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INFLUENCE OF MODES OF FLUX-CORED STRIP SURFACING ON THEIR WELDING-TECHNOLOGICAL PROPERTIES

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Influence of surfacing modes on welding-technological properties of different types of high-alloyed flux-cored strips was studied. Electrode metal melting, surfacing, loss factors, as well as the efficiency of electrode material melting and deposition rate, were determined. As the objects of study, the flux-cored strips PL-AN-101 and PL-AN-179 made on a shel strip-sheath, as well as the strip PL-AN-111 on the bes on nickel sheath, widely applied in industry, were selected. Surfacing of samples for investigations was performed in A-874N machine with AD-167 attachment and VDU-1201 power source in a wide range of modes: current of 600–900 A, voltage of 32–40 V, speed of 32–55 m/h. Obtained results are presented graphically. It is found that alongside the surfacing modes, the filler-powder composition and sheath strip material have a significant effect on the characteristics of welding-technological properties of flux-cored strips and chemical composition and hardness of deposited metal, respectively. In surfacing with PL-AN-111 strip with a nickel sheath, having a high ohmic resistance, the more intensive heating of the flux-cored strip at the stickout takes place, and, consequently, the coefficient of electrode material melting is increased. Melting efficiency was lower in surfacing with PL-AN-101 and PL-AN-179 strips. At current rise, losses for burn-out and spattering become greater for PL-AN-111 strip, and change only slightly for PL-AN-101 strip, while for PL-AN-179 strip they decrease abruptly in the current range of 900–1200 A because of the specifics of powder-filler composition. Values of melting and surfacing factors, as well as melting and deposition efficiency decrease with increase of process speed for all the strip types. For PL-AN-111 strip, however, these values change only slightly. 7 Ref., 1 Table, 3 Figures.

Keywords: *flux-cored strip, current, voltage, surfacing speed, melting and surfacing efficiency, losses for burn-out and spattering*

In the development of technological processes of restoration and hardening of parts with the use of flux-cored strip, an important tool for obtaining the desired effect is the selection of surfacing modes. A high coefficient of flux-cored strips filling allows conducting the process of surfacing with a high efficiency and producing the deposited layers with a high degree of alloying. Earlier, the attempts were made to study the processes of melting flux-cored strips and formation of deposited layer [1, 2]. But these works describe surfacing at the forced modes under a layer of flux. The specifics of melting flux-cored strips with an open arc required complex studies of influence of the technological parameters of surfacing process and a whole number of factors characterizing the formation and quality of the deposited metal. In previous works [3, 4], the effect of modes of surfacing using flux-cored strips of different compositions on geometrical parameters of the formed beads, chemical composition and hardness of the deposited metal was studied.

In the course of development of these works, the present paper describes the results of investigations on welding-technological properties of flux-cored strips, such as the electrode metal melting, surfacing, loss factors, as well as efficiency of melting the electrode material and efficiency of surfacing.

The mentioned parameters play a key role in the calculation of flux-cored strip compositions and affect the chemical composition, hardness and service characteristics of the deposited metal.

Three grades of flux-cored strips: PL-Np-300Kh25S3N2G2 (PL-AN-101) and PL-Np-400Kh20B7M7V2F (PL-AN-179) were investigated, made on the basis of steel strip-sheath, and also the strip PL-Np500Kh40N40S2RTs (PL-AN-111), which is made on the base of the nickel strip of the sheath [5–7]. The selection of flux-cored strip grades with a steel sheath is predetermined by the fact that the strip PL-AN-101 was made using a complex alloying in the composition of the powder-filler. The strip PL-AN-179 was made on the base of a mechanical mixture of refractory ferroalloys.

The experiments were carried out in the surfacing machine A-874N, equipped with the power source VDU-1201 and the attachment AD-167. Surfacing was performed in separate beads in a single layer at direct current of reverse polarity, at a constant value of stickout equal to 50 mm and a rigid external char-

Surfacing modes

Current, A	Voltage, V	Surfacing speed, m/h
600 ± 25	32 ± I	32 ± 1
750 ± 25	32 ± I	32 ± 1
900 ± 25	32 ± I	32 ± 1
1150 ± 25	32 ± I	32 ± 1
1200 ± *25*	32 ± I	32 ± 1
900 ± 25	24 ± I	32 ± 1
900 ± 25	28 ± I	32 ± 1
900 ± 25	36 ± I	32 ± 1I
900 ± 25	40 ± I	32 ± 1
900 ± 25	32 ± I	19 ± 1
900 ± 25	32 ± I	40 ± 1
900 ± 25	32 ± I	48 ± 1
900 ± 25	32 ± I	55 ± 1

acteristic of the power source. As the base metal, the plates from St3 with a thickness of 30 mm and a size of 300×400 mm were used. On each of the plates 6 beads were deposited with a length of 200–250 mm. To exclude the effect of preheating, each subsequent bead was applied after a complete cooling of the previous one. The surfacing modes using all the given strips are shown in the Table.

The coefficients of melting α_m and surfacing α_s were determined by the formulas:

$$\alpha_m = \frac{3600(m_{st} - m^1_{st})}{It},$$

where m_{st} is the mass of the strip before surfacing, g; $_{st}$ is the mass of the strip after surfacing, g; I is the current of surfacing, A; t is the time of surfacing, s;

$$\alpha \ = \frac{3600(m_p \quad m_p)}{It}$$

where m_p is the mass of the plate after surfacing, g; m^1_p is the mass of the plate before surfacing, g; I is the current of surfacing, A; t is the time of surfacing, s.

The loss coefficient K_l is determined by the formula

$$K_l = \frac{(m_{st} - m^1_{st}) - (m_p - m^1_p)}{(m_{st} - m^1_{st})}.$$

The efficiency of melting and surfacing (N, N') were determined by the formulas:

$$N = \frac{\Delta m \cdot 3.6}{t}, \quad N' = \frac{\Delta m' \cdot 3.6}{t},$$

where Δm is the difference between the masses of the strip segments before and after surfacing, g; $\Delta m'$ is the difference between the masses of the plates after and before surfacing; t is the time of surfacing, s.

Figure 1 presents data by coefficients of melting, surfacing and losses, as well as by efficiency of electrode melting and surfacing depending on current. The coefficient of melting of the electrode material

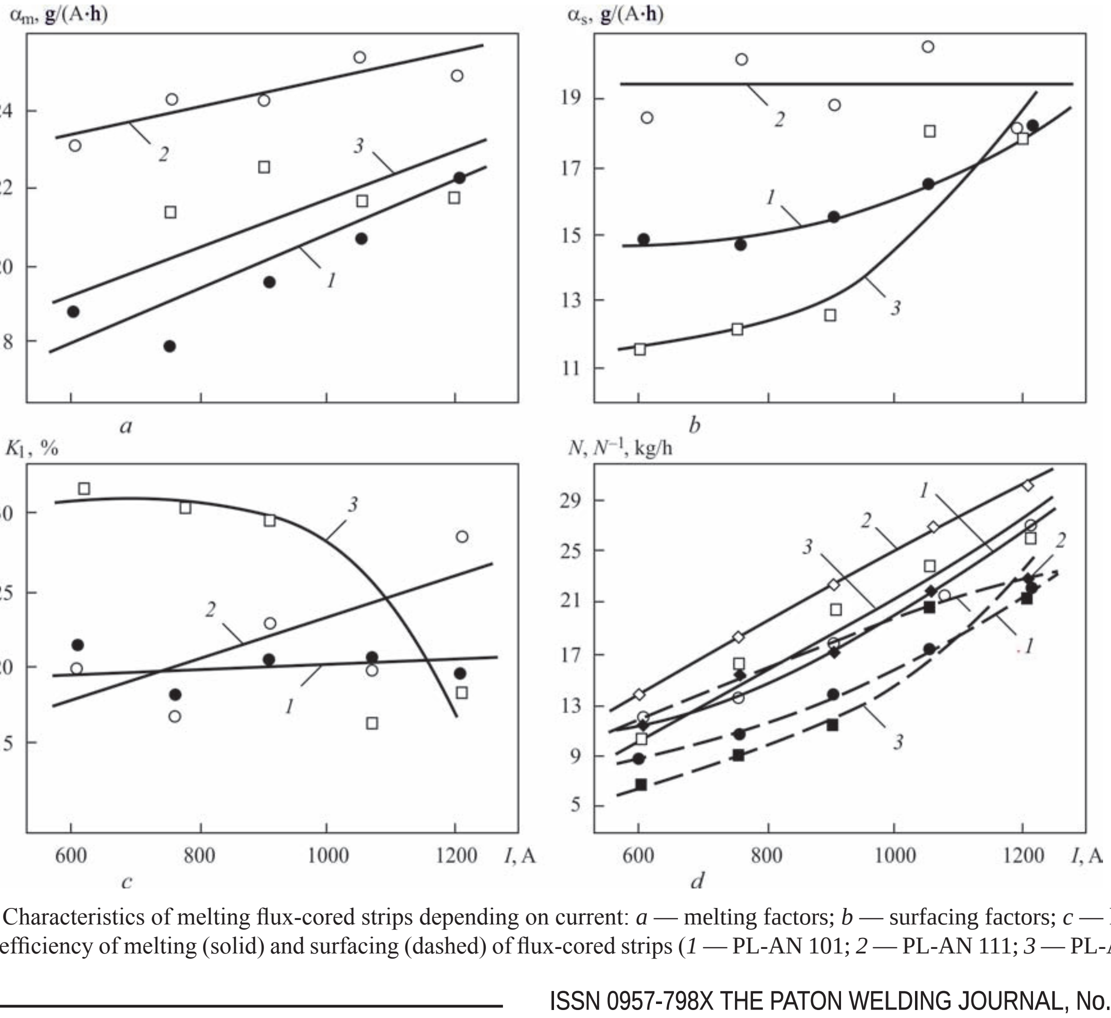

Figure 1. Characteristics of melting flux-cored strips depending on current: *a* — melting factors; *b* — surfacing factors; *c* — loss factors; *d* — efficiency of melting (solid) and surfacing (dashed) of flux-cored strips (*1* — PL-AN 101; *2* — PL-AN 111; *3* — PL-AN 179)

(Figure 1, *a*) increases with growing current for all tested flux-cored strips. At the same time, it should be noted that the coefficient of melting the flux-cored strip PL-AN 111 is significantly (by 2.5–4.0 g/A·h) higher than for the flux-cored strips PL-AN 101 and PL-AN 179. This is explained by differences in the nature of melting the electrode materials associated with the use of different strips-sheathes during manufacture.

Thus, the strip PL-AN 111 is manufactured with the use of nickel strip and, as was noted above, this causes its higher ohmic resistance, and consequently, the more intense heating of the electrode material at the stickout.

The deposition rate factor (Figure 1, *b*) for different strips with the increase in current from 600 to 1200 A behaves ambiguously. When using flux-cored strips PL-AN 101 and PL-AN 179, it increases, moreover, for the strip PL-AN 179 its growth is more pronounced. When using the flux-cored strip PL-AN 111, the change in the deposition rate factor with increasing current does not occur. This is explained by differences in varying losses with the increase in current from 600 to 1200 A (Figure 1, *c*). Thus, the relative value of losses for burn-out and spattering over the entire range of current variation for the flux-cored strip PL-AN 101 remains unchanged, and for the flux-cored strip PL-AN 111 it increases, and for PL-AN 179 it drops sharply.

Both the efficiency of melting flux-cored strips, as well as the efficiency of surfacing grows for all grades of tested flux-cored strips with the increase in current within the entire considered range (Figure 1, *d*).

Figure 2 presents data on characteristics of melting the flux-cored strips depending on the arc voltage. The coefficient of melting the flux-cored strips increases with growing arc voltage (Figure 2, *a*). For the flux-cored strips PL-AN 101 and PL-AN 179, as the arc voltage grows, the deposition rate factors also increase (Figure 2, *b*).

During surfacing using the strip PL-AN 111, a similar increase is observed when the voltage grows

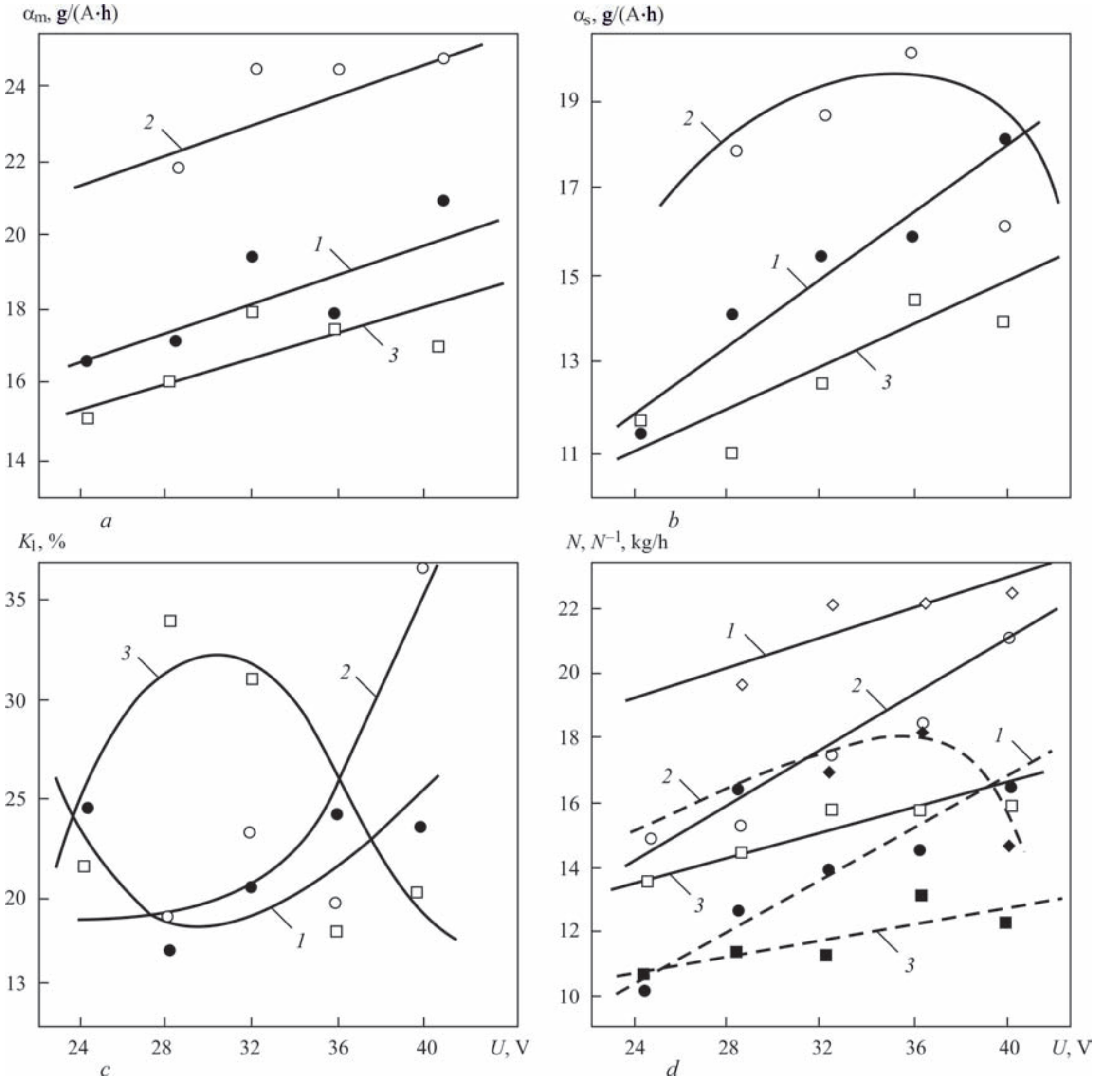

Figure 2. Characteristics of melting flux-cored strips depending on voltage (designations are the same as in Figure 1)

to 32–34 V. A further increase in voltage leads to decrease in the values of specified characteristics. At the same time, as is seen from the plot (Figure 2, *c*), the burn-out and spattering losses sharply increase, which, obviously, is first of all connected with the active oxidation of the electrode material components.

Figure 3 shows the coefficients of melting and surfacing, as well as the efficiency of melting and surfacing depending on the speed of arc movement for all the tested flux-cored strips.

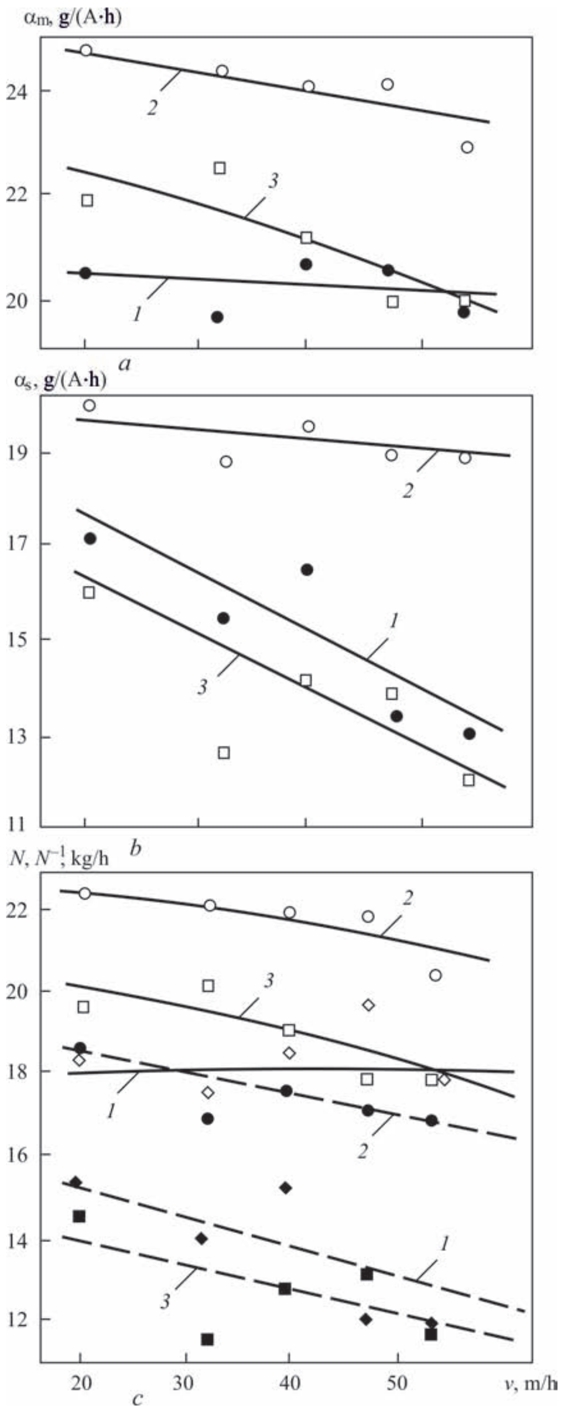

Figure 3. Characteristics of melting flux-cored strips depending on change in the rate of surfacing: *a* — melting factors; *b* — surfacing factors; *c* — efficiency of melting (solid) and surfacing (dashed) of flux-cored strips (*1* — PL-AN 101; *2* — PL-AN 111; *3* — PL-AN 179)

Considering the results obtained in general, the following should be noted. The characteristics of melting the flux-cored strips, and, consequently, the chemical composition and hardness of the deposited metal, in addition to surfacing modes, are significantly influenced by the composition of the powder-filler and the strip-sheath material. Thus, during surfacing using the flux-cored strip PL-AN 111, made on the base of nickel strip-sheath, all the studied characteristics are significantly different from the data obtained during surfacing using the flux-cored strips PL-AN 101 and PL-AN 179, made of steel strip-sheath. This can obviously be explained by a higher ohmic resistance of the nickel strip-sheath. At the same time, due to a higher voltage drop on the electrode stickout, a more intensive heating of the flux-cored strip on the stickout occurs, which, in turn, increases the efficiency of its arc melting, i.e. leads to a more efficient use of heat power of the arc. The resulting positive effect in the form of increasing coefficient of melting the electrode material, which is a decrease in the volume of the base metal, is leveled by increase in burn-out and spattering losses. It should be noted that the chemical composition of the metal deposited by the flux-cored strip PL-AN 111 with the simultaneous influence of the abovementioned factors, remains almost unchanged in the entire considered range of welding current. Increase in voltage leads to intensive oxidation of basic alloying components: carbon and chromium, which reduces the degree of alloying of the deposited metal and its hardness. During surfacing using the flux-cored strips PL-AN 101 and PL-AN 179, the efficiency of melting is somewhat lower than that in the flux-cored strip PL-AN 111, but at higher currents the amount of the deposited metal for all strips is approximately the same. This can be explained by difference in losses of electrode material for burn-out and spattering. Thus, the losses for the strip PL-AN 101 with an increase in current change very slightly, for the strip PL-AN 111, they grow, and for the strip PL-AN 179 they fall sharply in the range of 900–1200 A.

The drop of losses for the flux-cored strip PL-AN 179 is obviously connected with the nature of melting the powder-filler, which is characterized by the presence of a large number of refractory components. In addition, this strip is characterized by the highest filling coefficient among the tested strips, which is about 65 %. In our opinion, this causes large losses of electrode material at low currents because of the insufficient of heat power of the arc and insufficient preheating of the strip at the stickout.

Increase in voltage for all the flux-cored strips leads to decrease in the level of alloying the deposited layer. This is explained by both an increase in the volume of the base metal and an increase in burn-out losses. Moreover, the burn-out losses increase more, if the preheating at the electrode stickout is higher. Thus, they increase most strongly during surfacing using the flux-cored strip PL-AN 111.

The deposition rate has a less noticeable effect on the studied characteristics, which mainly depends on distribution of heat fluxes and heat power of the arc.

For a more complete explanation of the obtained results, it is of interest to further investigate the ohmic resistance of the tested flux-cored strips and to obtain data on their preheating at the stickout.

Conclusions

1. The coefficient of melting the electrode materials increases with rise both current as well as voltage for all the types of strips. This is especially evident during surfacing using the strip PL-AN-111 with nickel sheath, which has a higher ohmic resistance.

2. The deposition rate factor grows with the increase in current and voltage for the flux-cored strips PL-AN-101 and PL-AN-179. For the strip PL-AN-111, it is stable when the current grows, and with the increase in voltage to 36 V, it grows and then drops sharply, which is associated with the increase in losses for burn-out and spattering.

3. The efficiency of melting and surfacing of flux-cored strips increases with the growth of current and voltage for all types of flux-cored strips, however, when the voltage is higher than 36 V, for the strip PL-AN-111, the efficiency of surfacing drops sharply due to the increase in the coefficient of losses for burn-out and spattering.

4. The coefficient of losses depends little on the current and voltage for the strip PL-AN-101, but increases significantly with the growth of current for the strip PL-AN-111 and is especially high at the voltages higher than 36 V. For the strip PL-AN- 179, the coefficient of losses sharply decreases with the growth of current to higher than 800 A, and the voltage higher than 32 V. This is connected with the refractory strip core, for melting of which an increased heat power of the arc is required.

5. In the entire range of modes of the surfacing process, the values of melting and surfacing coefficients of all types of strips, as well as the efficiency of melting and surfacing decreases with the increase in deposition rate, but for the strip PL-AN-111 these values change insignificantly.

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