Features of melting high-chromium flux-cored wire in pulsed arc welding

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Abstract. The results of studies of the process of pulse-arc surfacing with flux-cored wire are presented. It is shown that with pulsed arc control, it is possible to increase the main parameters of the process to the values characteristic of a solid wire. The difference between the melting character of flux-cored and solid wire is shown.

1. Introduction

The use of flux-cored wires for welding and surfacing has a number of advantages compared to solid-section wires. However, there is also a certain list of problems that make it difficult to use them and, sometimes, lead to refusal to use them [1-6].

Flux-cored wires are characterized by uneven properties in cross-section, the charge (wire core) has a much lower electrical and thermal conductivity than the shell. The active arc spot is localized on the shell, and the wire core is heated by heat transfer from the shell, which changes the shape of the arc, the nature of thermal and physico-chemical processes at the end of the electrode, and also leads to different conditions of arc burning, formation and transfer of droplets than with a solid wire [7, 8, 9].

This leads to a decrease in the stability of arc burning, an increase in metal spattering, and a deterioration in the formation of the seam. At the same time, the typical welding modes used in modern welding machines often do not give an optimal result. This is especially true for wires that have an "unconventional" composition of the charge: with a small number of slag-forming components and, conversely, with a large number of metal components for a high degree of alloying of the deposited metal [10, 11].

The use of the pulse-arc process to regulate the stability of the arc often does not give a tangible result, which leads to the rejection of it in enterprises.

For welding alloy steels, wires with a high chromium content (12-27%) are used, which creates additional difficulties in developing the technology, which are associated with a decrease in the stability and uniformity of the melting of the flux-cored wire.

The aim of the study is to analyze the influence of the pulse-arc process on the characteristics of the melting process of high-chromium flux-cored wires.

2. Materials and methodologies

As the object of the study, a wire with a diameter of 1.2 mm was selected, which allows to obtain a deposited metal of the 50Cr18 type, additionally alloyed with nitrogen. A mixture of the K-18 type (82% Ar+18% CO2) was used as a protective gas. Studies of the characteristics of the welding process, the choice of its parameters and the methods used are described in detail in the works [10, 11]. Surfacing performed on the Storm-Lorch S5 SpeedPulse semi-automatic welding machine.
To study the melting process, the formation of droplets and the nature of the transfer of the electrode material, several variants of the technological process were used: the standard mode with continuous arc burning in a process with natural short circuits; SpeedPulse—the imposition of a modified pulse during the drop discharge period.

The nature of droplet formation was assessed visually by observing the arc, as well as indirectly by assessing the nature of splashing.

The spatter was evaluated by weighing the plates before and after surfacing and comparing them with the estimated weight of the spent wire. The quality of the roller formation was determined according to the developed method in points (from 0 to 5), evaluating the uniformity of the seam size, the presence of defects such as pores, slags, shells, the smoothness of the surface, the uniformity of weld surface with bead ripples (if any).

The arc current and voltage were oscillographed using the AWR224 welding parameter logger (ZAO Laboratory of Electronics, St. Petersburg).

The parameter ranges are shown in the table. 1. For each mode, five surfacings was made on plates with a thickness of 12 mm made of low-carbon steel.

| Table 1. Ranges of welding parameter values. |
|---------------------------------------------|
| Welding Parameters | Standart | SpeedPulse |
| Current, A | 120-200 | 100-200 |
| Wire Feed Rate, m/min | 5-9 | 7-12 |
| Voltage, V | 20-28 | 26-32 |
| Electrode extention, mm | 20-25 | 27-32 |

To determine the characteristics, an experiment was implemented in accordance with the orthogonal plan of the second order. In accordance with the plan of the experiment, surfacing was performed at 9 combinations of the main parameters of the mode (at the central point of the plan - 6 parallel experiments to determine the reproducibility indicators). After mathematical processing, regression equations are obtained that connect the determined characteristics with the parameters of the mode.

3. Results and discussion
In Figure 1 the obtained calculated dependences of splashing and seam formation on the arc voltage at different values of the wire feed rate (over 32V - extrapolation) are shown.

![Figure 1](image)

**Figure 1.** The effect of arc voltage and the wire feed rate on the loss of electrode material Ψ (%) (a) and seam formation (points) (b) during surfacing in standard modes.
It can be seen that over the entire range of the studied currents, an increase in voltage has an almost opposite effect on splashing and seam formation: thus, it is almost impossible to distinguish a voltage range characterized by both low losses of the electrode material and good weld formation.

Figure 2 shows the stringer beads obtained in standard modes. The beads are narrow (up to 10 mm wide), have swells and turns (deep undercuts) at the edges. Visible pores that come to the surface, and slag inclusions. There are many large splashes up to 4 mm in size. The level of metal losses reaches 15-18%, the formation of the seam is on average below satisfactory. The measured value of the surfacing coefficient is 16-20 g/A*h.

When switching to the SpeedPulse modes, there are positive changes in comparison with previous experiments: the width of the obtained beads is from 12 to 16 mm; the formation of the seam is noticeably improved; the beads are uniform, without surges; the surface is smooth, there are no pores and slag inclusions; there are no large drops and slag particles fused in; there is a small amount of small splashes, up to 0.5 mm in size.

Figure 3 shows the calculated dependence of the loss coefficient on the arc voltage at different values of the wire feed rate. It can be seen that when the voltage increases from about 32 to 34 V, there is no noticeable deterioration in the spray characteristics, and the loss coefficient itself is 12-17%. It is interesting that the very nature of the change in the loss value is different: in standard modes, when the voltage increases, the losses increase, and in the pulse mode, on the contrary, they decrease. The measured value of the surfacing coefficient is 27-30 g/A*h.

![Figure 2: Appearance of the deposited beads. Standard modes.](image1)

![Figure 3: The effect of arc voltage and the wire feed rate on the loss of electrode material Ψ (%) (a) and seam formation (points) (b) during surfacing in SpeedPulse modes.](image2)
Figure 4. Appearance of the deposited bead. SpeedPulse mode: a) voltage 32 V, b) voltage 28 V.

The analysis of the melting process indicators shows the following:

- at close current values, the surfacing performance in pulse modes is 1.60 - 1.80 times higher than in pulse-free modes;
- the value of the surfacing coefficient when using the pulse mode is higher by 30-35%;
- losses (burnuig, spattering) are reduced by 1.5-2 times in comparison with the pulse-free mode, while ensuring better weld formation.

These differences in the characteristics of the welding process can be explained by the different nature of the melting of the electrode, the dynamics of the formation and transfer of droplets. A special feature of the powder wire is that it consists of a metal shell and a core (charge), while the heat and, most importantly, the electrical conductivity of the charge is noticeably lower than that of the shell [9]. This leads to the fact that the charge melts only due to the heat transfer from the shell, on which, in fact, the arc burns. On the basis of these thermophysical features, possible melting schemes of the charge and shell are proposed. Figure 5 shows the two melting mechanisms of the charge and shell. In the implementation of option (a), the shell, melting, falls into the molten charge in small droplets, forming a metal-slag drop, which grows to a relatively large size and then, mainly under the influence of gravity, separates from the electrode.

Figure 5. Melting of powder wire during non-pulse welding (a) and modified pulse welding (b).
In option (b), small droplets from the shell are separately moved to the bath in the fine-drop transfer mode, and a drop of charge melted due to heat transfer from the shell grows until it breaks away from the electrode in the large-drop transfer mode.

It is obvious that option (b) in the non-pulse mode can be implemented only at large current values corresponding to the small-drop transfer. For cored wires, due to the smaller cross-section of the metal shell than for solid wires, this current can be relatively small: 150-200A.

In the SpeedPulse modes, the welding current pulse is modified in such a way that after the main pulse, the current does not immediately drop to the minimum value, but for some time the current is set just in the range of fine-drop transfer. This facilitates the transfer of a certain amount of shell metal in the form of small droplets without mixing them with the molten charge, which ultimately leads to a more stable flow of the process as a whole. Large drops of molten charge are separated, probably, under the influence of gravity with a frequency of 0.4-0.5 Hz, even at a low average current value-from 100-120A [11].

In non-pulse welding, mode (b) is not achieved, since there is no current lifetime corresponding to the fine-drop transfer.

According to the standard mode waveform (Fig.6) it can be seen that the process is a series of chaotic short circuits, which explains the high spatter.

![Figure 6](image)

**Figure 6.** Waveform of the welding process with natural short circuits (Standart mode) (V×10^{-1}).

The SpeedPulse mode waveform (Fig. 7) shows relatively rare periodic short circuits, apparently corresponding to the transfer of larger droplets. A characteristic step on the back edge of the pulse (Fig. 7b) is used to activate an additional stage of small-drop transfer after the main drop is detached.

![Figure 7](image)

**Figure 7.** Waveform of the pulse-arc welding process (SpeedPulse mode): a - the flow of the process as a whole; b – the increased time scale.
The lower frequency of the appearance of large droplets probably reflects the different mechanisms of melting of the shell and charge during welding with cored wire.

The formation of a series of small droplets without a short circuit is caused by the melting of the metal shell due to the heat of the active spot and the arc column. The periodic appearance of large droplets corresponds to the gradual melting of the wire charge due to heat transfer from the molten part of the metal shell.

4. Conclusions
In the pulse mode, when using a modified pulse, there are two types of transfer simultaneously: small-drop transfer of the shell metal and large-drop transfer of the charge material. The formation of droplets of different sizes is due to the difference in the thermophysical properties of the charge and the shell of the powder wire.

In this case, the transfer is ordered, which leads to increased arc stability and formation of the seam. The range of stable modes, in which better seam formation and reduced splashing is achieved, is located in the area of higher arc voltages (32V or more) than when using standard modes and (or) solid wire.

Increasing arc stability reduces metal losses on burning and spattering up to 1.7 times, the surfacing coefficient and productivity increase up to 1.5 times, compared with welding with natural short circuits.

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