^3; \quad V_{drop} = \frac{1}{12}\pi d^3 \text{ m}^3. \qquad (4)$$

The drop mass

$$m = \rho V_{drop}, \text{ kg}, \qquad (5)$$

where ρ is the density of drop liquid metal, kg/m^3, $\rho =$ $= 7\cdot10^3$ kg/m^3.

The electromagnetic force acts (horizontally) on the drop (in the direction of X axis):

$$F'_{\text{em}} = F_{\text{em}} V_{\text{drop}}, \text{ N}, \tag{6}$$

where F_{em} is the density of electromagnetic force in the drop, N/m^3.

At the given current of surfacing I_{s} and at the action of induction B_{d}:

$$F'_{\text{em}} = \frac{4I_{\text{s}}}{\pi d^2} B_d \rho V_{\text{drop}}, \text{ N}. \tag{7}$$

Under the action of force F'_{em} a drop of volume V_{drop}, will receive an acceleration

$$a = \frac{F'_{\text{em}}}{m}, \text{ m/s}^2. \tag{8}$$

Then

$$F'_{\text{em}} V_{\text{drop}} = \rho V_{\text{drop}} a; \quad F'_{\text{em}} = \rho a. \tag{9}$$

Taking into account (7) and (9), we shall receive:

$$a = \frac{F'_{\text{em}}}{\rho} = \frac{4I_{\text{s}} B_{\text{d}}}{\pi d^2}, \text{ m/s}^2. \tag{10}$$

The drop under the action of the force F'_{em} is removed (horizontally along the axis X) at a speed

$$V = \sqrt{2La}, \text{ m/s}, \tag{11}$$

where L is the length of the drop «acceleration» at the electrode end, m.

Obviously, that $L = d$, then

$$V = \sqrt{2da}, \text{ m/s}. \tag{12}$$

The time of a drop removal from the electrode end (displacement along path $L = d$):

$$t = \sqrt{\frac{2d}{a}}, \text{ s}. \tag{13}$$

The minimum level of induction B_{d}, that removes a drop at a given frequency is:

$$B_{\text{d}} = \frac{2\rho\pi d^3 f^2}{I_{\text{s}}}, \text{ T}. \tag{14}$$

By the formula (14), the value of the induction B_{d} (as the minimum level) was calculated, which removes a drop from the electrode end as-applied to the arc surfacing with wire Sv-08A of diameters 3–5 mm, current I_{s} = 300–1000 A and different frequency f of TMF. The data shows (Figure 3) that with the growth in current I_{s} (as it should be expected from the formula (14)) and the given frequency of TMF, the level of induction B_{d}, at which a drop is removed from the electrode end, decreases. As the frequency f of TMF increases from 5 to 10 Hz, the level of induction B_{d} increases significantly. This is clear, because with the growth in frequency f of TMF, the duration of a pulse action (t_{p}) of TMF decreases.

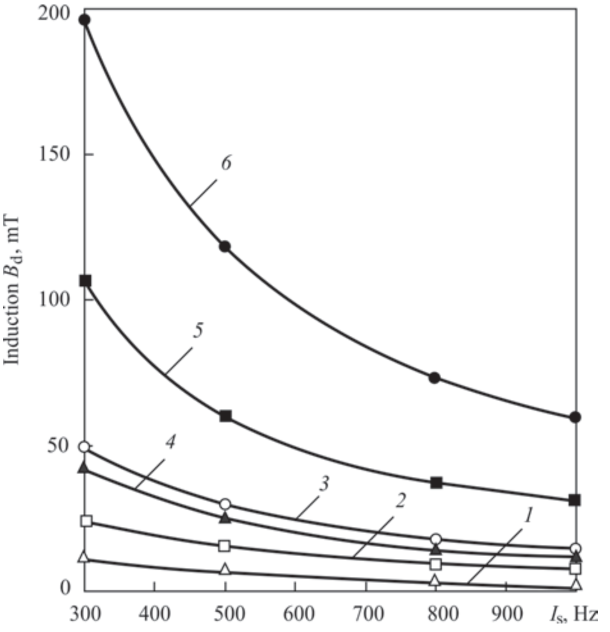

Figure 3. Dependence of induction B_{d} on surfacing current I_{s}: *1, 4* — d = 3 mm; *2, 5* — d = 4 mm; *3, 6* — d = 5 mm; *1, 2, 3* — f = = 5 Hz; *4, 5, 6* — f = 10 Hz

At a preset current (I_{s} = 500 A in Figure 4), an increase in the frequency f of TMF leads to a sharp increase (according to the quadratic dependence in compliance with the formula (14)) in induction B_{d} of TMF. This is also caused by a sharp decrease in duration of pulses (t_{p}) of TMF at the increase in the frequency f of TMF. From Figure 4, it follows that at the level of induction B_{d} = 30 mT (and current I_{s} = = 500 A), at which deposits were produced (Figure 2), a decrease in the growth of α_{m} is associated with an insufficient level of induction B_{d}.

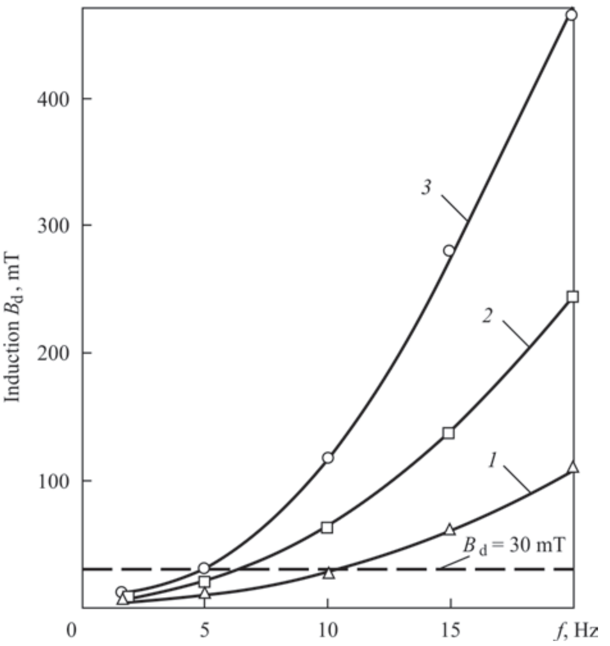

Figure 4. Dependence of induction B_{d} on frequency f (I_{s} = 500 A): *1, 2, 3* — diameters of wires, respectively, 3, 4, 5 mm

Thus, the effect of increase in the coefficient α_m under the conditions of action of the alternating TMF during arc surfacing and welding consists in a sufficient level of the induction B_d in a pulse of TMF and in a pulse duration t_p (and, accordingly, frequency value) of TMF.

The developed calculation procedure for determination of the minimum level of induction B_d in TMF at a preset frequency of TMF makes it possible not only to explain the observed effects of alternating TMF on the efficiency of melting the electrode wires during submerged-arc surfacing, but also to recommend optimal parameters of such TMF for arc surfacing (and welding).

It should be noted that the observed effects of increasing α_m during submerged-arc surfacing occur when other wires are used (both ferromagnetic and non-ferromagnetic, for example, 06Kh18N10T). It is obviously, that if the duration of pauses (t_{pause}) of rectangular pulses at a preset frequency (or close to the frequency f of TMF) is increased, then the effect of TMF on α_m of the wires in arc surfacing (at a given frequency and a level of the induction B_d) will decrease. As the optimal value, $t_p = 0.01–0.02$ s should be taken.

It should be noted that in welding and surfacing, only alternating TMF improves the formation of welds and deposited beads. Alternating TMF induces flows of liquid metal in the weld pool from its head part to the tail part and back again. This leads to the refinement of structural components of the weld metal (deposited bead), thus improving the mechanical properties of welds and deposited metal [3, 5]. Here, the use of alternating TMF with a frequency of up to 20 Hz [3, 5, 7] is effective.

In the present work, as in the works [5, 6], TMF ID was used, on the rods of which the windings (coils) of insulated copper wire with a number of turns $W = 100–150$ were placed. To prevent the windings from overheating, the current in them should not exceed 20 A. In this case, in the zone of an electrode drop and in the head part of the pool, a transverse component of the TMF induction (B_d) of about 30 mT is provided, sufficient to control the transfer of electrode drops and to induce flows in the liquid metal of the pool (at $f = 10–20$ Hz). The increase in the number of turns in the windings or the diameter of their wire increase the bulkiness of design of TMF ID (striving to reach the level of $B_d = 60$ mT and higher, see Figure 4). Therefore, it should be recommended to apply TMF with the frequency of not higher than 15–20 Hz (better — 5–10 Hz). In this case, the increase in α_m reaches the values of up to 15 g/(A·h), which improves the efficiency of arc surfacing and welding processes. It should be noted that for the convenience of performing these processes, it is desirable to use a transverse arrangement of rods of TMF ID with respect to the weld (bead) axis.

Conclusions

1. In submerged-arc surfacing at the increase in frequency of alternating transverse magnetic field, the effect of growing the coefficient of electrodes melting decreases to zero values at the frequencies of the order of 10–20 Hz of TMF.

2. A calculation procedure was developed, which allows determining the minimum value of a transverse component of the TMF induction, which removes a drop from the melting end of the electrode wire at a preset frequency of this field. The calculated values of the minimum level of induction of the alternating TMF are given, which made it possible to explain the effects of such TMF on the coefficient of melting the electrode wires during arc surfacing (welding)

3. In submerged-arc surfacing and welding, in order not only to provide the removal of electrode drops from the end of the electrodes and to increase their melting efficiency, but also for efficient mixing of liquid metal in the pool, it is rational to use the alternating TMF of up to 10 Hz frequency.

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