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INLUENCE OF ELECTRODE WIRE FEED SPEED ON BASE METAL PENETRATION IN ARC SURFACING

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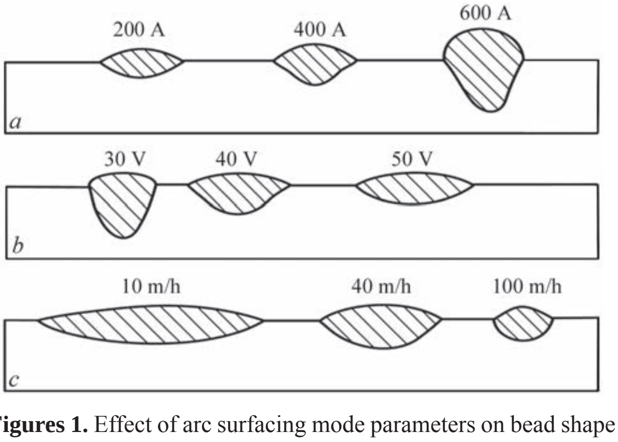
Influence of electrode wire feed speed on base metal penetration and geometrical dimensions of deposited beads at submerged-arc surfacing was studied. Four flux-cored wires of 1.2; 1.6; 1.8 and 2.0 mm diameter were used in the experiments. Feed speed adjustment was performed in the range from minimum value $V_{f.min}$, at which a stable surfacing process can be in place for these conditions, and up to maximum value $V_{f\,max}$ = 450 m/h, which was determined by the characteristics of the used surfacing unit. It is found that at surfacing with high wire feed speeds, there exists such an optimum ratio of feed speed and other surfacing parameters for each wire diameter, at which increase of this speed leads to reduction in penetration depth and share of base metal in the deposited metal at rising current of surfacing. Results, obtained in this work, were successfully applied at wear-resistant arc surfacing of 3 mm steel sheets, and can also be used in selection of modes of arc surfacing of other parts, which to the greatest extent meet their operating conditions, and requirements to deposited metal and base metal penetration. 10 Ref., 4 Tables, 5 Figures.

Keywords: *arc surfacing, surfacing modes, electrode wire feed speed, base metal penetration, deposited metal formation, flux-cored wire, deposited metal*

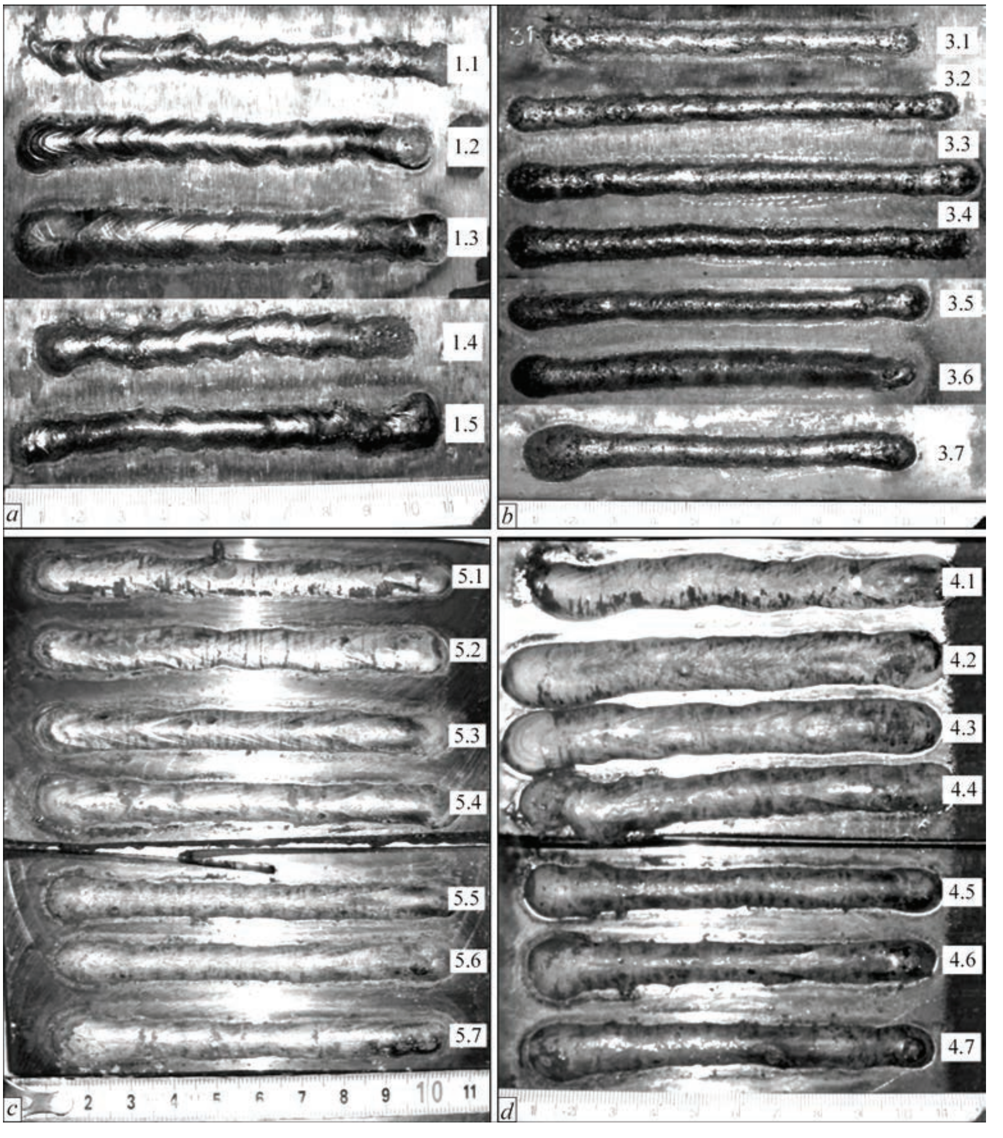
One of the main characteristics of different methods of surfacing is the value of penetration of base metal and, as a result, the share of base metal (SBM) in the deposited metal. As a rule, in arc surfacing with electrode wires, the share of base metal in deposited metal varies in the range of 30–50 %. As a result, in order to reach the desired chemical composition in deposited metal, it is necessary to deposit 4–5 layers. Thus, reduction in the value of penetration and SBM should improve technical and economic characteristics of the arc surfacing process, and the development of measures for their reducing remains an urgent task [1].

It is widely known that the quality of the deposited metal formation, its composition and structure, as well as penetration depth of base metal and SBM, depend mainly on surfacing modes [1–5]. The basic parameters of surfacing mode are current value (electrode wire feed speed); polarity and kind of current; arc voltage; surfacing speed; diameter (cross-section) of electrode material; surfacing pitch; and during surfacing of rotation bodies, displacement from the zenith or nadir. Among them, when developing the technology of arc surfacing of specific parts, the values of current and voltage, surfacing speed and diameter (cross-section) of the electrode material are usually preset [1, 5–8]. Such parameters as kind and polarity of current, the value of electrode wire stickout, etc., have a lower influence on penetration depth and SBM, shape and sizes of deposited beads [6]. At the same time, in the first place the selected mode of surfacing should provide a good formation of the deposited metal and a minimum, but sufficient penetration of base metal or a previously deposited layer [1].

Among the mentioned parameters of arc surfacing modes by electrode wire the current of surfacing has highest effect on the depth of penetration of base metal and SBM. A growth of current leads to a sharp increase in the penetration depth and formation of high and narrow beads (Figure 1) [3]. At the same time, it is necessary to remember about the necessary condition for surfacing, namely, maintaining a stable arc process. In order to do that, the electrode wire feed speed should be equal to the speed of its melting so, that during surfacing no short circuits or breaks of welding arc can occur [5, 7].



Figures 1. Effect of arc surfacing mode parameters on bead shape [5]: *a* — current; *b* — voltage; *c* — speed



Figures 2. Appearance of specimens after surfacing using wires with the diameter: *a* — 1.2; *b* — 1.6; *c* — 1.8; *d* — 2.0 mm

The current of surfacing is closely related to the electrode wire feed speed, and with increase in the latter, the current of surfacing increases proportionally. At a constant surfacing speed this leads to an increase in the volume of metal deposited, getting to the surface deposited in a unit of time, which should result in changing the geometric characteristics of depositing beads. In industrial practice, in arc surfacing of different parts, the electrode wire feed speed usually does not exceed 200 m/h, and the feed mechanisms of the most existing surfacing equipment and automatic devices are designed for this value, which does not exceed 450 m/h [1].

The aim of this work is to study the effect of electrode wire feed speed (current of surfacing) on penetration depth of base metal, SBM and formation of deposited beads during arc surfacing.

To study the effect of wire feed speed on penetration depth of base metal in arc surfacing, a series of experiments on surfacing of single beads with flux-cored wires of 1.2; 1.6; 1.8 and 2.0 mm diameters under flux was conducted. The feed speed was controlled in the range from the minimum value $V_{f.min}$, at which a stable arc process was possible for these conditions, and to the maximum value $V_{f.max}$ = 450 m/h, which, as was mentioned above, was determined by the characteristics of the used surfacing installation U-653 completed with the power source VDU-506.

Surfacing with all four flux-cored wires was carried out at a constant speed of surfacing V_s = 27 m/h. The arc voltage also remained constant during surfacing with a wire of the same diameter: for the wire with a diameter of 1.2 mm it was 22 V; for the wire with a diameter of 1.6 mm it was 24 V and for the wires with a diameter of 1.8 and 2.0 mm it was 26 V. The appearance of specimens after surfacing is shown in Figure 2.

In the process of surfacing, the values of wire feed speed and the value of current, which corresponded to the first ones, were fixed. From deposited billets,

Table 1. Effect of wire feed speed on the formation of deposited beads and penetration depth of base metal in surfacing using the wire of 1.2 mm diameter

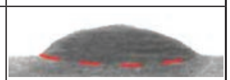
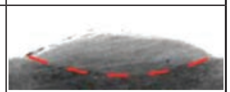
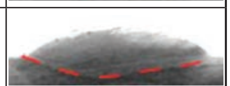
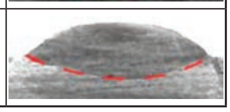
V_f, m/h	I_s, A	Dimensions of deposited beads, mm			γ_0, %	Macrosections of cross-section of beads
		width	height	depth		
210	110	5.9	1.6	0.87	33	
260	130	7.6	1.7	0.91	34	
310	150	7.8	1.9	0.68	29	
360	160	7.9	1.9	0.92	31	
405	170	8.1	2.1	1.13	33	
450	190	8.5	2.2	1.17	31	

Table 2. Effect of wire feed speed on the formation of deposited beads and penetration depth of base metal in surfacing using the wire of 1.6 mm diameter

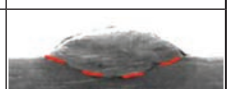
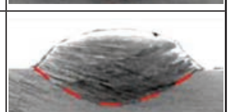
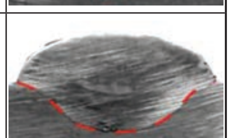
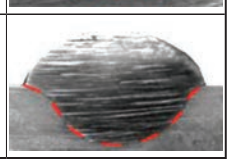
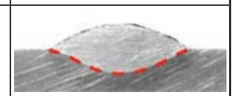
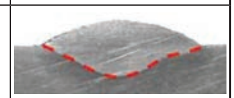
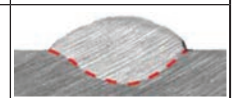
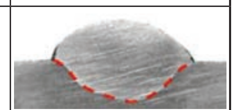
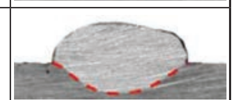
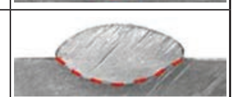
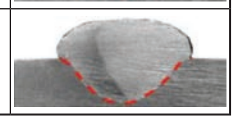
V_f, m/h	I_s, A	Dimensions of deposited beads, mm			γ_0, %	Macrosections of cross-section of beads
		width	height	depth		
175	170	6.7	1.6	1.24	41	
210	190	7.1	2.1	1.45	38	
260	220	8.2	2.3	1.85	40	
310	260	7.8	2.5	2.49	46	
360	290	7.4	3.6	2.21	35	
405	320	9.9	3.5	3.04	40	
450	350	8.5	3.9	4.6	47	

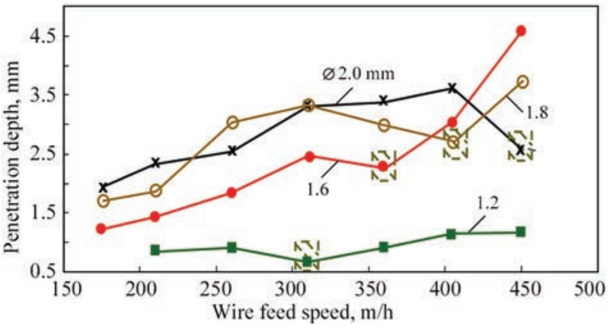
Table 3. Effect of wire feed speed on the formation of deposited beads and penetration depth of base metal in surfacing using the wire of 1.8 mm diameter

V_f, m/h	I_s, A	Dimensions of deposited beads, mm			γ_0, %	Macrosections of cross-section of beads
		width	height	depth		
175	200	9.9	1.7	1.74	48	
210	240	10.9	1.9	1.86	45	
260	280	9.9	3.2	3.04	45	
310	310	9.7	3.3	3.35	46	
360	330	9.3	3.6	2.99	38	
405	360	9.3	3.7	2.70	38	
450	390	8.7	3.8	3.74	39	

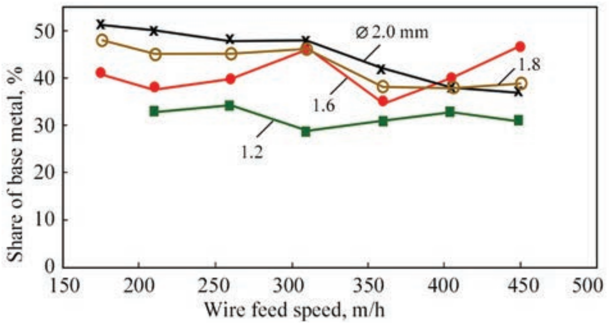
transverse macrosections were manufactured, on which the width and height of deposited beads, penetration depth were measured, as well as SBM was calculated. Macrosections of cross-sections of deposited beads and their dimensions are given in Tables 1–4.

Based on the obtained data, the dependences of the effect of electrode wire feed speed on penetration depth of base metal (Figure 3) and SBM (Figure 4) were plotted. It was established that with an increase in electrode wire feed speed, the height of deposited bead increases, penetration depth and also the width of bead varies slightly (Figure 3, Tables 1–4). At the same time, with the increase in the diameter of the applied flux-cored wire, these dependences grow. Thus, for example, for the wire with a diameter of 1.2 mm, an increase in the wire feed speed from 210 to 405 m/h leads to a growth in the height of the bead by 1.3 times, and for the wire with a diameter of 2.0 mm, the same parameter in the same range of feed speeds is increased by 2.4 times, which is associated with a proportional increase in the volume of deposited metal per a unit of the bead length.

At a gradual increase in the wire feed speed, and, consequently, in the value of welding current from the minimum possible value, at which a stable process



Figures 3. Effect of wire feed speed on penetration depth: shading indicates the area of decreasing penetration depth with increasing current

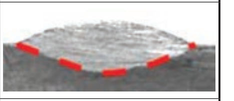
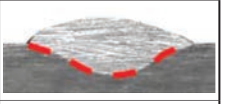
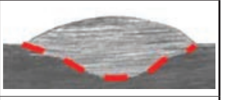
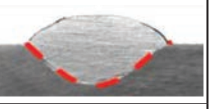


Figures 4. Effect of feed speed of electrode wire of different diameters on SBM

is observed, to the maximum value, provided by the feed mechanism of the installation, a slight decrease in SBM is noted for almost all the diameters of the tested wires (Figure 4). This is explained by the fact that with an increase in current and the wire feed

Figures 5. Appearance of 3 mm thick steel sheet prepared for surfacing (*a*) and a fragment of deposited sheet (*b*)

Table 4. Effect of wire feed speed on the formation of deposited beads and penetration depth of base metal in surfacing using the wire of 2.0 mm diameter

V_f, m/h	I_s, A	Dimensions of deposited beads, mm			γ_0, %	Macrosections of cross-section of beads
		width	height	depth		
175	250	11.7	1.7	1.94	51	
210	290	11.9	1.9	2.34	50	
260	320	12.0	2.3	2.57	48	
310	350	10.2	2.6	3.32	48	
360	380	8.8	3.7	3.4	42	
405	410	9.2	4.4	3.6	38	
450	450	9.7	4.7	2.57	37	

speed at a constant surfacing speed, the growth rate of the area of deposited metal significantly exceeds the growth rate of the penetration area, and the deposited beads obtain a «mushroom-like» shape. This is especially peculiar during surfacing using flux-cored wires with a diameter of 1.6 mm and more.

At the same time, it was established that in surfacing using the wire of each diameter, a certain range exists, where the proportionality of wire feed speed effect on penetration depth is violated. In this range, with increase in the feed speed (at rising current), a decrease in the penetration depth occurs (Figure 3, dashed areas).

This dependence is the most significantly pronounced in surfacing with a wire of 1.2 mm diameter. In case of surfacing at the electrode wire feed speed V_f = 310 m/h, not only a decrease in penetration depth by 25 % is observed as compared to surfacing at a feed speed V_f = 260 m/h, but also the minimum value of penetration (0.68 mm) for the entire investigated range of wire feed speeds are observed. Also, for surfacing with a wire of 1.2 mm diameter at the feed speed V_f = 310 m/h, the SBM is characterized by a decrease from 34 to 29 %, which is also the minimum value for the whole investigated range.

It was also noted that the larger the wire diameter, then a decrease in penetration depth is observed at the higher feed speed. Thus, for the diameter of 1.2 mm, this effect is pronounced at a feed speed of 310 m/h; for the diameter of 1.6 mm — at 360 m/h; for the diameter of 1.8 mm — at 405 m/h; and for the diameter of 2.0 mm — at a speed of 450 m/h.

However, in this case the values of current density *J*, at which this phenomenon is observed, are in a narrow range for all the investigated diameters of electrode wire: for the diameter of 1.2 mm the current density is $J = 136$ A/mm^2, for the diameter of 1.6 mm $J = 144$ A/mm^2; for the diameter of 1.8 mm $J = 142$ A/mm^2, and for the diameter of 2.0 mm $J = 143$ A/mm^2. The average value of current density for all the diameters is $J \approx 140 \pm 4$ A/mm^2. Obviously, in this case, the favourable heat balance of the surfacing process is established, in which the growth in the area of deposited metal is higher than the growth in the area (depth) of penetration. The results obtained in this work are protected by the patent of Ukraine [9].

Surfacing at increased flux-cored electrode wire feed speeds was successfully applied in wear-resistant arc surfacing of 3 mm thick steel sheets. It is known [10] that one of the main problems in surfacing sheets of such a thickness is the probability of arising burn-outs in the process of surfacing.

Surfacing of sheets with the dimensions of 3×200×300 mm was performed with a flux-cored wire of 1.2 mm diameter under the flux at the mode: $V_f = 310$ m/h ($I = 150$ A), $U = 22$ V, $V_s = 30$ m/h, overlapping of the neighbouring beads is ≈ 50 %. To reduce deformation of sheets in the process of surfacing, a device with a cooled copper table was used, on which the sheets were fixed with the help of hold-down straps. The appearance of the sheet prepared for surfacing and fixed in the fixture is shown in Figure 5, *a*; and the appearance of a fragment of a deposited sheet is shown in Figure 5, *b*. The control confirmed the quality formation of deposited metal and the absence of surfacing defects in the form of burn-outs, pores, cracks and other defects.

Conclusions

1. In arc surfacing using high wire feed speeds, for each diameter of the wire such an optimal ratio of value of feed speed and other surfacing parameters exist, at which its increase leads to a decrease in penetration depth and SBM at a rising current of surfacing.

2. The values of current density *J*, at which a decrease in penetration depth is observed, for all investigated diameters of electrode wire are in a narrow range: for the diameter of 1.2 mm, $J = 136$ A/mm^2; for the diameter of 1.6 mm, $J = 144$ A/mm^2; for the diameter of 1.8 mm $J = 142$ A/mm^2 and for the diameter of 2.0 mm $J = 143$ A/mm^2. The average value of the current density for all diameters is $J \approx 140 \pm 4$ A/mm^2. In this case, a favourable heat balance of the surfacing process is established, in which the growth in the area of deposited metal is higher than the growth in the area (depth) of penetration.

3. The results of investigations were successfully used in the development of technology for wear-resistant arc surfacing and of 3 mm thick steel sheets under the flux. The control confirmed the quality formation of deposited metal and the absence of surfacing defects in the form of burn-outs, pores, cracks and other defects.

1. Ryabtsev, I.A., Senchenkov, I.K. (2013) *Theory and practice of surfacing works*. Kiev, Ekotekhnologiya [in Russian].
2. Pokhodnya, I.K., Suptel, A.M., Shlepakov, V.N. (1972) *Flux-cored wire welding*. Kiev, Naukova Dumka [in Russian].
3. Yuzvenko, Yu.A., Kirilyuk, G.A. (1973) *Flux-cored wire surfacing*. Moscow, Mashinostroenie [in Russian].
4. Babinets, A.A., Ryabtsev, I.A., Panfilov, A.I. et al. (2016) Influence of methods of arc surfacing with flux-cored wire on penetration of base metal and formation of deposited metal. *The Paton Welding J.*, **11**, 17–22. https://doi.org/10.15407/as2016.08.01
5. Frumin, I.I. (1961) *Automatic electric arc surfacing*. Kharkov, Metallurgizdat [in Russian].
6. Akulov, A.I., Belchuk, G.A., Demyantsevich, V.P. (1977) *Technology and equipment of fusion welding*. Moscow, Mashinostroenie [in Russian].
7. Panteleenko, F.I., Lyalyakin, V.P., Ivanov, V.P. (2003) *Restoration of machine parts: Refer. Book*. Ed. by V.P. Ivanov. Moscow, Mashinostroenie [in Russian].
8. Ivanov, V.P., Lavrova, E.V. (2016) Controlling penetration zone formation in arc surfacing. *The Paton Welding J.*, **8**, 2–6. https://doi.org/10.15407/as2016.11.04
9. Ryabtsev, I.O., Babinets, A.A., Lentyugov, I.P. (2018) Method of submerged-arc surfacing with flux-cored wire. Pat. 127598, Ukraine [in Ukrainian].
10. Babinets, A.A., Ryabtsev, I.A. (2017) Flux-cored wire for wear-resistant surfacing of thin-sheet structures. *The Paton Welding J.*, **1**, 54–57. https://doi.org/10.15407/as2017.01.10

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