doi.org/10.15407/tpwj2017.01.11

FLUX-CORED WIRE FOR WEAR-RESISTANT SURFACING OF THIN-SHEET STRUCTURES

A.A. BABINETS and **I.A. RYABTSEV**
E.O. Paton Electric Welding Institute, NASU
11 Kazimir Malevich Str., 03680, Kiev, Ukraine. E-mail: office@paton.kiev.ua

The electric arc surfacing of wear-resistant layers on sheet structures of less than 4 mm thickness is connected with a risk of occurrence of burn-outs and excessive deformation of sheets due to their high penetration. One of the possible ways to decrease penetration is the selection of an optimum method of surfacing and development of appropriate technologies and surfacing materials. It was experimentally found, that to provide a minimum penetration with account for a quality formation of deposited metal is possible by using the open-arc surfacing with a flux-cored wire of less than 1.6 mm diameter. The application of the developed technology and technique of surfacing using an improved self-shielding flux-cored wire PP-AN198 provided a quality formation of the deposited metal, absence of burn-outs, pores and other defects, as well as reduced the residual deformations in surfacing of sheets of 3 mm thick steel St3 to minimum. The obtained results can be used in selection of surfacing materials and technologies for surfacing the wear-resistant layers on thin-sheet structures, which are operating in mining and metallurgical industries under the conditions of different types of abrasive wear. 8 Ref., 1 Table, 3 Figures.

Keywords: *arc surfacing, flux-cored wire, thin-sheet structures, penetration, deformations, deposited metal*

Due to their versatility, the flux-cored wires found a wide application for mechanized and automatic arc surfacing in different branches of industry. First of all, it is explained by a sufficiently simple adaptation of their chemical composition to the composition and properties of the parts being surfaced, high stability of arc burning, relatively low spattering of the electrode metal and a good formation of deposited layers [1–6].

One of the promising directions for application of flux-cored wires is their use for surfacing of thin-sheet structures (thickness of sheets ≤ 4 mm), operating in mining and metallurgical industries under conditions of different types of abrasive wear.

The main problems in surfacing of thin-sheet structures consist in a possible occurrence of burn-outs and large deformations of these structures. To solve these problems it was decided to apply the surfacing flux-cored wires of a small diameter (1.2–1.6 mm) and minimum possible modes of surfacing, at which a stable process and quality formation of the deposited layers will be provided [7].

For experiments the flux-cored wire PP-AN198 of Fe–C–Cr–Mn–Si system of alloying, developed at the E.O. Paton Electric Welding Institute, was taken as a prototype.

Thus, the aim of the present work was the optimizing the charge composition of the flux-cored wire PP-AN198 for producing the required composition of the deposited metal at a minimum diameter of the wire and development of technique and technology of surfacing, providing a good formation of the deposited layer and absence of defects like burn-outs, pores and other types in it.

It is known that the method of surfacing (under flux, in shielding gas and with open arc) effects greatly the value of penetration and quality of deposited metal formation even during surfacing at similar conditions and application of wire of the same grade and diameter [8].

Coming from this, it was necessary, first of all, to find out at which method of surfacing it is possible to obtain a minimum penetration of the base metal at the formation of high quality deposited beads. For experiments, six test batches of the flux-cored wire PP-AN198 of 1.6 and 1.8 mm diameter were manufactured for surfacing under flux, in shielding gas and with open arc. In prior series of experiments the surfacing was performed on plates of steel St.3 and wide range of modes by current (150–300 A) and voltage (20–28 V) at constant surfacing speed of 30 m/h.

Figure 1 gives the experimental data of penetration depth of base metal for wires of 1.6 mm diameter (solid lines) and 1.8 mm diameter (dashed lines) during surfacing by three different methods: under flux (*a*), in shielding gas (*b*), and with open arc (*c*). It is seen from Figure 1 that with increase in current and voltage the penetration depth of the base metal is also increased. Here, it is possible to provide a minimum penetration with account for the quality formation of deposited metal during open-arc surfacing using flux-cored wire of 1.6 mm diameter. Coming from the obtained results

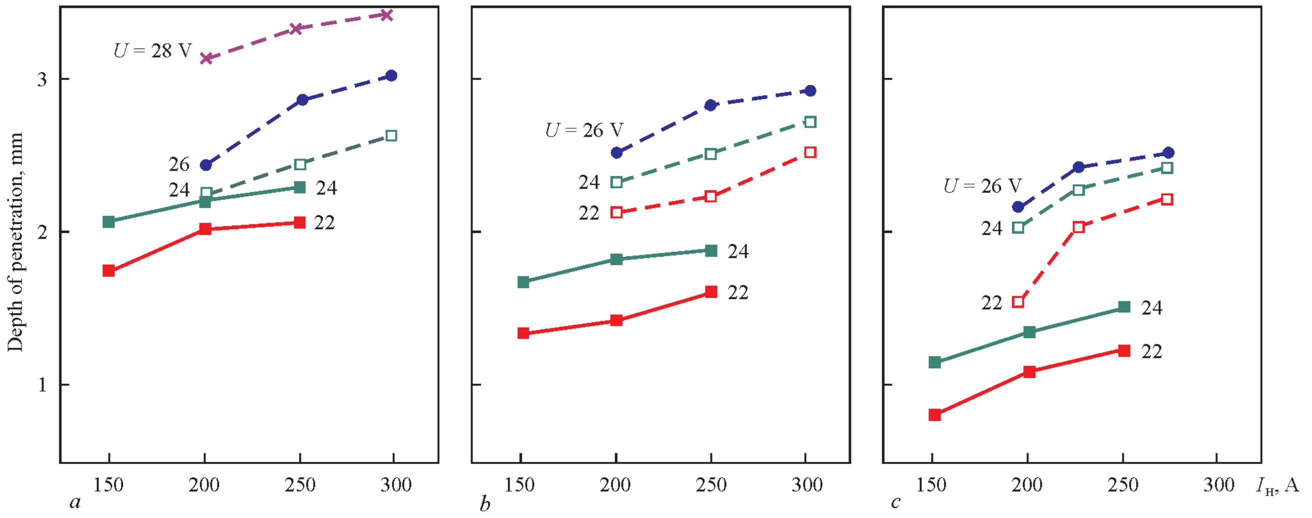

Figure 1. Effect of current on penetration depth in surfacing under flux (*a*), in shielding gases (*b*) and using open arc (*c*) (solid lines — wire of 1.6 mm diameter; dashed lines — wire of 1.8 mm diameter)

it was decided to continue the works using this type of the flux-cored wire.

To provide a reliable protection of the welding pool and produce the quality deposited metal at minimum possible modes, it was necessary to select properly a gas-slag-forming system of the flux-cored wire.

For this purpose, four test variants of self-shielding flux-cored wires PP-AN198 of 1.6 mm diameter with different systems of gas-slag-forming components were manufactured: $CaO + TiO_2 + MgO + CaF_2 + Al_2O_3$ (wire with designation PP-Op-1); $CaO + MgO + CaF_2 + Al_2O_3$ (PP-Op-2); $CaO + CaF_2 + Al_2O_3$(PP-Op-3) and $CaO + Al_2O_3 + C_6H_{10}O_5$(PP-Op-4).

During the process of surfacing by the mentioned wires the expert evaluation of welding-technological properties of self-shielding flux-cored wires of all four types was carried out (nature of metal transfer, value of spattering, covering of deposited beads with a slag, etc). In this case the following system of estimates was used. The metal transfer was characterized by numbers: 1 — fine-drop; 2 — coarse-drop; 3 — mixed; spattering was also evaluated in numbers: 1 — small; 2 — medium; 3 — high; the degree of covering with a slag was evaluated in percents; the presence of pores was characterized by two indices: available and no available; formation of deposited metal was characterized as good, fair or poor.

To evaluate the welding-technological properties the surfacing of specimens at similar current of 160–180 A and surfacing speed of 30 m/h was performed. Since the decisive effect on pores formation and quality of deposited beads during surfacing by the flux-cored wires with an open arc is exerted by voltage [4], the latter it was varied from 20 V and higher up to the appearance of pores in the deposited metal or up to deterioration of the quality of formation for each type of the flux-cored wire (Table).

From the results of experiments it was found that among four flux-cored wires the self-shielding flux-cored wire PP-AN198 (Op-1) possesses the best complex of welding-technological properties and, therefore, it was used further for surfacing of thin sheets.

As was mentioned above, one of the main problems during surfacing of sheets of <4 mm thickness is the probability of burn-outs formation. This probability is increased in the process of surfacing due to the growth of temperature of the sheet being deposited and its deformation, which results in increased gap between the sheet and the surface of the surfacing table. As in the work the sheets of relatively small size (3×400×600 mm) were used, then to reduce their

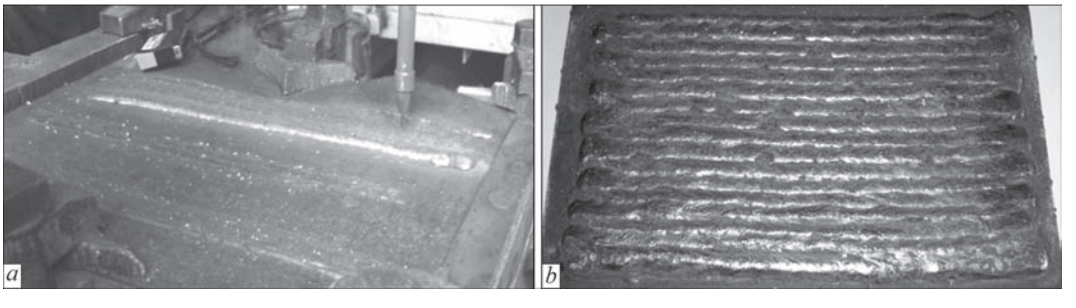

Figure 2. Process of surfacing of 3 mm thick steel plate fixed on water-cooled copper table (*a*) and appearance of deposited plate (*b*)

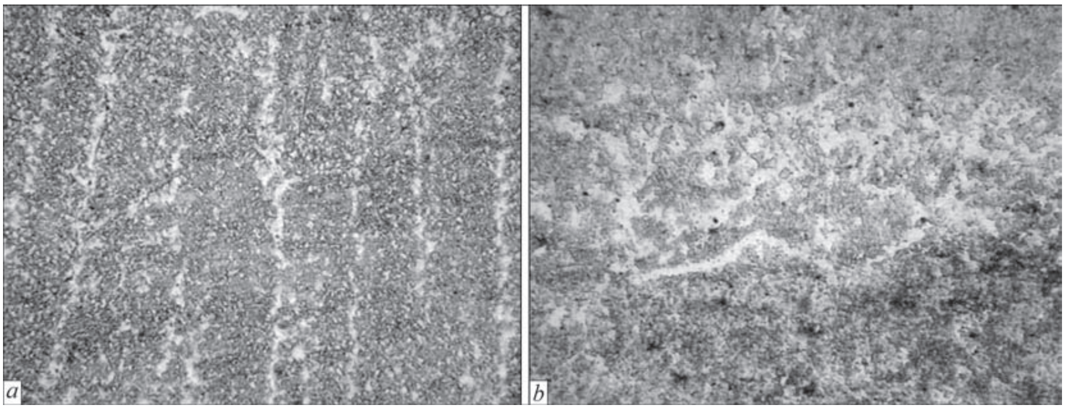

Figure 3. Microstructure (×250) of metal deposited using self-shielding flux-cored wire PP-AN198 (*a*) and zones of its fusion with steel St3 (*b*)

Results of evaluation of welding and technological properties of test self-shielding flux-cored wires of type PP-AN198

Designation of wire	Voltage, V	Type of transfer, numbers	Spattering, numbers	Covering with slag, %	Pores	Quality of formation
PP-AN198 (Op-1)	20	2	1	100	No	Good
	22	3	2	100	No	Good
	24	3	2	100	Available	Fair
PP-AN198 (Op-2)	20	3	1	100	No	Fair
	22	3	2	80	Available	Poor
PP-AN198 (Op-3)	20	3	1	100	No	Good
	22	3	2	100	No	Fair
	24	3	3	80	Available	Fair
PP-AN198 (Op-4)	20	2	1	90	No	Good
	22	3	2	90	No	Fair
	24	3	3	90	Available	Poor

temperature and deformation a device with a cooled copper table was used, where the sheets were fixed by means of clamping straps (Figure 2, *a*).

For experiments on optimizing the technology of arc surfacing of 3 mm thick sheets of steel St3, the flux-cored wire PP-AN198 (Op-1) of 1.6 mm diameter was manufactured. In manufacture of flux-cored wire the strip of steel 08kp (rimmed) of production of «Zaporozhstal» metallurgical plant was used as a sheath. The strip has a relatively low elongation values (~ 25 %), so it was not possible to manufacture the wire of a smaller diameter. The experience shows that using a strip of foreign production, the elongation of which is at the level of 40 % the surfacing flux-cored wire with the diameter of 1.2–1.4 mm can be manufactured.

The surfacing of 3 mm thick sheets of steel St3 using the flux-cored wire PP-AN198 (Op-1) of 1.6 mm diameter was carried out at the following modes: current 160–180 A, voltage 21–22 V; surfacing speed of 30 m/h; overlapping of adjacent beads was 50 %. Figure 2, *b* shows the appearance of the sheet deposited using above-mentioned technology. The visual inspection revealed that on the surface of the deposited sheet the burn-outs, pores, cracks and other defects were absent.

The metallographic examinations of specimens of deposited metal and its fusion zone with the base metal were carried out. It was found that the microstructure of the upper layer of metal, deposited using wire PP-AN198, consists of ferrite, concentrated along the boundaries of crystallites and martensite-sorbite mixture with a small amount of chromium carbides located in the body of crystallites (Figure 3, *a*). Ferrite fringes at the boundaries of crystallites have a width of 10–20 μm. The width of crystallites is 40–75 μm. The hardness of the upper deposited layer is *HV*1-2970–3090 MPa.

In the structure of deposited metal near the boundary of fusion with the base metal the amount of ferrite component is somewhat higher, than near the surface, respectively, its hardness is lower, i.e. *HV*1-1930–1980 MPa. Along the fusion line of base metal with the deposited one the discontinuous ferrite band is formed (Figure 3, *b*). Thus, the metallographic examinations confirmed also producing of a quality joint and the absence of defects both in the deposited metal as well as in the fusion zone.

Conclusions

1. It was found that for electric arc surfacing of thin-sheet structures ($\delta \leq 4$ mm) it is necessary to use the

self-shielding flux-cored wires of the diameter of ≤ 1.6 mm and the minimum surfacing modes, providing the absence of burn-outs and a good formation of deposited beads.

2. The device was manufactured and techniques and technology for surfacing of steel sheets of 3 mm thickness using self-shielding flux-cored wire PP-AN198 of 1.6 mm diameter of improved composition were developed. The application of these technologies and surfacing materials allows producing thin bimetallic sheets on which the burn-outs, pores and other defects are absent and residual deformations are reduced to a minimum.

1. Pokhodnya, I.K., Suptel, A.M., Shlepakov, V.N. (1972) *Flux-cored welding*. Kiev: Naukova Dumka.
2. Pokhodnya, I.K., Yavdoshchin, I.R., Paltsevich, A.P. et al. (1994) *Metallurgy of arc welding, interaction of metal with gases*. Kiev: Naukova Dumka.
3. Pokhodnya, I.K., Shlepakov, V.N., Maksimov, S.Yu. et al. (2010) Research and developments of the E.O. Paton Electric Welding Institute in the field of electric arc welding and surfacing using flux-cored wire (Review). *The Paton Welding J.*, **12**, 26–33.
4. Yuzvenko, Yu.A., Kirilyuk, G.A. (1973) *Flux-cored surfacing*. Moscow: Mashinostroenie.
5. Ryabtsev, I.A. (2004) *Surfacing of machine parts and mechanisms*. Kyiv: Ekotekhnologiya.
6. Kondratiev, I.A., Ryabtsev, I.A. (2014) Flux-cored wires for surfacing of steel hot mill rolls. *The Paton Welding J.*, **6/7**, 95–96.
7. Lankin, Yu.N., Ryabtsev, I.A., Soloviov, V.G. et al. (2014) Effect of electric parameters of arc surfacing using flux-cored wire on process stability and base metal penetration. *Ibid*., **9**, 25–29.
8. 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. *Ibid*., **11**, 17–22.

Received 23.11.2016